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Review Article

A systematic review of the best practices for teaching mathematical modelling in education context

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ABSTRACT

This research aims to examine recent studies on the dimensions necessary for developing mathematical modelling instruction and established frameworks used in teaching mathematical modelling. The study followed the steps outlined as such: identification, screening, eligibility, inclusion, and data analysis throughout three search engines: ERIC, ScienceDirect, and Scopus. The study followed the preferred reporting items for systematic reviews and meta-analysis (PRISMA) protocol and found 18 articles related to the topic. The findings showed that a well-balanced approach to implementing the three dimensions of teaching mathematical modelling; design of activity, pedagogy, and assessment systems which enhances the teaching and learning experience. The findings of the systematic literature review showed that most authors emphasized the authenticity and uniqueness of activities, highlighting the importance of engaging learners with interesting tasks. Finally, authors from Hong Kong, Australia, and Germany have been widely active in developing frameworks and dimensions for teaching mathematical modelling as they emphasize the application of modelling in secondary schools. A key significance of this study is that reviewing effective frameworks for designing mathematical modelling tasks, teaching modelling lessons, and assessing students' work can help educators improve their lessons and create a better classroom environment.

Keywords: education, framework, mathematical modelling, PRISMA, systematic review, teaching

INTRODUCTION

Recent literature and curriculum studies (Geiger et al., 2021; Kannadass et al., 2023; Lo et al., 2022; Wess et al., 2021) from countries such as Hong Kong, Australia, and Germany have widely documented the growing use of mathematical modelling. It is now generally acknowledged that modelling is essential to mathematics education since it improves students' mathematical abilities and promotes civic responsibility (Maaß et al., 2019). Blum and Borromeo Ferri (2009) assert that mathematical modelling seeks to promote development of diverse mathematical skills and constructive behavior, besides contributing to students; improved understanding of mathematics. Modelling activities have been shown to motivate students and improve comprehension of complex topics, such as differential equations (Lopes & Reis, 2022). Engaging in real-world modelling tasks can alter one's perception of mathematics, shifting it from a field of exact precision to an understanding of the inherent inaccuracies in measurement and the imprecision of real-world estimations (Blum, 2015). Mathematical modelling begins with the 'unedited' real world, and its results are evaluated within the original context. This is the main distinction between mathematical modelling and problem-solving tasks (such as standard word problems). Nonetheless, problem-solving starts with mathematically expressed, idealized real-world conditions and concludes with a mathematical solution (Pollak, 2011).

Instruction for mathematical modelling covers diverse definitions, objectives, frameworks, and perspectives, tailored to different audiences. Teaching mathematical modelling helps to connect theoretical mathematics with real-world applications. Integrating mathematical modelling into the curriculum supports the European Commission's findings, which stress the importance of innovative teaching strategies to enhance students' mathematical skills (Delić-Zimić & Destović, 2018). This aligns with the newly introduced national curricular standards in many countries, which now include modelling competencies as essential elements of mathematics education (Lu & Kaiser, 2022), a trend also seen in Malaysia. Research indicates that students taught using modelling approaches demonstrate improved problem-solving skills and enhanced mathematical performance compared to those taught through traditional methods (Rezaei & Asghary, 2024). In several studies, students have displayed excellent skills in representation and communication during mathematical modelling. Even those who typically struggle academically can be motivated to engage with the task (Hodgson & Wilkie, 2022). Improving students' mathematical thinking, encouraging their independence in mathematics education, and strengthening their critical thinking abilities are the several advantages of mathematical modelling (Wei et al., 2022). Nonetheless, some educators are reluctant to integrate mathematical modelling into their classes because they lack confidence in their ability to teach it and find modelling classes uncomfortable (Hodgson & Wilkie, 2022). For example, many pre-service teachers face challenges due to insufficient training in mathematical modelling, resulting in difficulties when attempting to implement effective teaching practices (Guerrero-Ortiz & Borromeo Ferri, 2022). Peter et al. (2020) emphasized that the lack of structured resources causes inconsistencies in teaching practices and student experiences. Additionally, inadequate frameworks can lead to flawed data validation or estimation, resulting in ineffective practices.

The current literature demonstrates a substantial body of research on mathematical modelling in educational contexts (Cevikbas et al., 2021; Hidayat et al., 2023). About half of the examined publications employed projects as the primary instrument for mathematical modelling in mathematics education, as stated by a literature analysis on the measurement of mathematical modelling by Hidayat et al. (2023). Other methods included written tests, questionnaires, and reports. However, the study found no articles focusing on trainee or expert mathematics instructors using hands-on tests, portfolios, or contests. Analyzing students' written work, such as through teacher assessments, is one method of assessing their competence in mathematical modelling (Hodgson & Wilkie, 2022). The current research trend in mathematical modelling focuses on the challenges faced in teaching and learning (Guerrero-Ortiz & Borromeo Ferri, 2022), integration with real-world problems (Pelemeniano & Siega, 2023) and the advantages of incorporating mathematical modelling into education (Luczak & Erwin, 2023). To the researchers' best understanding, there is no systematic review specifically addressing best practices for teaching mathematical modelling effectively. Therefore, in this study, the researchers synthesized research on the key dimensions involved in developing mathematical modelling instruction through a systematic review. The researchers also provided an overview of existing frameworks developed for teaching mathematical modelling to school students. Thus, for research questions, the analysis focused on five areas of relevance, as follows:

1. What countries of the authors are contributing to the development of mathematical modelling instruction?
2. What kinds of dimensions are involved in developing mathematical modelling instruction?
3. What are the sub-dimensions involved in developing mathematical modelling instruction?
4. Which level of institutional study is the focus in developing mathematical modelling instruction for teaching?

