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A systematic literature review of measurement of mathematical modeling in mathematics education context

Riyan Hidayat [1*], Mazlini Adnan [1], Mohd Faizal Nizam Lee Abdullah [1], Safrudiannur [2]

[1] Department of Mathematics, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, Perak, MALAYSIA
[2] Faculty of Teacher Training and Education, Mulawarman University, Kalimantan Timur, INDONESIA

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Abstract

The research presented in this article is a systematic review of the literature on the assessment of mathematical modeling in the setting of mathematics education published in the previous five years. This research has compiled the current best information from around the world to offer an overview of the assessment of mathematical modeling for pre-service mathematics teachers or mathematics teachers. We followed the approach used in Joklitschke et al. (2021), which involved 10 steps in systematic literature review (SLR). We accessed using Web of Science (WoS), Scopus, and mathematics education journals that are ranked 1-10. Based on a full-text analysis of 18 peer-reviewed papers published in English, most of the research was conducted among pre-service mathematics teacher and most of the studies were conducted in Turkey, United States, and Germany. The future trends and opportunities were also discussed. We also found that most test types employed for measuring modeling competency were project, cognitive dimension, holistic approach, and the tests utilized more qualitative approach.

Keywords: mathematics teachers, measurement, modeling competency, preservice mathematics teachers, systematic review

INTRODUCTION

In recent years, the rise of mathematical modelling is well documented in related literature (Albarracín, 2021; Hidayat et al., 2020, 2021a; Rellensmann et al., 2020) and curriculum (Schukajlow et al., 2018) in countries like Australia, Germany, and Singapore because the approach helps students to tackle real-world issues using mathematics (Kohen & Orenstein, 2021). According to Leong (2014), not only does one learn how mathematics is applied in the actual world, but one also builds a model representation that would be used to deal with the problem. Furthermore, according to recent research (Hallström & Schönborn, 2019), model and modelling concepts should be used as methods to increase science, technology, engineering, and mathematics (STEM) competence, as well as the transition of knowledge and skills between scenarios within and outside STEM fields of study. Modeling problems go much further than conventional word problems as in the former, the solution may be discovered by exclusively applying processes to the quantities specified in the statement of the problem (Degrande et al., 2018). The primary distinction between mathematical modelling and problem solving (standard word problem) is that modelling problems begin with 'unedited real world' and the outcome is considered in the original context, whereas problem solving begins with ideal real-world conditions in mathematical terms and ends with a mathematical decision.

Blum (2012) indicated that mathematical modelling was first utilized in the teaching and learning process to create links between mathematics and life. Aside from this broad overview, the teaching and learning process in mathematical modelling encompasses a diverse set of definitions, aims, frameworks, and perspectives for various target audiences. Abassian et al. (2020) divide the five general categories described into five categories: educational modelling, realistic modelling, socio-critical modelling, epistemological modelling and models and modelling perspectives. Our angle notices modeling in

✉ riyanhidayat@fsmt.upsi.edu.my **(*Correspondence)** ✉ mazlini@fsmt.upsi.edu.my ✉ faizalee@fsmt.upsi.edu.my
✉ safrudiannur@fkip.unmul.ac.id

Contribution to the literature

- A systematic review of mathematical modelling studies published in the last five years will give a framework for future research.
- The current SLR is conducted to review the research subjects, types of instrument, characteristics of mathematical modeling measurement, kinds of approaches in mathematical modeling measurement, the research methods, and the geographical distribution of the authors.
- The current investigation focuses on pre-service mathematics teachers or mathematics teachers.

educational modelling as a pedagogical strategy. Most notably, the framework proposed by Stillman et al. (2007) is one example of a complex model in an educational viewpoint on mathematical modelling competency. This model not only incorporates problem solving individually by students, but it also serves as the foundation for instructors in making judgments about the teaching and learning process. Hence, the widespread use of mathematical modelling frameworks, models, and techniques in educational modelling has radically altered the focus of mathematical modelling away from assessment and operational definitions and toward concepts and questions.

Contribution to the Literature

Current literature proves that there is sufficient literature review in mathematical modeling in educational settings (Cevikbas et al., 2021; Frejd, 2013; Gutiérrez & Gallegos, 2019; Schukajlow et al., 2018; Sokolowski, 2015) including engineering education (Lyon & Magana, 2020). Frejd (2013), for example, conducted a literature analysis on modes of modelling assessment, selecting 10% of 700 studies relevant to assessment. The findings of his study also showed that the criterion employed in assessment criterion was rarely generated from a theoretical study, but were instead based on informal constructs, experience from assessment scenarios, or empirical examinations of students' work. The forms of modelling evaluation described included written examinations, projects, hands-on assessments, portfolios, and contests. Recently, by doing systematic literature review (SLR), Lyon and Magana (2020) found that modeling tasks should be assessed in terms of both solution and process, the variety and influence in the nature of feedback, and different assessments required for mathematics and mathematical modelling. However, there are limited SLR on mathematical modeling in higher education towards assessment. Therefore, in the current study, we synthesized studies on the use of evaluation related to mathematical modelling in the educational field especially in higher education by conducting a literature review.

Research Questions

We concentrated our analysis on six areas of particular relevance, as follows:

1. Who were the research subjects: prospective mathematics teachers, or mathematics teachers?
2. What types of instrument related to mathematical modeling employed in mathematics education context?
3. What kinds of characteristics of mathematical modeling measurement in mathematics education context?
4. What kinds of approaches (holistic and atomistic) in mathematical modeling measurement in mathematics education context?
5. What are the research subjects employed in mathematical modeling measurement in mathematics education context?
6. What is the geographical distribution of the authors in mathematical modeling measurement in mathematics education context?

