

# Integrating Modelling Competence and Pedagogical Readiness of Pre-Service Mathematics Teachers in Implementing Modelling-Based Classroom Learning

Riza Natania Zulyatina<sup>1\*</sup>, Arief Ardyansyah<sup>2</sup>, Alha Rizqi Salsabila Putri<sup>3</sup>

<sup>1</sup> *Mathematics Education, Faculty of Mathematics and Natural Sciences Education, Indonesia University of Education, Indonesia*

<sup>2</sup> *Teaching of Mathematics, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Indonesia*

<sup>3</sup> *Mathematics Education, Faculty of Mathematics and Natural Sciences, State University of Malang, Indonesia*

\*Corresponding author. Email: [rizanataniazulyatina@gmail.com](mailto:rizanataniazulyatina@gmail.com)

## ABSTRACT

Mathematical modelling competence has become a key component of 21st-century mathematics education, emphasizing the ability to connect abstract concepts with real-world contexts. However, teacher education programs in Indonesia still demonstrate limited focus on developing modelling pedagogy. This study aims to assess pre-service mathematics teachers' competencies in mathematical modelling and their pedagogical readiness to implement modelling-based learning in classrooms. The research aligns with the 2025 National Mathematics Curriculum, which positions teachers as facilitators of contextual and future-ready learning. A mixed-method approach was employed, involving mathematics education students from several universities in Indonesia. Data were collected through a diagnostic modelling task and a pedagogical readiness rubric assessing participants' ability to design, guide, and reflect on modelling lessons. Quantitative analysis revealed that participants showed strong conceptual understanding in formulating and solving mathematical models, yet struggled with validation and didactical reasoning. Qualitative findings supported these results, showing varied pedagogical awareness in scaffolding students' modelling processes. The findings highlight a gap between mathematical mastery and pedagogical application in modelling instruction. The study concludes that integrating modelling pedagogy into teacher education curricula is essential to empower future teachers and foster curriculum innovation that supports transformative mathematics learning in the digital era.

**Keywords:** *curriculum innovation, mathematical modelling, pedagogical readiness, teacher education*

## 1. INTRODUCTION

Mathematical modeling has become a key element in 21st-century mathematics education due to its ability to bridge abstract concepts with authentic real-world situations. This competency not only demands procedural skills but also conceptual understanding, reasoning, creativity, and pedagogical reflection. Aligned with the transformation of the 2025 National Mathematics Curriculum, teachers are required to act as facilitators who can design contextual learning experiences and encourage students to construct understanding through the modeling process.

However, various studies indicate that the integration of modeling in learning still faces significant challenges in Indonesia. At the teacher education level, the development of modeling competency has not been fully structured within either the curriculum or coursework. As a result, pre-service teachers often only understand modeling from a mathematical standpoint but lack the pedagogical readiness to implement it in an actual classroom context.

Ferri (2018) developed a comprehensive model regarding the competencies required by teachers to effectively implement mathematical modeling instruction. This model consists of four primary interconnected dimensions: (1) the theoretical dimension, (2) the task dimension, (3) the instructional/teaching dimension, and (4) the diagnostic dimension. These four dimensions form a competency framework that teachers must possess to be able to design, facilitate, and evaluate modeling activities in the classroom.

#### 1. The Theoretical Dimension

This dimension emphasizes the conceptual understanding and theoretical foundations of mathematical modeling. Teachers need to understand:

- a. The modeling cycle, including the processes of describing phenomena, constructing models, analyzing, interpreting, and validating results.
- b. The goals and perspectives of modeling, both as a tool for solving real-world problems and as a means to develop students' mathematical competencies.

#### 2. The Task Dimension

This dimension relates to the teacher's ability to understand, analyze, and select types of modeling tasks that are appropriate for students. This includes:

- a. Diverse modeling problems, including open-ended tasks, contextual investigations, and authentic problems.
- b. Cognitive analysis of tasks, which involves assessing the cognitive demands, solution steps, and potential difficulties students might encounter.