5. Which topics are involved in developing mathematical modelling instruction for teaching?

LITERATURE REVIEW

Mathematical Modelling Competency

Cognitively, an individual's competency refers to their ability to perform specific actions effectively and purposefully (Blum, 2015). Maaß (2006) suggests that mathematical modelling not only requires the knowledge and expertise to execute the process effectively and purposefully but also the motivation to apply it. This demonstrates that skills are an essential part of the sub-skills associated with mathematical modelling. In education, mathematical modelling promotes cognitive skills and essential competencies in students, particularly in mathematics. It improves learning efficiency in both offline and online settings, aligning with contemporary educational standards (Aniskin & Rakhmatullina, 2023). Mathematical modelling competency involves multiple stages, such as identifying real-world problems, simplifying them, creating mathematical representations, and interpreting the results (Özbek & Köse, 2022). For instance, within the framework of a mathematical modelling process, students must actively engage with preexisting mathematical concepts, competencies, and reasoning abilities. To draw mathematical conclusions, they must manipulate or reason with mathematical representations. Metacognition, especially cognitive strategies such as planning and self-checking, have important roles in mathematical modelling competency. For example, self-checking was found to have a positive relationship with both horizontal and vertical mathematization, highlighting its significance within the modelling process (Hidayat et al., 2023). Employing modelling-based texts may enhance students' ability to modelling and allows the learners to utilize scientific data in building conceptual understanding.

Teaching Mathematical Modelling

The secondary mathematics curriculum in Malaysia aims to nurture students' profound mathematical understanding to enable them to solve problems and make decisions. A significant body of empirical research has been conducted in the previous two decades on the teaching and learning of mathematical modelling (Blum, 2015). These days, developing students' ability to use mathematical knowledge and abilities to address real-world issues is the aim of mathematics education in many nations (Tangkawsakul et al., 2024). Consequently, the teacher's role has evolved from merely imparting mathematical concepts and techniques to nurturing students' ability to apply this knowledge through real-world problems related to mathematics (Kaiser & Grünewald, 2015). These problems have specific criteria and can be interpreted in different ways, including modelling problems, application problems, and contextualized problems (McGrane, 2020). However, many researchers highlight the challenge of integrating contextual mathematical modelling problems into school mathematics, as authentic situations cannot be easily replicated within the confines of school education (Borromeo Ferri & Blum, 2010). It is still rare to see problem-solving techniques used in math classes, particularly when it comes to contextual mathematical modelling problems. Modifications to the curriculum and teaching methods are frequently required to make modelling instruction feasible and successful in educational contexts. While assessment gets more complicated as mathematical modelling is taught, instruction is more flexible. This complexity serves as the primary barrier to applications and modelling (Blum, 2015; Mohd Saad et al., 2023).

Araújo et al. (2020) stated that the process of engaging students with real-world resources, encouraging collaborative learning, and empowering them to create mathematical knowledge relevant to their everyday lives are all elements of classroom-based mathematical modelling teaching. This approach encourages practical comprehension of mathematical ideas and fosters student engagement. The development of 21st century abilities depends on the critical thinking and autonomous exploration of mathematical concepts that are fostered by teaching mathematical modelling in schools (Wei et al., 2022). To handle modelling problems and other metacognitive activities, such as mathematizing in a variety of contexts and areas, teachers can assist students in developing appropriate individual techniques (Blum, 2009; Hidayat et al., 2021a, 2021b). According to Ang (2015), it is heartening that many teachers are willing and prepared to incorporate mathematical modelling into their curricula despite the obstacles faced. Even though they are sometimes unaware of it, teachers have an important effect on how students modelling processes. A useful framework to assist instructors in developing modelling instructions, activities, or classroom-based learning experiences

Table 1. Keywords used for best practices for teaching mathematical modelling in education

Keyword	The strings and combinations of keywords
Framework	("framework" OR "model") AND
Mathematical modelling	("modelling" OR "mathematical modelling competency") AND
Education	("mathematics education")

is urgently required. Additionally, such a framework would assist educators in creating a shared understanding of what classroom-based mathematical modelling involves. It would also provide educators with a standard vocabulary in which to discuss and debate mathematical modelling challenges. This may result in more structured and professional relationships, ultimately improving the current situation.

METHODOLOGY

To address the present study, the researchers employed a systematic literature review (SLR) in this work. One way to review current literature in a structured manner is by conducting SLR (Jabar et al., 2022). At every phase of the process, it employs systematic, open, and duplicable techniques to ascertain and assess pertinent literature in its totality. A SLR synthesizes existing research on a specific topic by identifying trends, gaps, and patterns in the literature. It offers a comprehensive overview, providing a thorough understanding of the subject (Brignardello-Petersen et al., 2024); in this case, best practices for teaching mathematical modelling in educational contexts and offers alternatives to help with decision-making. Therefore, the goal of the current research on best practices for teaching mathematical modelling in an educational context is examined in a systematic manner in this paper.