LITERATURE REVIEW

Modeling Competency

Modeling is a means of engaging in more genuine learning activities (Niss et al., 2007). The model is composed of an action plan and an operational coordination structure (Steffe & Kieren, 1994). Developing a model should concentrate on the communication between students and teachers, and it should be both general to account for the variability of individuals' mathematical development and particular to account for the progress of specific students within a series of lessons (Cobb & Steffe, 1983). The success of models is determined by their simplicity of use and forecast accuracy (Edwards & Hamson, 1989). Maaβ (2006) captured the concept using a comprehensive mathematical modelling competence framework that included components of cognitive, affective, and metacognitive abilities. This description is unclear since it incorporates affective and metacognitive components (Frejd & Arlebäck, 2011). In term of cognitive perspectives, the modelling competency refers to its cycle (Maaß, 2006; Niss et al., 2007). Although mathematical modelling is evaluated in terms of its different component abilities, Stillman et al. (2007) believed that modelling should involve a process of formulation, solution, interpretation, and assessment. Hence, while the idea of mathematical modelling was originally thought to primarily include cognitive, affective, and metacognitive dimensions, we assume that there will be a wide range of measurement elements and practical interpretations of mathematical modelling.

In the process of mathematical modeling, students must perform various steps that refer to the definition of modeling itself (Anhalt et al., 2018). The first step that needs to be done in the modeling process is to develop a situation model. Before beginning the modelling process, activities such as simplifying, and structuring must be completed. Before arriving at a mathematical model, the process of mathematics must be completed by translating objects, data, connections, and circumstances into the realm of mathematics. Calculations or procedural knowledge must be triggered in this scenario to obtain mathematical outcomes. The mathematical answer is then converted back into a scenario model to see whether it is suitable or needs to be revised. Finally, students must re-translate the scenario model to the actual situation to see whether any ideas for the next mathematical modelling step are required.

It has been highlighted that mathematical modelling is a dynamic process and has been used in a variety of contexts in the literature (Shahbari & Peled, 2017; Sokolowski, 2015). All mathematical modelling procedures are difficult to distinguish because they vary depending on the perspective utilized (Blomhøj, 2009; Kaiser & Sriraman, 2006). However, these processes often include a visual presentation step. Even though there is no agreement cycle for mathematical modelling, the process is not linear, multi-phased, complex, continuous, and repetitive. According to Maaß (2006), mathematical modeling consists of the skills and ability to conduct the modelling process properly and purposefully, as well as the motivation to use it. It may be inferred that abilities are an important component of mathematical modelling sub-competencies. Students, for example, must engage existing mathematical ideas, skills, and reasoning abilities at the level of a mathematical modelling process that involves manipulating or reasoning with mathematical representations to draw mathematical inferences (Kehle & Lester, 2003). To look at it another way, a wide range of abilities are required to support mathematical modelling competences. The different sub-competencies of mathematical modelling are explicitly discussed in depth.

Theoretical Background on Mathematical Modeling Measurement

Modeling tasks are generally employed as descriptive, normative, and meta-cognitive to assist in assessing student achievement, planning courses, and selecting relevant content (Henning & Keune, 2005). Furthermore, when developing modelling activities, teachers must give a set of principles. Galbraith (2006) outlines five criteria for ensuring modelling activities in math classes. The task

1. includes 'relationships with the students' real world';
2. allows students to 'distinguish and determine' appropriate mathematical questions;
3. requires students to make assumptions or collect data during the formulation process;
4. includes solutions that the student can achieve; and
5. includes 'evaluation procedures' for testing the model.

There are two extreme viewpoints to examine mathematical modelling through teaching and learning procedures. Blomhoej and Jensen (2003) distinguished between holistic and atomistic approaches. In a holistic approach, students should engage with a full-scale mathematical modelling process, which includes problem formulation, systematization, mathematization, mathematical analysis, result interpretation and assessment, and model validity evaluation. While a holistic approach may explore all aspects of student work, it also necessitates time and effort in mathematization and analysis. On the other hand, the time spent studying real-world issues by transforming real-world complexity into mathematical models is restricted. Holistic methods to research are uncommon now (Frejd, 2012). However, recent studies have attempted the holistic criterion to assess students' modelling ability (Chang et al., 2020; Rellensmann et al., 2020; Tong et al., 2019).

According to Frejd (2013), written testing is an atomistic approach on mathematical modelling that focuses on products rather than processes, whereas projects are the ideal way to assess mathematical modelling competencies more holistically, although project dependability obstacles are found. Houston (2007) highlights the importance of evaluating the entire thing or comprehensive evaluation in developing students' mathematical modeling. Even though it does not offer a complete perspective of mathematical modelling, this form of evaluation generally assists teachers in identifying mathematical modelling issues among pupils and degrees of conceptual comprehension (Haines & Crouch, 2001). The modelling learning process in the atomistic approach, on the other hand, focuses on the cycle of mathematizing and analyzing the model mathematically (Blomhoej & Jensen, 2003). Moreover, the researchers' reasoning for utilizing the atomistic approach in mathematics teaching is that it promotes mathematical learning (Frejd & Bergsten, 2018). To date, recent research has sought to use the atomistic approach to measure students' mathematical modeling (Fu & Xie, 2013; Hidayat et al., 2018, 2021b) and combine between atomistic and holistic criteria (Durandt et al., 2021; Zöttl et al., 2011).