#### 3. The Instructional/Teaching Dimension

This dimension pertains to the teacher's ability to design and implement modeling instruction. This competency includes:

- a. Planning modeling-based instruction, including setting objectives, sequencing activities, selecting contexts, and scaffolding strategies.
- b. Implementing modeling instruction, specifically the ability to facilitate discussions, provide minimal yet effective guidance, manage group work dynamics, and support student exploration.

#### 4. The Diagnostic Dimension

This dimension focuses on the teacher's ability to identify students' thinking processes and monitor their progress in modeling. This includes:

- a. Identifying the stages of the modeling process, such as where difficulties arise in model formulation, interpretation, or validation.
- b. Identifying errors and obstacles, including both mathematical errors and conceptual errors related to the context.

Recent research emphasizes that pedagogical readiness, particularly for complex instruction, encompasses three primary interconnected components: PCK, PDC, and Teacher Noticing (and Reflection).

PCK, first defined by Shulman (1986), is a core foundation for teachers, involving the integration of subject matter (such as mathematics, which is abstract and interconnected) with appropriate pedagogical strategies, thus requiring both content mastery and effective instructional planning. In the context of modeling-based instruction, the PCK of pre-service teachers is manifested through their ability to explain abstract concepts, understand student misconceptions, and select appropriate scaffolding.

PDC refers to the capacity of pre-service teachers to design relevant and authentic learning experiences. Due to the open-ended nature of modeling instruction, PDC is crucial in ensuring that the learning experience is not rigid and can accommodate the various solution pathways that students might take. The core components of PDC required in complex instruction include sequencing of activities, selection of authentic contexts, preparation of dynamic scaffolds, and formative assessment of the process. PDC is also reflected in the general ability of pre-service teachers to develop curriculum frameworks, design syllabi, and create Lesson Plans (RPP) that are grounded in students' critical thinking.

Teacher Noticing is the teacher's ability to attend to students' strategies, difficulties, and thinking patterns during the learning process. This competency is crucial as it determines the quality of interventions that teachers provide while guiding students, particularly in open-ended tasks such as modeling. The noticing framework developed by Jacobs et al. (2010) outlines the development of this competency, wherein teachers must be able to use robust evidence, rather than limited or insufficient evidence, as an indicator for intervention. Noticing enables teachers to identify key moments in student learning and provide timely interventions. Based on this situation, there are several key problems:

1. A gap between mathematical ability and pedagogical readiness in mathematical modeling among pre-service teachers.
2. A lack of training and authentic experience in designing and implementing modeling-based instruction.

3. A lack of comprehensive mapping of pre-service teachers' modeling competencies in Indonesia based on empirical data across universities.

A lack of understanding of how pre-service teachers provide scaffolding for students during the modeling process. These problems indicate an urgent need for a systematic evaluation of pre-service teachers' mathematical modeling competencies as well as their pedagogical readiness.

This study is designed using a mixed-method sequential explanatory approach, thereby providing a comprehensive overview of pre-service teachers' mathematical modeling competencies.

The problem-solving steps include:

1. Collecting quantitative data through a modeling diagnostic task to assess participants' conceptual understanding at each stage of modeling.
2. Analyzing pedagogical readiness using a rubric that assesses the ability to design, guide, and reflect on modeling instruction.
3. Supplementing the data with qualitative analysis through participants' written reflections and documentation of their solution process, in order to capture the depth of their didactic awareness.
4. Synthesizing the quantitative and qualitative findings to map a profile of modeling competencies and identify pedagogical gaps.
5. Generating recommendations for curriculum improvement in teacher education, particularly regarding the integration of modeling pedagogy.

This approach ensures that the research findings are not merely descriptive, but also provide relevant directions for intervention.

This study aims to:

1. Assess the mathematical modeling competencies of pre-service teachers, specifically in the stages of model formulation, solution, interpretation, and validation.
2. Evaluate the pedagogical readiness of pre-service teachers in designing and implementing modeling-based instruction.
3. Identify the gaps between mathematical competencies and pedagogical competencies within the context of modeling.