The researchers reviewed the dimensions and sub-dimensions involved in developing mathematical modelling instruction, the level of institutional study focused on mathematical modelling in teaching, the mathematics topics covered, and the geographic distribution of the authors; factors which were elusive in previous reviews. The current SLR acquired primary sources using literature searches in the 'ERIC', 'ScienceDirect', and 'Scopus' databases, starting from the oldest possible date until November 2024. Scopus offers comprehensive tools for browsing, searching, filtering, and storing, and, unlike the science citation index, Scopus covers a wider range of content. One of the most prominent citation indexes globally is Scopus, a well-regarded and particularly competitive source. Furthermore, the ERIC database is the most significant database for educational research worldwide (Wright & Pullen, 2007). Additionally, the ScienceDirect website encourages readers to delve into the world of scientific literature (Tober, 2011). After formulating the research questions, the researchers identified relevant keywords to locate journal articles throughout three search engines. To ensure comprehensive coverage, they initially conducted the search without any restrictions on publication dates. The key terms selected from the titles for the review included framework, model, modelling, mathematical modelling competency, and mathematics education. Next, these keywords were combined using Boolean operators, such as "OR" and "AND" to create a search string for the literature identification process. All three databases utilized the same list of terms in their title, abstract, and keyword sections. These keywords were selected to ensure consistency in the search parameters, and they were utilized consistently throughout all three databases to preserve consistency and accuracy in retrieving pertinent information. The search technique used identical keywords across all databases to collect a comprehensive and coherent set of results that corresponded to the specific research emphasis. **Table 1** presents a summary of the literature search plan.

In order to extract suitable journal articles, the preferred reporting items for systematic reviews and meta-analysis (PRISMA) technique was adopted, following the flowchart (Mohamed Shaffril et al., 2021). PRISMA is a widely recognized flow diagram designed to clarify the review's aim and outline the analytical and methodological approach before conducting the review (Moher et al., 2015). The procedure attempts to improve transparency and accuracy in systematic reviews; simultaneously reducing the possibility of inaccurate reporting. The protocol consists of four stages: identification, screening, eligibility, and inclusion.

Identification

The three primary search engines used to find pertinent publications were ERIC, ScienceDirect, and Scopus. A variety of search result specialization possibilities are offered by these databases. When looking for

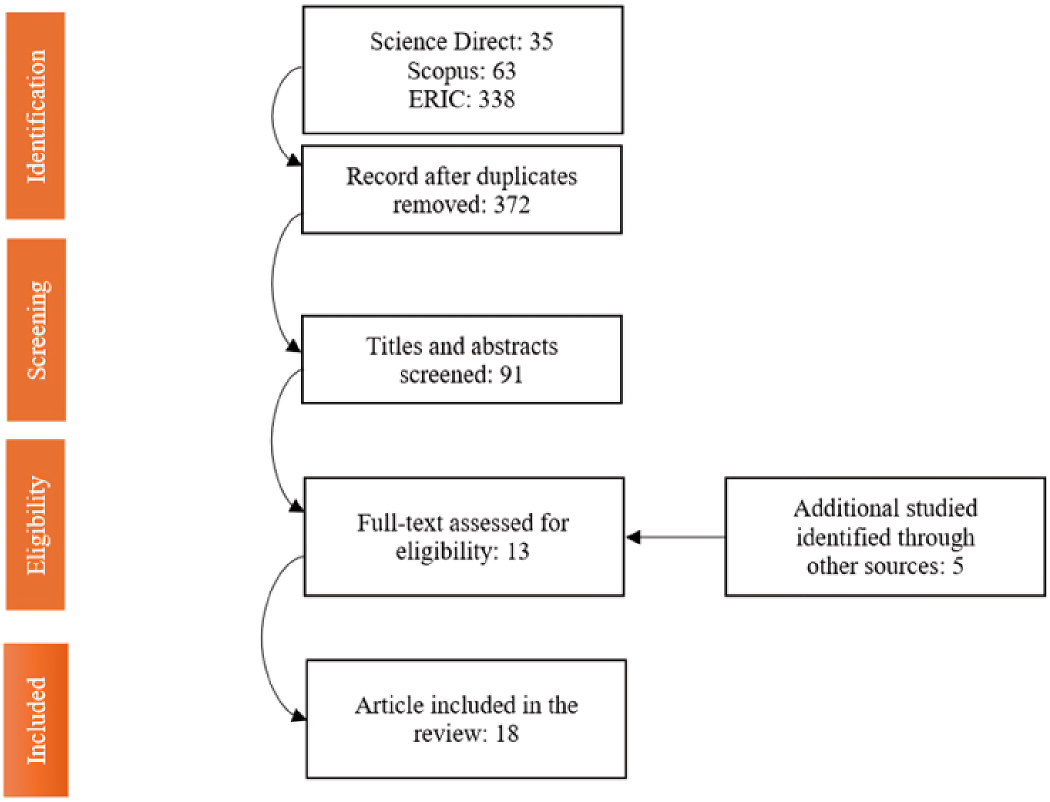

Figure 1. PRISMA protocol flow chart [Adapted from Mohamed Shaffril et al. (2021)]

publications with SLR titles, the keywords listed in **Table 1** were used: ((“framework” OR “model”) AND (“modelling” OR “mathematical modelling competency”) AND (“mathematics education”)). At this point, the researchers considered solely the specified keywords to produce the search engine results. To ensure the query was adequate, the researchers developed a set of search terms using the abstracts and titles of a preliminary collection of articles that included reviews that had already been published (Cevikbas et al., 2021; Hidayat et al., 2023; Wei et al., 2022). The first criterion used to choose the articles was their abstracts. ERIC yielded 338 results, 35 from ScienceDirect, and Scopus provided 63 results. In total, there were 436 results that required filtering. Due to the limited number of papers retrieved from the search engine, a snowballing technique was employed to gather numerous relevant documents as possible. The hybrid search method is often effectively used in SLRs (Wohlin et al., 2022).