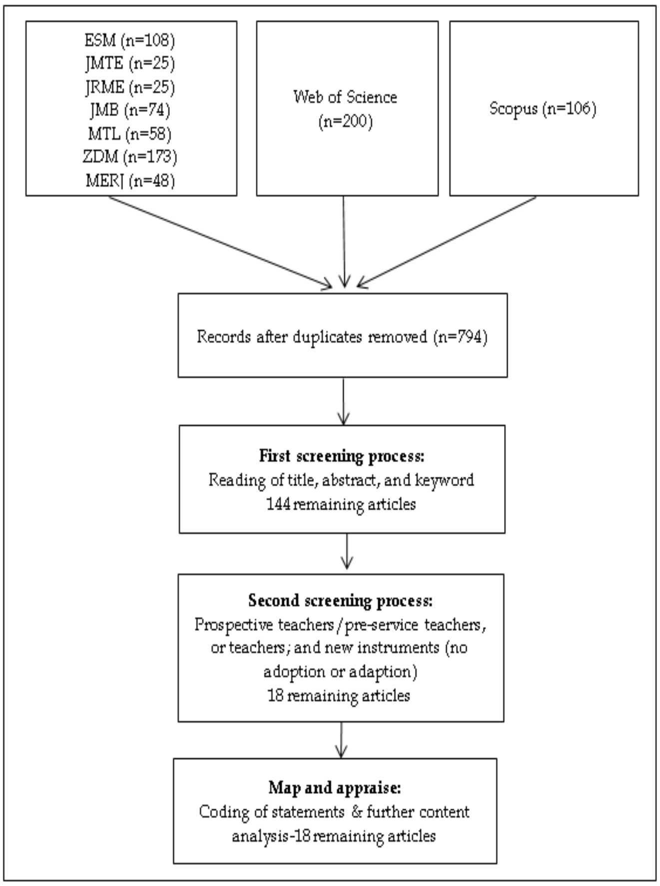

Figure 1. Flow chart of study selection process

RESEARCH METHODS

We follow the approach used in Joklitschke et al. (2021) that was originally developed by Gough et al. (2013). The approach has 10 steps that we explain below together what we did in each step (**Figure 1**).

Step 1 & Step 2: Needs and review questions. In the introduction part, we have described the need for our SLR and the research questions of the SLR.

Step 3. Scope: Gough et al. (2013) suggested the determination of some criterion for a systematic review. To determine the criterion, Joklitschke et al. (2021) suggested considering the quality of articles that would be reviewed. Therefore, our first criterion was to include articles from peer-reviewed journals in the field of mathematics education. To ensure the quality of the journals, our second criterion was to include journals whose rank were 1-10 based on the studies conducted by Dreyfus (2006a, 2006b), Holbrook et al. (2009), Toerner and Azarello (2012), Williams (2008), and Williams and Leatham (2017). There are eight journals based on the second criterion: Journal for Research in Mathematics Education (JRME), Educational Studies in Mathematics (ESM), Journal of Mathematical Behavior (JMB), For the Learning Mathematics (FLM), Mathematical Thinking and Learning (MTL), Journal of Mathematics Teacher Education (JMTE), Zentralblatt für Didaktik der Mathematik [Central Journal for Didactics of Mathematics] (ZDM), and Mathematics Education Research Journal (MERJ). However, as our third criterion focused on including empirical articles on modelling, we excluded FLM whose articles were mostly not on empirical studies. Further, our fourth criterion was the inclusion of studies that (i) measured modelling competencies by developing new instruments and (ii) the participants were teachers or pre-service teachers/prospective teachers. The fifth criterion was to include papers published in English. By concentrating on English journal papers, we were able to avoid the risk of difficult or ambiguous translations. The last criterion was to include articles published in 2017-2021.

Step 4. Search: We use the word "modelling", "modeling test", "modeling", "preservice teacher", "prospective teacher", "teacher", and "educator" to search articles. The last search of the literature was conducted on October 23, 2021, in the following databases: (i) Web of Science (WoS), (ii) Scopus, and (iii) JRME, ESM, JMB, MTL, JMTE, ZDM, and MERJ (based on Scopus because all determined journals are indexed by Scopus). By searching on JRME, ESM, JMB, MTL, JMTE, ZDM, and MERJ, we could also take the abstracts of all detected article. In this step, we acquired 511 articles. Additionally, we also searched for articles by using the database from WoS. We got 200 potential articles from WoS. We also searched for articles by using the database from Scopus. We acquired 106 potential articles from Scopus. Finally, after removing duplicates from JRME, ESM, JMB, MTL, JMTE, ZDM, and MERJ; Scopus, and WoS, we had 794 articles.

Step 5. Screening: After doing the first screening (reading the title, abstract and keywords of all articles), we excluded 650 articles from 794 articles (the rest are 144 articles). After the first screening, we did the second screening by reading the method section of all articles. This process also included criteria such as new instrument not adopted or adapted (using existing instrument). Articles discussing studies that focused on teachers or pre-service teachers/prospective teachers as the participants were included. Finally, we found only 18 articles satisfying the criterion mentioned in step 6.

Step 6. Code: We developed codes for conducting the content analysis on those 18 articles (**Table 1**).