## **2. METHODOLOGY**

### **2.1 Research Design**

This study uses a mixed-method approach with a sequential explanatory design. This design was chosen to obtain a comprehensive understanding of pre-service teachers' mathematical modeling competencies and pedagogical readiness. In the first phase, quantitative data were collected through a modeling diagnostic task. These quantitative results were analyzed to map participants' conceptual abilities at each

stage of modeling. The second phase consisted of qualitative analysis using pedagogical reflections and an observation rubric to explore the depth of participants' didactic reasoning and the context influencing their performance. The integration of both data types was conducted using a merging and comparing technique, allowing the qualitative findings to explain in greater depth the patterns that emerged from the quantitative results.

## **2.2 Research Participants**

The participants in this study were mathematics education students from several public and private universities in Indonesia. The sampling technique used was purposive sampling, as the selected participants had to meet the following criteria:

1. Enrolled in a mathematics education program (at least in their third semester).
2. Having taken a course related to learning strategies or basic PCK.
3. Willing to participate voluntarily.

The total number of participants in this study was 126 students. From this group, 32 participants were selected to complete the full diagnostic modeling task. The participants were from several universities in Indonesia, which provided a diversity of academic contexts and learning experiences.

## **2.3 Research Instruments**

This study used two primary instruments designed to measure the two main variables: pre-service mathematics teachers' mathematical modelling competence and their pedagogical readiness to implement modelling instruction.

### **1. Modeling Diagnostic Task**

Mathematical Modelling Competence functions as a dependent variable, central to this study's evaluation. It embodies the content-specific competency of pre-service teachers in applying mathematical knowledge to modeling contexts. Mathematical Modelling Competence was measured using a Modeling Diagnostic Task themed "The Trajectory of a Boom Crane Tip." This instrument was developed based on the modeling process framework (Blum & Leiss, 2007) and assessed using a rubric adapted from Garfunkel & Montgomery (2019), which covers the seven stages of modeling: Describe/Understanding, Specifying/Simplifying, Formulating/Mathematizing, Solving, Interpreting, Evaluating/Validating, and Reporting. The task was administered online to 32 participants. Scores were analyzed descriptively (e.g., mean, median) for each stage. Participants' output included calculations, graphs, model justifications, and brief reflections regarding the model's validity.

## **2. Pedagogical Readiness for Modeling Questionnaire (30 Likert-Scale Items)**

Pedagogical Readiness is the second dependent variable, representing the teaching-specific competency required for implementing modeling-based instruction. A pedagogical readiness for modelling questionnaire comprising 30 likert-scale items (ranging from strongly disagree to strongly agree) designed to measure six key aspects: (a) familiarity and initial readiness with modeling, (b) perceptions of lesson plans and learning sequences, (c) perceptions of scaffolding within the task structure, (d) pedagogical reflection and relevance, (e) experience with implementing modeling tasks, and (f) analysis of student readiness and potential conceptual difficulties. The questionnaire data were analyzed descriptively by calculating the mean score for each aspect to profile the participants' perceived readiness. The data from both instruments were then integrated and comparatively analyzed to identify potential gaps between the participants' subject-matter modelling competence and their pedagogical readiness to implement it.

### **2.4 Data Analysis Techniques**

The research data were analyzed using a mixed-method sequential explanatory approach, which sequentially integrated quantitative and qualitative analysis to obtain a comprehensive picture. In the quantitative phase, participants' answers on the modeling diagnostic task were assessed using a five-level rubric for each modeling stage. Participants' scores were analyzed descriptively, calculating the mean, median, standard deviation, and the distribution of proficiency for each stage.

Questionnaire data were analyzed using descriptive statistics to map the pedagogical readiness profile across the six measured aspects. The qualitative phase was conducted through thematic analysis of participants' reflections and their narrative responses on the questionnaire. Integration of both data types was performed using the joint display technique, which involves comparing quantitative and qualitative findings to identify gaps between mathematical competency and pedagogical readiness. These integrated results were used to strengthen the interpretation of the findings and to formulate recommendations for teacher education development.