Screening

Duplicates in the results from the identification stage were removed to facilitate the next steps in the process. A total of 64 duplicates out of 436 results were identified and removed using the PRISMA protocol. Following a review of the remaining results, publications that did not precisely meet the criteria for article title, year of publication, document type, language, and accessibility were excluded. The titles should relate to mathematical modelling or mathematical modelling competency in the educational setting. Articles from various disciplines, including science, engineering, mathematics, and social sciences, were considered, as the topic was relevant to mathematical education. Since the implementation of mathematical modelling in educational contexts is still evolving, only articles published between 2018 and 2024 were included in order to confirm that the data gathered was up to date. Regarding document type, book chapters and conference reviews were omitted; instead, papers from academic journals were selected. Additionally, since English is a global language, the articles the researchers selected were written in English, which allowed them to include studies from a variety of countries. By focusing on English-language journal articles, they minimized the possibility of misinterpretation or misleading translations. Furthermore, only full-text articles were chosen. All three search engines used underwent the same screening process. As a result, a total of 281 findings were excluded at this stage (**Figure 1**).

Table 2. Criteria of inclusion and exclusion

Criteria	Inclusion	Exclusion
Article title and content	Relevant title and fulfilled the requirements of the study	The title is irrelevant and fails to align with the study's objectives
Publication year	Publications from 2018 to 2024	Publications other than the identified range
Publication type	Original studies and journal article type only	Reviews, editorials, and non-empirical studies
Language	English	Others
Field of article study	Mathematics education	Other than mathematics education
Accessibility	Full-text articles	Preview articles and requires payment or subscription

Eligibility

This phase involves manually reviewing the remaining 91 results to select appropriate articles for inclusion in this SLR. In the third screening stage (the eligibility phase), the review authors evaluated the selected articles manually to confirm that all remaining articles (after filtering) fulfilled the criteria. The procedure also included criteria such as whether a new framework or dimension was adopted, or if an existing framework was used. Articles were omitted if they had unrelated titles or if the research focused more on learning mathematics rather than modelling in mathematics education. Additionally, articles were excluded if they discussed the application of mathematical modelling in disciplines outside the educational context. After excluding publications which were unsuitable for this SLR, the authors reviewed 13 full-text papers. The researchers focused on the different types of dimensions and sub-dimensions involved in developing mathematical modelling instruction, as well as on frameworks that concentrated on secondary-level institutions. After collecting all the articles, the authors unanimously resolved any potential differences of opinion. The researchers also evaluated the reliability and quality of previous research using a standard to examine defects, discrepancies, and contradictions.

Inclusion

During the screening phase of the full-text research, five additional relevant papers were identified using a technique known as backward and forward tracking. These five studies were considered relevant and added to the pool of 13 previously recognized studies. The data were acquired from secondary sources, which include documents, books, journals, reports, and other similar materials. This citation tracking process helped to uncover significant contributions that complemented the initial set of research articles. Using these tracking tools, the researchers can gain a full overview of the academic landscape, identify noteworthy contributions, and situate their work on best practices in mathematical modeling within the greater academic debate. For backward tracing, they checked the reference lists of relevant articles, while for forward tracking, they used Google Scholar to find articles that mentioned the original research. **Table 2** outlines the criteria for inclusion and exclusion.

Data Analysis

To conclude the literature review, important results and findings from prior studies are compiled and used to address the research question. The review aimed to synthesize the findings of various studies and explore ways to advance previous research. Overall, inter-rater consensus for the coding of the examined publications was assessed to strengthen the SLR validity. Additionally, thematic analysis was utilized, which is a method for identifying themes or trends in qualitative data (Nowell et al., 2017). The included research was sorted before inclusion, resulting in a total of 18 publications from which the data were extracted. To gain a comprehensive perspective, studies published across different regions of the world were compiled. Furthermore, to gather the necessary material to address the research questions, every abstract subsection, including the introduction, methodology, findings, and discussion, were properly scrutinized. The findings were classified as qualitative data because the research focused on summarizing and evaluating the findings, as mentioned in this SLR. However, to ensure the validity of the current work, the author constructed and defined the themes by categorizing the data based on their commonality or relevance. After reviewing all 18 retained papers, the authors reached a consensus on a preset coding process comprising main domains such as dimensions, framework or model, mathematical modelling competency, mathematics education, institutional level, topic focused, and geographic distribution of the authors.

FINDINGS

This section presents the findings from the data synthesis and analysis. Following the eligibility screening, 18 articles were selected for the systematic review. Five research questions guided the analysis of all the selected publications. **Table 3** presents a list of the items that were stored.