Step 7 & Step 8: Map and appraise: Based on the codes in step 6, we mapped the articles as presented in **Table 1**. Column 1 and column 2 comprised the main foundation of our map which helped us (in the appraisal step) to interpret the gap/difference (between modeling research on pre-service teachers/prospective mathematics teachers and mathematics teachers; and to identify the need for modeling research in the future.

Step 9 & Step 10. Synthesize and communicate: The synthesis and communication will be presented in the results and discussion.

Table 1. The content analysis on reviewed articles

Author/year	RQ 1	RQ 2	RQ 3	RQ 4	RQ 5	RQ 6
Biehler/2018	PT	Project	Cognitive	Holistic	QA	Germany
Greefrath/2021	PT	Project	Cognitive	Holistic	QNA	Germany
Orey/2018	PT	Project	Cognitive	Holistic	QA	Brazil
Sevinc/2017	PT	Written tests	Cognitive	Holistic	QA	Turkey
Villarreal/2018	PT	Project	Cognitive	Holistic	QA	Argentina
Asempapa/2020	MT	Questionnaire	Affective	NA	QNA	USA
Galleguillos/2018	MT	Project	Cognitive	Holistic	QA	Chile
Geiger/2021	MT	Project	Cognitive	Holistic	DRA	Australia
Wilkerson/2018	MT	Written tests	Cognitive	Holistic	QA	USA
Jacobs/2017	PT	Questionnaire	Affective	NA	QNA	South Africa
Kula Unver/2018	PT	Written tests	Cognitive	Holistic	QA	Turkey
Shahbari/2018	MT	Reports	Cognitive	Holistic	MMA	Israel
Asempapa/2020	MT	Questionnaire	Affective	NA	QNA	USA
Kertil/2019	PT	Questionnaire	Cognitive	Holistic	DRA	Turkey
Viseu/2020	PT	Project	Cognitive	Holistic	QA	Portugal
Hidiroglu/2017	PT	Written tests	Cognitive	Holistic	QA	Turkey
Jung/2019	PT	Written tests	Cognitive	Holistic	QA	USA
Sen Zeytun/2017	PT	Project	Cognitive	Holistic	QA	Turkey

Note. RQ: Research question; PT: Preservice teachers; MT: Mathematics teachers; NA: Not applicable; QA: Qualitative approach; QNA: Quantitative approach; DRA: Design-based research approach; MMA: Mixed methods approach

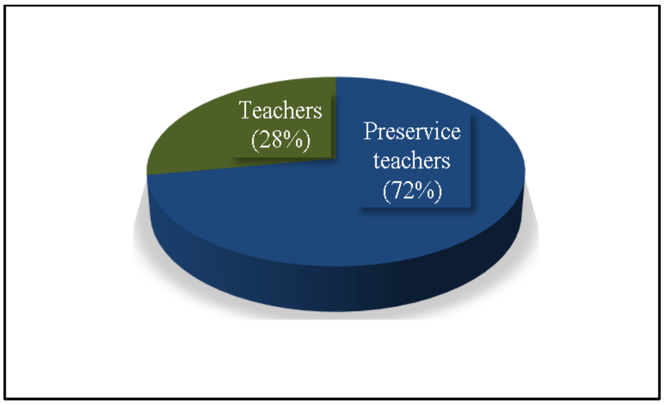

Figure 2. Research subjects in the reviewed articles

REVIEW RESULTS

A total of 18 papers were chosen for the systematic analysis after being screened using the eligibility requirements. The main eligibility requirements were new instrument not adopted or adapted (using existing instrument) for preservice mathematics teacher or mathematics teacher. This study used six research questions to guide its review of the selected articles. First, who were the research subjects: prospective mathematics teachers or mathematics teachers. Second, what types of instrument related to mathematical modeling employed in mathematics education context. Third, what kinds of characteristics of mathematical modeling measurement in mathematics education context. Fourth, what kinds of approaches (holistic and atomistic) in mathematical modeling measurement in mathematics education context. Fifth, what are the research subjects employed in mathematical modeling measurement in mathematics education context. Sixth, what is the geographical distribution of the authors in mathematical modeling measurement in mathematics education context.

Table 1 summarizes and compares the papers that were chosen, which included the inclusion criterion of a systematic review of the literature, namely types of instruments related to mathematical modeling employed in mathematics education context, kinds of characteristics of mathematical modeling measurement, research subjects, kinds of approaches, research method used for investigating modeling competency, and geographical distribution of the authors. Each of these research questions is further discussed in the subsections that follow.

Research Subjects

The first research question was concerned with the research participants (pre-service mathematics teacher or mathematics teacher). The population characteristics of the research were also examined in this review research (**Figure 2**).

There has been a significant growth of research on pre-service mathematics teachers. Most of the research (72%, n=13) recruited pre-service mathematics teacher (Biehler et al., 2018; Greefrath et al., 2021; Hidiroglu et al., 2018; Jacobs & Durandt, 2017; Jung et al., 2019; Kertil et al., 2019; Kula Unver et al., 2018; Orey & Rosa, 2018; Sen Zeytun et al., 2017; Sevinc & Lesh, 2018; Villarreal et al., 2018; Viseu et al., 2020; Wilkerson et al., 2018). Eight of research subjects were pre-service secondary school mathematics teachers, three of research subjects were pre-service primary school teachers, and two of the research subjects were not mentioned specifically.