## **3. RESULTS AND DISCUSSION**

### **3.1. Assessment Results of the Modeling Diagnostic Task for Pre-service Mathematics Teachers**

The following is a recapitulation of the assessment results for the modeling diagnostic task. This task was assessed using the modeling rubric designed by Garfunkel & Montgomery (2019) in GAIMME, which evaluates criteria across the seven stages of mathematical modeling. The results are as follows:

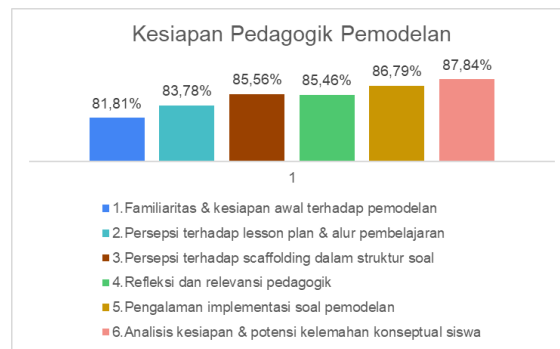
**Table 1.** Assessment Results of the Modeling Diagnostic Task

No	Aspect	Average
1	Describing/Understanding	94,44%
2	Specifing/Simplifyng	90,22%
3	Formulating/Mathematising	84,72%
4	Solving	77,78%
5	Interpreting	86,11%
6	Evaluating/Validating	79,17%
7	Reporting	86,11%
<b>Overall</b>		<b>85.52%</b>

The assessment results of the diagnostic task indicate that the pre-service teachers' modeling competency was high, with an overall score of 85.52%. The Describe/Understanding stage obtained the highest score (94.44%), indicating that participants were highly capable of understanding the context and identifying relevant information. The Specify or Simplifying and Formulating or Mathematizing stages also showed good achievement (90.22% and 84.72%, respectively), suggesting that pre-service teachers were sufficiently competent in simplifying phenomena and constructing mathematical models. However, performance on the Interpreting and Evaluating/Validating stages was lower (86.11% and 79.17%, respectively), reflecting a tendency for pre-service teachers to be stronger in the mathematical aspects compared to the reflective and evaluative aspects of the model.

These findings are in line with various international studies that show similar patterns. Maass et al. (2019) and Schukajlow & Kaiser (2020a) reported that pre-service teachers typically excel in the formulation and solution stages but are weaker in interpretation and validation, especially when assessing the model's suitability with the real-world phenomenon. Ferrando and Font (2021) also found that pre-service teachers struggled to provide justifications for the model's assumptions or limitations due to a lack of authentic experience in modeling instruction. Thus, although these findings indicate that pre-service teachers' modeling abilities are quite good, strengthening the interpretation, validation, and reporting stages remains a critical need in the development of mathematics teacher education curricula.

### 3.2. Pre-service Teachers' Pedagogical Readiness in Mathematical Modeling Instruction



**Figure 1.** Pedagogical readiness for mathematical modeling among preservice teachers

In general, the research findings indicate that the pedagogical readiness of pre-service teachers in mathematical modeling instruction was high, with scores for all aspects ranging from 81–88%. These findings indicate that the pre-service teachers possess a strong foundation in understanding modeling concepts, instructional design, and the practical dynamics of facilitating the modeling process in the classroom. Specifically, the measured aspects reflect the key elements of pedagogical readiness identified in recent literature, such as understanding the modeling sequence, providing scaffolding, conducting process assessment, and analyzing student thinking (Kaiser & Brandenburg, 2022; Jacobs et al., 2010). The high overall score suggests that the intervention, consisting of the modeling task and the contextual lesson plan, successfully provided a meaningful learning experience for the pre-service teachers.

For the first three aspects, pre-service teachers demonstrated good initial familiarity with modeling (81.81%), positive perceptions of the lesson plan quality and learning sequence (83.78%), and a highly positive perception of the scaffolding within the task structure (85.56%). They understood that modeling differs from ordinary contextual problems and that the lesson plan sequence was progressively structured according to the modeling stages.