Table 3. The content analysis on reviewed articles

Author/year	Country	Dimension	Sub-dimension	School	Topic
Stillman et al. (2007)	Australia	Pedagogy	-Messy real-world situation -Real-world problem statement -Mathematical model -Mathematical solution -Real world meaning of solution -Revise model or accept solution	Secondary	Mathematical modelling
Borromeo Ferri and Blum (2010)	Germany	Pedagogy	-Theory-oriented competency -Task-related competency -Teaching competency Diagnostic competency -Assessment competency	Primary & secondary	Mathematical modelling
Oh and Oh (2011)	The United States	Pedagogy	-Exploratory modeling -Expressive modeling -Experimental modeling -Evaluative modeling -Cyclic modeling	Primary	Mathematical modelling
Ng (2013)	Singapore	Pedagogy	-Discuss -Plan -Experiment -Verify -Present -Reflect	Primary & secondary	Mathematical modelling
Borromeo Ferri (2018)	Germany	Pedagogy	-Theoretical dimension -Task-related dimension -Teaching-related dimension -Diagnostic dimension	Secondary	Mathematical modelling
Geiger et al. (2021)	Australia	Pedagogy	-Pre-engagement -Modelling process review -Initial problem presentation -Body of lesson	Secondary	Mathematical modelling
Wess et al. (2021)	Germany	Pedagogy	-Knowledge about interventions -Knowledge about modelling processes -Knowledge about modelling tasks -Knowledge about aims and perspectives	Secondary	Mathematical modelling
Dede and Güzel (2023)	Turkey	Pedagogy	-Conducting warm up activities -Sharing norms -Sharing assessment criteria -Presenting modelling task -Tracking students' works	Secondary	Mathematical modelling
Lesh and Doerr (2003)	The United States	Design of activity/task	-Reality -Model construction -Self-assessment -Model documentation -Simple prototype -Generalizability	Secondary	Mathematical modelling
Ang (2015)	Singapore	Design of activity/task	-Decide on the learning level of mathematical modelling -Listing all abilities and competencies -Write down the concepts or formulas or mathematical equations required -Preparing and providing logical solutions to problems -Listing factors and outcomes that may explain why this lesson is considered successful	Secondary	Mathematical modelling

Table 3 (Continued).

Author/year	Country	Dimension	Sub-dimension	School	Topic
Reit and Ludwig (2015)	Germany	Design of activity/task	-Authentic context -Realistic numeric values -Problem solving character -Naturalistic format for questions -Openness relating to the task space	Secondary	Mathematical modelling
Ng (2013)	Singapore	Design of activity/task	-Selection of mathematical learning outcomes to be assessed -Choosing meaningful and relevant real-world contexts -Open-endedness of the task -Involving real-life data collection and students argue for a decision to be made based on mathematical calculations	Secondary	Mathematical modelling
Fulton et al. (2019)	United States	Design of activity/task	-Attributes of modelling -Variation -Access -Relevance	Secondary	Mathematical modelling
Siller and Greefrath (2020)	Austria	Design of activity/task	-Reality relation -Relevance -Authenticity -Openness -Promoting sub-competencies	Secondary	Mathematical modelling
Dogan (2020)	Turkey	Design of activity/task	-Reality -Openness -Complexity -Model eliciting	Secondary	Mathematical modelling
Geiger et al. (2021)	Australia	Design of activity/task	-Nature of problem -Relevance and motivation -Accessibility -Feasibility of approach -Feasibility of outcome -Didactical flexibility	Secondary	Mathematical modelling
Lo et al. (2022)	Hong Kong	Design of activity/task	-Setting diversified learning objectives -Cross-subject collaboration -More mathematical modelling activities -Strengthening the evaluation of modelling outcomes -Providing relevant supporting materials	Primary & secondary	-Probability -Exponential & logarithmic functions -Differentiation
Dede and Güzel (2023)	Turkey	Design of activity/task	-Identifying the goals -Deciding the modelling task -Making preparations	Secondary	Mathematical modelling
Jensen (2007)	Denmark	Assessment system	-Degree of coverage -Technical level -Radius of action	Primary	Mathematical modelling
Diefes-Dux et al. (2012)	The United States	Assessment system	-Mathematical model complexity -Re-usability -Modifiability -Share-ability	University	Mathematical modelling
Dede and Güzel (2023)	Turkey	Assessment system	-Presenting solution -Discussing solutions and revisions -Assessing cognitive/affective/ social competencies -Sharing assessment results and arriving at decisions	Secondary	Mathematical modelling

What Are the Countries of the Authors Contributing to the Development of Mathematical Modelling Instruction?

This systematic review considered solely papers published in English; nonetheless, the studies were conducted in diverse cultural situations worldwide (**Figure 2**). Germany, the United States and Turkey, with similar and large numbers of empirical studies, each accounted for 19% (n = 4) of the outcomes. Next, 3

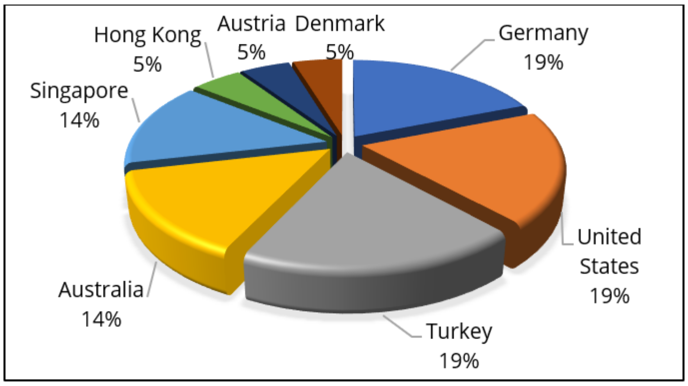

Figure 2. Distribution of published articles by countries (Generated by authors, 2024)

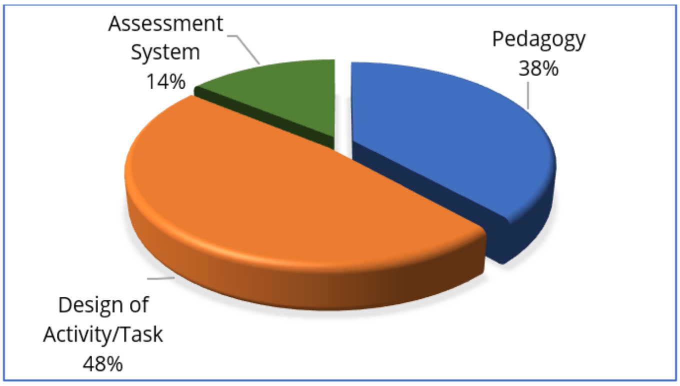

Figure 3. Distribution of published articles by types of dimensions (Generated by authors, 2024)

studies (14%) were conducted in Australia and Singapore each on the development of mathematical modelling instruction. Lastly, only a few studies were conducted in Hong Kong, Austria, and Denmark, with just one study (5%) from each.