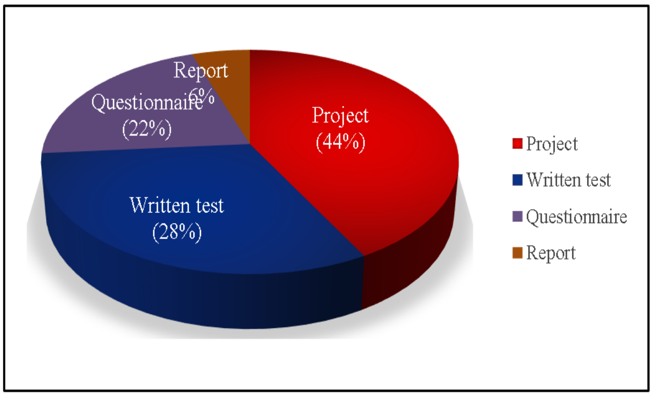

Figure 3. Distribution of published articles by types of instruments

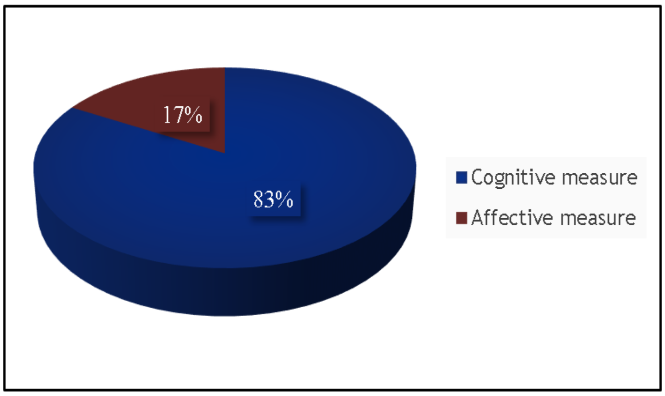

Figure 4. Distribution of published articles by characteristics of instrument

Types of Instruments Used for Modeling Competency

The second research question was concerned with the types of instruments related to mathematical modeling employed in mathematics education context. The types of instruments used to measure modeling competency in mathematics education context in the current study were written tests, projects, hands-on tests, portfolio, contest and questionnaire. The data gathering methods employed to measure modeling competency in mathematics education context were examined.

As seen in Figure 3, the majority of types test employed for measuring modeling competency were project (n=8), followed by written test (n=5), questionnaire (n=4), and report (n=1). The project method (Biehler et al., 2018; Galleguillos & de Carvalho Borba, 2018; Geiger et al., 2021; Greefrath et al., 2021; Orey & Rosa, 2018; Sen Zeytun et al., 2017; Villarreal et al., 2018; Viseu et al., 2020) has been widely employed in mathematics education context to measure modeling competency among pre-service mathematics teacher or mathematics teacher. Biehler et al. (2018), for example, employed a modeling task using TinkerPlots to measure the reasoning of pre-service mathematics teacher.

Types of Characteristics of Modeling Measurement

The third research question was concerned with characteristics of mathematical modeling measurement (cognitive or affective measures). The characteristics of mathematical modeling measurement in mathematics education for pre-service mathematics teacher or mathematics teacher were categorized into cognitive or affective dimension. Previous studies have looked at the types of characteristics of modeling measurement using a variety of methodologies (Figure 4). Obviously, cognitive dimension was one characteristic of mathematical modeling measurement in mathematics education used most frequently (Biehler et al., 2018; Galleguillos & de Carvalho Borba, 2018; Geiger et al., 2021; Greefrath et al., 2021; Hidiroglu et al., 2018; Jung et al., 2019; Kertil et al., 2019; Kula Unver et al., 2018; Orey & Rosa, 2018; Sen Zeytun et al., 2017; Sevinc & Lesh, 2018; Shahbari, 2018; Villarreal et al., 2018; Viseu et al., 2020; Wilkerson et al., 2018). Orey and Rosa (2018), for example, found that students' competency in modeling had developed such as pre-service mathematics teacher learnt how to identify and investigate the problems. Moreover, by combining modeling activities with virtual learning environment (VLE), they could do interactive and collaborative investigation on their topics by sharing questions and sharing information with academics, teachers, and classmates in discussion boards and web conferences. Lastly, only a few studies (17%) utilized the affective dimension for measuring modeling competency in mathematics education context.

Types of Instruments' Approaches Used for Modeling Competency

The fourth research question was concerned with the kinds of approaches (holistic and atomistic approach) in mathematical modeling measurement for preservice mathematics teachers or mathematics teachers. Holistic and atomistic approaches in the present work were only related to cognitive measures. It can be observed that most of the approach used to measure modeling competency were conducted by holistic (n=18) (e.g, Biehler et al., 2018; Greefrath et al., 2021; Hidiroglu et al., 2018; Jacobs & Durandt, 2017; Jung et al., 2019; Kertil et al., 2019; Kula Unver et al., 2018; Orey & Rosa, 2018; Sen Zeytun et al., 2017; Sevinc & Lesh, 2018; Villarreal et al., 2018; Viseu et al., 2020; Wilkerson et al., 2018). Meanwhile, two measures utilized the affective domain (Asempapa, 2020; Asempapa & Brooks, 2020) (Figure 5).

Researchers in modeling competency used modeling cycle as cognitive competence in modeling activities. For example, Hidiroglu et al., 2018 employed the 7-stage modelling process to examine their modeling competency. It was found that beginning with the third step of mathematizing, student instructors had difficulty solving problems, and these challenges increased as they progressed through the phases of developing mathematical models and linking them.