The high score for scaffolding (85.56%) indicates that pre-service teachers recognize how incremental support can guide students without compromising their learning autonomy, which is consistent with the findings of Park & Lee (2023) and Doerr & English (2022). This finding confirms that their understanding of modeling-based instructional design is well-developed, although their practical experience still needs to be strengthened.

In the next three aspects, the pre-service teachers' level of pedagogical readiness was even stronger. Pedagogical reflection and relevance received a high score (85.46%), indicating that participants were able to connect the modeling experience with didactic reasoning and noticing of student thinking. Experience with implementing

modeling tasks (86.79%) was also rated very positively, signifying that activities such as the Boom Crane task helped them understand how mathematical concepts can be authentically connected to real-world phenomena, as recommended by Doerr & English (2022).

The final aspect, the analysis of student readiness and potential conceptual difficulties, received the highest score (87.84%), indicating that the pre-service teachers possess strong diagnostic abilities. This aligns with the findings of Schukajlow & Kaiser (2020b), who emphasized the importance of a teacher's ability to identify the most difficult stages in modeling in order to provide appropriate pedagogical interventions. Overall, these three aspects (Aspects 4, 5, and 6) indicate that the pre-service teachers possess a solid foundation for implementing modeling instruction reflectively and responsively to student needs.

### **3.3. A Lesson Plan for a Scaffolded Modeling Task**

The lesson plan in the Modeling Worksheet was designed as an alternative that pre-service teachers can use to implement modeling instruction in the classroom. In this study, the lesson plan was provided on the page before the modeling task narrative was given. This lesson plan included: modeling learning objectives, material prerequisites for students, required tools and materials, and the connection between the task's context and the national curriculum's learning outcomes.

The modeling task followed the seven-stage cycle (Describe–Report) with incremental scaffolding to systematically guide students in understanding the context, building the model, and evaluating outcomes. Each stage included targeted guiding questions—such as formulating assumptions, selecting coordinate systems, constructing equations, and interpreting results.

Scaffolding was provided in the form of simplified steps, information organization, and reflective guidance that enabled students to connect the real-world phenomenon with mathematical representations. This design is consistent with the GAIMME approach (Garfunkel & Montgomery, 2019) and is reinforced by recent research emphasizing the effectiveness of scaffolding in modeling instruction (Kaiser & Brandenburg, 2022; Park & Lee, 2023). Overall, this lesson plan presents a learning structure that is contextual, progressive, and capable of supporting both students and pre-service teachers in navigating the comprehensive modeling process.

## **4. CONCLUSION**

This study indicates that the mathematical modeling competencies of pre-service teachers are high, particularly in understanding the context, simplifying the situation, and formulating the model. However, abilities in model interpretation and validation remain a weak point, indicating a gap between mathematical mastery and didactic understanding. On the other hand, the pedagogical readiness of pre-service teachers is

also at a high level, as evidenced by their ability to understand the modeling sequence, assess lesson plan quality, utilize scaffolding effectively, and identify potential student conceptual difficulties. These findings confirm that although pre-service teachers are strong in the cognitive aspects of modeling, strengthening the reflective, evaluative, and pedagogical aspects remains necessary to ensure that the classroom implementation of modeling instruction is optimal.

Based on these findings, this study suggests that teacher education programs broaden authentic learning experiences that allow pre-service teachers to practice modeling directly through microteaching, real-world context projects, and the analysis of modeling-based instruction practices. Faculty and curriculum developers are advised to strengthen instruction that emphasizes model validation and evaluation, as well as provide scaffolding tools that can serve as a reference for pre-service teachers in designing instruction. Furthermore, partner schools and field mentors can serve as a practical environment that supports the development of pedagogical noticing and modeling facilitation skills. Through this collaborative effort, the integration of mathematical modeling in teacher education can be realized more effectively and contribute to producing teachers who are competent, reflective, and prepared for the demands of 21st-century learning.

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