What Kinds of Dimensions Are Involved in Developing Mathematical Modelling Instruction?

Table 3 displays the distribution of articles presenting frameworks and dimensions for developing mathematical modelling instruction. The body of research in this area has grown significantly. **Figure 3** shows that 48% (10) of the research developed frameworks for the design of mathematical modelling activities or tasks. Eight studies (38%) developed frameworks for the pedagogy, meaning for the teaching practice of mathematical modelling. The remaining articles (14%, n = 3) developed frameworks for assessment systems to evaluate learners' responses in mathematical modelling activities or tasks.

What Are the Sub-Dimensions Involved in Developing Mathematical Modelling Instruction?

Table 3 shows the distribution of sub-dimensions involved in developing mathematical modelling instruction, based on the reviewed articles. Under the dimension of pedagogy, the most common sub-dimensions were the theoretical dimension, task-related dimension, teaching-related dimension, and diagnostic. Additionally, Dede and Güzel (2023) developed a pedagogy framework that outlines the steps in teaching mathematical modelling, starting with warm-up activities and concluding with the tracking of students' work. Conversely, under the dimension of designing modelling activities or tasks, the most frequently mentioned sub-dimensions in nearly all the reviewed articles were reality, relevance, openness related to the task space, the naturalistic format of questions, and the complexity of tasks. Finally, under the assessment system for modelling tasks, the most developed sub-dimensions were presenting solutions, discussing solutions and revisions, and assessing cognitive, affective, and social competencies.

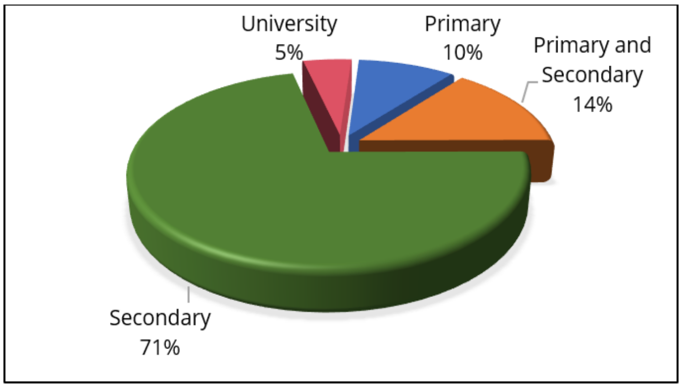

Figure 4. Distribution of published articles by level of institutional study (Generated by authors, 2024)

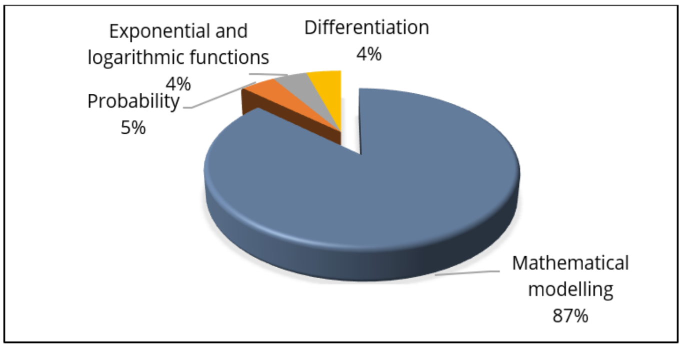

Figure 5. Distribution of published articles by topics involved (Generated by authors, 2024)

Which Level of Institutional Study Is the Focus in Developing Mathematical Modelling Instruction for Teaching?

The third research question looked into the level of institutional study involved in developing mathematical modelling instruction for teaching. According to **Figure 4**, 71% (15) of the studies focused on the secondary level while developing frameworks for mathematical modelling instruction. 14% of the studies (3) developed frameworks for mathematical modelling instruction, focusing on both primary and secondary levels of education. Thirdly, 10% of the studies (2) developed frameworks for mathematical modelling instruction, focusing on the primary level of education. Lastly, a handful of studies (5%, n = 1) looked into university level education while developing mathematical modelling instruction for teaching. In general, the development of mathematical modelling in education is focused entirely on all groups of learners.

Which Topics Are Involved in Developing Mathematical Modelling Instruction for Teaching?

The third research question looked into identifying the mathematics topics involved in the development of mathematical modelling instruction. **Figure 5** shows the topic distribution covered in the reviewed papers. The studies exposed that most of the instructional frameworks and models (87%, n = 20) developed were focused on the topic of mathematical modelling itself. Only one reviewed article provided results on different topics, such as probability (5%, n = 1), exponential and logarithmic functions (4%, n = 1), and Differentiation (4%, n = 1). It can be concluded that the authors of the reviewed papers narrowed the scope of their framework development to the general topic of mathematical modelling.