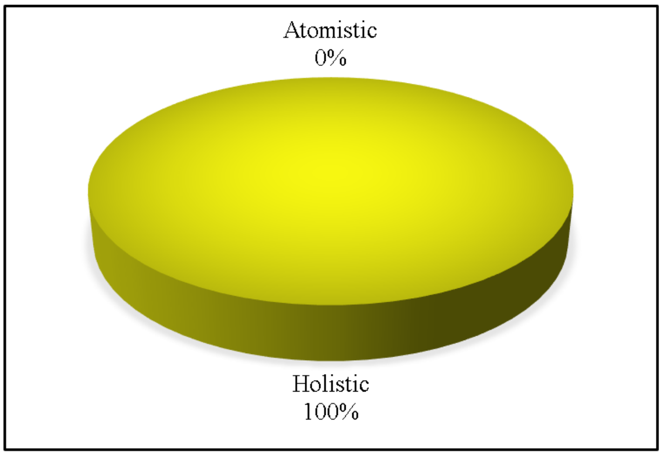

Figure 5. Distribution of published articles by types of instruments' approaches

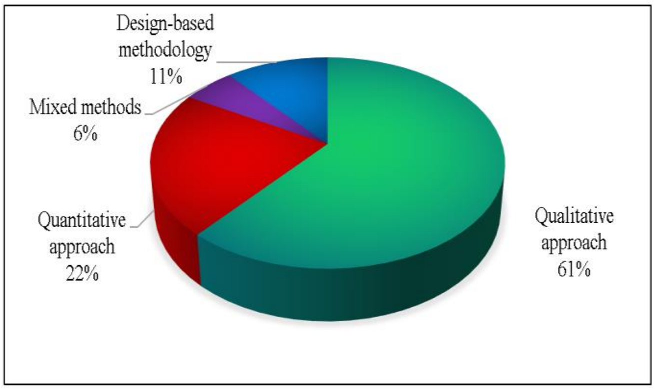

Figure 6. Distribution of published articles by research methodologies

Research Methodologies

The fifth research question was concerned with research methodologies (qualitative method, quantitative method or mix methods in their empirical research on modelling). **Figure 6** depicts the distribution of research methodologies employed in the reviewed papers. It was revealed that the qualitative approach was the most frequently employed research methods for data collection (61%) (e.g, Orey & Rosa, 2018; Sevinc & Lesh, 2018; Villarreal et al., 2018).

This was followed by the research that utilized quantitative approach (22%) (e.g., Asempapa, 2020; Jacobs & Durandt, 2017), design-based research (11%) (Geiger et al., 2021; Kertil et al., 2019), and mixed methods (6%) (Shahbari, 2018). In qualitative approach, for example, a case study design was the most frequently employed research design for data collection. This indicated that qualitative approach with case study design was effective to be adopted for measuring mathematical modeling for both pre-service mathematics teacher and mathematics teachers. The adoption of a case study methodology would improve the results and give more meaningful interpretations in modeling competency.

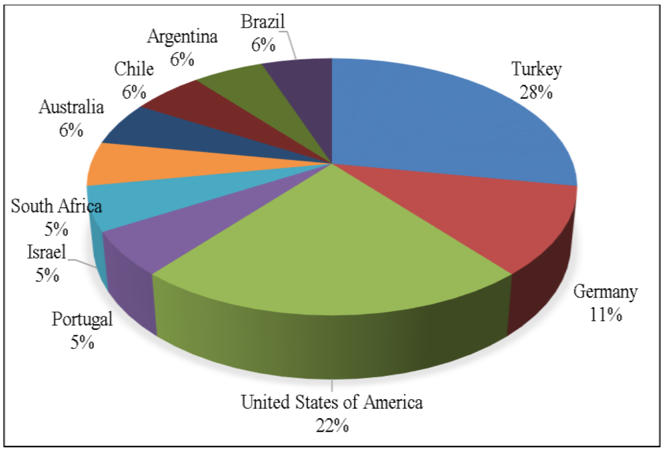

Figure 7. Distribution of published articles by geographical distribution

Geographical Distribution

The sixth research question was concerned with geographical distribution of the authors (**Figure 7**). Our systematic review only included papers published in English; nevertheless, the investigations were done in a variety of cultural contexts across the world. With the most empirical investigations, Turkey had dominated the outcomes (28%) (Hidiroglu et al., 2018; Kertil et al., 2019; Kula Unver et al., 2018; Sevinc & Lesh, 2018; Sen Zeytun et al., 2017), followed by United States (22%) (Asempapa, 2020; Asempapa & Brooks, 2020; Jung et al., 2019; Wilkerson et al., 2018), and Germany (11%) (Biehler et al., 2018; Greefrath et al., 2021). Only a few investigations were conducted in Brazil (6%) (Orey & Rosa, 2018), Argentina (6%) (Villarreal et al., 2018), Chile (6%) (Galleguillos & de Carvalho Borba, 2018), Australia (6%) (Geiger et al., 2021), South Africa (5%) (Jacobs & Durandt, 2017), Israel (5%) (Shahbari, 2018), and Portugal (5%) (Viseu et al., 2020).