DISCUSSION

Regarding the geographical location of the authors, the studies showed that the majority of those developing mathematical modelling frameworks in teaching were from Germany, the United States, Turkey, Australia, and Singapore, with only a few studies conducted in Hong Kong, Austria, and Denmark. The results may explain why academics in Turkey, the United States and Germany were interested to implement mathematical modelling drastically in education. Since 2003, mathematical modelling has been recognized as a crucial competency in German educational standards, encouraging pupils to think critically and solve problems (Greefrath et al., 2021). One of the possible reasons could be explained through looking at the curriculum and policy documents like the guidelines of assessment in mathematical modelling education report in the United States, the German Federal Ministry of Education and Research that devised the modelling and measuring competencies framework in higher education in Germany and Turkish Ministry of National Education (2009) documents in Turkey. According to Turkey's curriculum designer, learners who can apply mathematics in everyday life, solve problems, convey answers and viewpoints, demonstrate self-confidence, and have a positive outlook should be encouraged. In Singapore, it is evident that mathematics teachers are enthusiastic and eager to involve students in mathematical modelling tasks during class. Nevertheless, the findings also indicated a deficiency in the variety of countries, particularly within the Asian context, to create mathematical modelling instruction for teaching. For instance, while modelling was integrated into the mathematics curriculum in Singapore, Ng (2013) discovered that the majority of teachers in Singapore had never assumed the role of a modeler, which led to challenges in recognizing the advantages of integrating modelling assignments into their teaching. Likewise, the Malaysian secondary mathematics curriculum had more emphasis in problem solving, reasoning, communication, making connections and the use of technology. Without sufficient resources and support, like examples and modelling tasks, educators would be struggle to effectively teach mathematical modelling (Leong, 2014). Consequently, this topic requires deeper investigation in other countries, particularly in the development of mathematical modelling instruction for teaching purposes.

Based on the SLR's findings, mathematical modelling seems to be on the verge of reaching its full development, particularly in the field of education. Almost half of the articles reviewed developed frameworks for designing mathematical modelling activities or tasks. The current findings from the reviewed articles support the perspective of Maaß et al. (2019) on the implementation of mathematical modelling in classroom teaching and learning. To implement modelling-based education successfully, teachers must select relevant modelling tasks, design lessons that are suited for modelling, and assess students' performance in modelling activities. Next, the researchers discussed the framework developed under the dimension of pedagogy to enhance mathematical modelling instruction in education, which was also a significant part of their findings. This study's result reinforces Henn's (2007) assertion that "an adequate modelling pedagogy is necessary," highlighting the significance of relevant issues, instructional strategies, and modes of instruction. Structured mathematical modelling pedagogy, supported by frameworks, helps nurture critical thinking and enables learners to synthesize information effectively. For example, the pedagogy framework developed by Ng (2013) provides a process for handling modelling tasks effectively in the classroom, while Wess et al. (2021) constructed a framework on the knowledge needed to conduct modelling activities. On the other hand, frameworks for assessment systems guide educators in evaluating students' work by outlining steps for assessment, such as presenting solutions, discussing solutions, assessing competencies, and making decisions (Dede & Güzel, 2023). Overall, the frameworks aim to facilitate the effective design and implementation of mathematical modelling tasks. The researcher found that the diverse development of frameworks in the design of activities and pedagogy demonstrates that the teaching of modelling is emphasized worldwide.

When designing activities and tasks, struggling with openness in modelling and posing relevant mathematical problems to address real-world situations appear to be the most important aspects to focus on. The recent findings from the reviewed articles support the perspective of Reit and Ludwig (2015) on the openness of alternative mathematical models to solve the tasks and authenticity of a task by having its origin (Palm, 2002). The task space reflects the task's openness, as it allows for multiple solution techniques. These methodologies differ in the mathematical models used, giving students multiple possibilities for arriving at a solution. Geiger et al. (2021) emphasized that the problem should be open-ended and include both intra- and extra-mathematical knowledge. They also highlighted the importance of relevance (Dogan, 2020; Fulton et al., 2019; Lesh & Doerr, 2003), stating that tasks must have a meaningful connection to students' real-world experiences. For example, for students to engage in model construction, they must first understand the problem and be able to make connections to mathematize and solve it. This is possible only if the modelling activities are designed with realistic numerical values and a problem-solving character (Reit & Ludwig, 2015) that involves real-life data collection, allowing students to argue for a decision based on mathematical calculations (Ng, 2013). Based on the findings, the pedagogical framework developed primarily focuses on the theory-oriented and task-related dimensions (Borromeo Ferri, 2018; Borromeo Ferri & Blum, 2010). The teaching of mathematical modelling requires educators to possess the necessary knowledge of theoretical aspects, such as modelling cycles, goals, and perspectives, as well as the ability to solve modelling problems, analyze potential barriers, and identify the required competencies. This aligns with the framework of Wess et al. (2021) that suggested knowledge about interventions, modelling processes, modelling tasks, aims and perspectives are the core requirements for educators to conduct mathematics modelling lessons. The entire process of teaching modelling in the classroom is ongoing, beginning with discussing the task and continuing through presenting solutions and reflecting on the process (Ng, 2013). The frameworks for the assessment system emphasize the reusability, modifiability, and shareability of the models developed (Diefes-Dux et al., 2012). At the end of the task, teachers should be able to assess students' work and measure their competency in cognitive, affective, and social skills. A descriptive framework for mathematical modelling is believed to help teachers plan and execute lessons effectively by ensuring that all relevant components; planning, implementation, and assessment are addressed (Dede & Güzel, 2023). The researcher found that a variety of reliable frameworks have been developed to reinforce the design of modelling tasks for teaching.