DISCUSSIONS

In relation to the focus of the studies on the research subjects: prospective mathematics teachers or mathematics teachers, there had been a huge increase in preservice mathematics teacher research compared with mathematics teachers. The current findings of reviewed articles supported the idea of Cevikbas et al. (2021), which indicated 20% employed populations of preservice mathematics teachers. This meant that the samples obtained serious attention after secondary school students. As a result, there was a pressing need to examine modeling competency among pre-service mathematics teachers or mathematics teachers by developing a new instrument in Asian settings. In Indonesia, for example, learning based on the real world had also been introduced several decades ago (Sembiring, 2010; Sembiring et al., 2008). However, mathematical modeling courses for pre-service mathematics teachers were not formally introduced in the curriculum (Widjaja, 2013). This topic, therefore, must be examined further in pre-service mathematics teachers or mathematics teachers especially developing new modeling task.

Second research question is related types of instrument related to mathematical modeling employed in mathematics education context. Our findings indicated that around half of the reviewed papers used projects, followed by written test, questionnaire and report. However, it was obvious that there were no articles published which featured pre-service mathematics teachers or mathematics teachers using hands-on tests, portfolio and contest. These findings were in line with outputs of using the holistic approach to measure modeling competency. Projects are the best way to capture a more comprehensive modelling competency (Frejd, 2013). A project-based assessment is usually student-centered and necessitates reflection on both the process and the content in order to be effective. Furthermore, some reviewed papers also utilized the written report to measure modeling competency. Although the written test was richly linked to atomistic test (Frejd, 2013), this test was still popular among modeling researchers in which participants needed to complete a series of modeling problems (Niss, 1993). However, no investigation into designing a new evaluation of mathematical modelling for pre-service mathematics teachers or mathematics instructors utilizing the atomistic technique in conjunction with a written test has been conducted. Furthermore, only one research employed the report approach as a tool to measure modeling competency in mathematics education context (Shahbari, 2018). The researcher found that changes in teachers' perceptions about the mathematical modeling activities finally influenced their beliefs about mathematics.

Concerning kinds of characteristics of mathematical modeling measurement, most research conducted among pre-service mathematics teachers or mathematics teachers concentrated on cognitive measures. Sen Zeytun et al., 2017, for example, tested students' cognitive and pedagogical knowledge via the modeling cycle. At the same time, only five studies (28%) dealt with mathematics education teachers (Asempapa, 2020; Asempapa & Brooks, 2020; Galleguillos & de Carvalho Borba, 2018; Geiger et al., 2021; Shahbari, 2018) with focus on cognitive and affective measures. Conversely, limited research has been conducted to develop new instruments in term of affect-related issues. This finding was in line with a systematic review conducted by Schukajlow et al. (2018) which indicated that affective components were mentioned in roughly 10% of the journal papers analyzed concerning modelling teaching and learning. Prior studies only focused on educators' or parents' beliefs, students' interest, value, enjoyment, self-efficacy, competence and autonomy experiences, teachers' or parents' views. For example, Asempapa (2020) focused on affective measures and developed a new instrument to measure the mathematical modeling attitude scale, which involved four components (constructivism, understanding, relevance and real-life, and motivation and interest). Therefore, to foster measurement on affective components, future research should concentrate on developing new tools in affect-related issues.

Forth research question is related kinds of approaches (holistic and atomistic) in mathematical modeling measurement. Most authors from the reviewed research employed the holistic approach to measure the modeling competency for pre-service mathematics teachers or mathematics teachers. The holistic method is based on a full-scale modelling cycle in which learners engage in all stages of the modelling process (Cevikbas et al., 2021; Hankeln et al., 2019). This was in line with previous work which utilized holistic tasks to assess students' modelling ability (e.g., Kreckler 2017; Rellensmann et al., 2017). Researchers who focused on the holistic approach normally looked at students' ability to simplify the situation by making assumptions about the problem, to represent relevant quantities and their relationships mathematically, to solve the problem using a mathematical formula and show accurate calculations, to interpret the outcome to mathematical situations and to evaluate and reflect on solutions which had been identified. In terms of the atomistic approach, there was no research to develop a new measure of mathematical modeling for pre-service mathematics teachers or mathematics teachers. Frejd (2013) stated that the written exam was an atomistic approach in modeling competency that focused more on the product than the process. The objective for developing an atomistic technique could be used to assess level of students' modelling abilities before proceeding to the complete modelling phase in holistic approach. This is because using the holistic approach in modeling classroom always ended up in problems. Hankeln et al. (2019), for example, discovered that students always struggled and do not create simplification and interpretation cycle. Therefore, this discovery also offered up a new research channel, with future studies concentrating on the atomistic approach which could be more effective regarding the modeling competency cycle.

Concerning our fifth research question, our findings indicated that qualitative research methods were used in more than half of the examined studies, followed by quantitative, design-based research approaches and mixed methods research. This work partially supported research conducted by Cevikbas et al. (2021) which focused on conceptualizing, measuring, and fostering mathematical modeling competency. However, it did not focus only on preservice mathematics teacher or mathematics teacher. The fact that the reviewed research employed a wide range of data gathering methodologies was encouraging such as test, protocol interview, protocol observation and questionnaire. According to Hankeln et al. (2019), the qualitative examination of the students' responses allowed for the identification of potential coding challenges, which resulted in minor formulation revisions. For example, Tong et al. (2019), using the qualitative approach, found that most of the students improved their mathematical modelling ability, indicating that they not only had the necessary desire to study but also assisted them in putting mathematics into practice. Furthermore, this finding opened a new research avenue, with future studies focusing on design-based research and mixed techniques to capture the entire modelling capability of preservice mathematics teachers or mathematics teachers.

Concerning the geographical distribution of the authors, the findings indicated that the predominant authors developing the modeling task were in Turkey, United States, and Germany, and only a few research conducted in Brazil, Argentina, Chile, Australia, South Africa, Israel, and Portugal. This finding may explain why academics in Turkey and United States were keen to establish a modelling exam for prospective mathematics teachers or current mathematics teachers. One the possible explanation is related to curriculum and policy issues such as guidelines of assessment in mathematical modeling education (GAIMME) report in United States, the German Federal Ministry of Education and Research that created the modeling and measuring competencies in higher education in Germany and Ministry of National Education [MEB] (2009) in Turkey. For example, students who can utilize mathematics in everyday life, solve issues, communicate answers and opinions, show self-confidence, and have good attitudes, according to the curriculum designer in Turkey, should be nurtured. At the same time, in United States, GAIMME (COMAP & SIAM, 2016) aids in the identification of fundamental competences that should be included in student experiences, as well as providing guidance on how to improve mathematical modelling instruction at all levels. However, the results also showed that there was a lack of diversity of countries especially in the Asian context to develop the modeling task for preservice mathematics teacher or mathematics teacher. For example, although modeling was included in Singapore's mathematics curriculum, Ng (2013) found that most instructors in Singapore had never played the role of a modeler and hence faced difficulties appreciating the benefits of using modelling assignments in their classroom. Likewise, the Malaysian secondary mathematics curriculum had more emphasis in problem solving, reasoning, communication, making connections and the use of technology (Leong, 2014). Therefore, this topic must be examined further in other nations especially developing new modeling tasks for preservice mathematics teachers or mathematics teachers.

CONCLUSIONS

Mathematical modeling competency could be defined as cognitive, effective, and metacognitive dimensions. However, some researchers argued that this definition seemed to be ambiguous since this definition included effective and metacognitive dimensions (Frejd & Ärlebäck, 2011). This was also in line with the current investigation in measurement in modeling competency which also involved the cognitive measurement. We found that the most often employed aspect of mathematical modelling measurement in mathematics education were the cognitive component. At the same time, written examinations, projects, hands-on assessments, portfolios, contests, and questionnaires were utilized to assess modelling ability in the context of mathematics education. However, the current development, in our systematic review of preservice mathematics teachers or mathematics teachers, focused on the project method. The project method was also regarded as the best way to implement the holistic approach in mathematical modeling measurement. Our findings indicated that most of the approaches employed to assess modelling proficiency were holistic in nature. Since modeling is commonly thought of as a collaborative process (Houston, 2007), holistic approach is the best method to assess students' modeling competency. Moreover, the current systematic review also revealed that almost a third of the published papers employed the qualitative approach as the data collection method. Pre-service mathematics teachers have been featured in many studies. The highest percentage of the participants in the study were pre-service mathematics teachers. Finally, Turkey, United States, and Germany were the most prolific scholars in developing the modelling tasks, with just a few studies completed in Brazil, Argentina, Chile, Australia, South Africa, Israel, and Portugal.

Limitations

This SLR has severe flaws, and additional study into how modeling competency is measured in educational setting for pre-service mathematics teachers and mathematics teachers. Within the previous five years, JRME, ESM, JMB, MTL, JMTE, ZDM, and MERJ; Scopus and WoS were the only sources used. Several articles that we are unaware of may not have been included in our data analysis. Another limitation is linked to key word used. We employ the word "modelling", "modeling test", "modeling", "preservice teacher", "prospective teacher", "teacher", and "educator" to find articles. Several researchers used term of mathematical modeling competency. As a result, there may have been some subjectivity or the exclusion of potentially important publication in modeling competency. We only include mathematics education journals that are ranked 1-10, suggested by previous study. Finally, we remove publication that do not develop new instrument in modeling competency for pre-service mathematics teachers and mathematics teachers.

Future Directions

The scarcity of diverse types of instruments (written tests, projects, hands-on tests, portfolio, contest, and questionnaire) in this field emphasizes the need for methods that have the potential to improve upon existing instruments. The creation of more test instruments related to written tests, projects, hands-on tests, portfolio, contest, and questionnaire should be encouraged in the future especially when it concerns preservice mathematics teachers or mathematics teachers. In addition, it is a good idea to include more research design in quantitative approach, design-based research and mixed methods. Concerning the research population, most of the participants in the study were pre-service mathematics teachers. The emphasis on mathematics teacher (primary or secondary schools) should be much more involve in future research for enhancing professional development. Likewise, professional development programs and university modelling courses can help in-service and pre-service teachers improve their modelling knowledge and practice (Alhammouri, 2018). Especially with geographical distribution of the authors, more research in developing a new instrument to measure modeling competency for preservice mathematics teacher or mathematics teacher is needed in the Asian context. This is because modeling tasks are authentic tasks in the real-life context, and they need informal understanding of the situation before developing the new model. In other words, the task should be in line with students' environment and experience. Future studies also should look at the kinds of approaches especially the atomistic approach as the initial stage in the modeling cycle before requiring the students to complete all stages of the modeling competency. This is also beneficial to research since the mathematical modeling cycle is much challenging. Finally, although most research contends that modeling competency is cognitive based, however, affective measures are needed in the upcoming research for pre-service mathematics teachers or mathematics teachers. Learners' cognitive and affective dimensions are vital aims of mathematics education (Schukajlow et al., 2018).

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