Based on the findings, more than half of the reviewed papers developed instructional mathematical modelling frameworks or models focusing on the secondary level curriculum. As discussed earlier, the mathematical modelling cycle is complex, and careful attention is required to follow the step-by-step process in both teaching and learning. Mathematics education in the primary years is crucial, as it impacts students' attitudes and skills in mathematics. It focuses on foundational concepts, such as converting fractions to decimals, understanding time, identifying characteristics of shapes, and interpreting graphs. A wider field of mathematics, including calculus, algebra, and statistics, is introduced in the secondary curriculum, where problem-solving involving real-life questions is tested. Therefore, the current findings from the reviewed articles support the perspective Alibekova et al. (2023) that secondary education involves teaching more complex mathematical ideas, allowing for the application of mathematical modelling in real-world situations. This helps students improve their critical thinking and analytical skills by tackling challenging problems. Wickstrom and Arnold (2023) added that secondary students typically have a higher level of abstract reasoning, which enables them to understand the intricacies of mathematical modelling more effectively compared to primary students. For instance, mathematical modelling procedures are student-centered, where students independently understand and relate the task to real-life problems, mathematize using various formulas, and self-assess their own models. In general, secondary students have the maturity, patience, and more life experiences that help them solve modelling problems more effectively. Studies show that, in teaching, secondary educators frequently participate in professional development focused on creating and implementing modelling activities, which are essential for effective instruction and task design (Barquero & Ferrando, 2024). This supports the finding on why more frameworks were developed for secondary curriculum. However, while greater maturity in modelling is often associated with better skills, some students may still struggle to apply their knowledge effectively. This shows that maturity alone doesn't guarantee success in modelling tasks, highlighting the need for tailored teaching approaches to address each student's specific needs. This finding paves the way for future research, highlighting the need to develop additional frameworks for teaching in both primary and secondary curricula to help both teachers and learners become more familiar with essential mathematical modelling competencies.

Concerning mathematics topics involved in the development of mathematical modelling instruction, most research focused on mathematical modelling in general. This means that the framework developed for teaching provides significant insight into how to design modelling tasks, conduct modelling lessons, and assess solutions to modelling problems. It depends on the educators to integrate in whichever topic lesson of the day which is more general, and no curfew being set to the frameworks. For example, if the teacher plans to teach the topic of functions, she will need to design an activity that incorporates real-life problems, which can then be mathematized into functions using the knowledge taught in the lesson. Researcher finds this as a freedom for the educator to conduct the modelling lesson without curfews because there is no need to follow any specific framework for the implementation. Utilizing mathematical modelling across different mathematical topics can improve comprehension and forecasting in complex systems. According to Egamov et al. (2024), integrating mathematical modelling into the teaching of probability and statistics can enhance students' critical thinking and problem-solving abilities. This aligns with one of the reviewed articles from Hong Kong by Lo et al. (2022), where three topics were the focus for the development of mathematical modelling instruction: probability, exponential and logarithmic functions, and differentiation. For example, including modelling tasks in probability applications to real-world scenarios can help students learn, draw conclusions about decision-making processes, create reliable forecasts, and foster critical thinking (Lo et al., 2022). The researcher found that having a general mathematical modelling instruction is enough to be incorporated in mathematics topics with the help of teachers with mastery modelling competencies.

CONCLUSION

Numerous studies and literature reviews have explored the importance of incorporating mathematical modelling, along with the challenges encountered in the educational context. However, this systematic review focuses on the best practices for teaching mathematical modelling. The developed frameworks in the review findings are specifically aimed at teaching within the context of secondary education. Secondary school learners possess a broader and deeper understanding of mathematical concepts and real-life scenarios relevant to their age, enabling them to follow the step-by-step modelling cycle and self-assess the purpose of their models. Moreover, the current systematic review reveals that the teaching dimensions developed around mathematical modelling are integrated into topics such as differentiation in the secondary syllabus, where interpretation and analysis are crucial components of the topic. Thus, based on the reviewed papers, this explains why the mathematical modelling frameworks were primarily designed for the secondary level. Enthusiasm for teaching and learning modelling is more evident at the secondary level, where students gain greater exposure to problem-solving questions and teachers participate in training programs (Barquero & Ferrando, 2024) focused on developing an understanding of mathematical modelling through practical experiences, such as designing modelling tasks for secondary education. Finally, just as the national curriculum emphasizes the implementation of mathematical modelling in education, the teaching frameworks developed in those countries are also increasingly aligned with this focus. Turkey, the United States, Germany, Australia, and Singapore have been the most prolific contributors to the development of mathematical modelling instruction, with only a few studies conducted in Denmark, Hong Kong, and Austria.

Limitation, Future Direction, and Implication of Study

The systematic review was limited to specific contexts, which made it challenging for researchers to collect data efficiently and may have affected the findings to some extent. Firstly, this study was limited to journals included only in the ERIC, ScienceDirect, and Scopus databases. Therefore, the review may not cover all studies on the development of mathematical modelling instruction in mathematics teaching. Secondly, the lack of sufficient filters to refine search results in the databases led to a massive number of results, many of which were unrelated to development of mathematical modelling instruction and focused instead on general teaching and learning skills. This, in turn, caused delays in identifying relevant articles. Next, limited results were found using the keyword combination used: ((“framework” OR “model”) AND (“modelling” OR “mathematical modelling competency”) AND (“mathematics education”)), with most findings consisting of journal articles focused on the application and challenges of mathematical modelling. This led to a scarcity of relevant reference materials. Additionally, this study was limited to research published in the form of articles. Several articles were behind paywalls or restricted to subscribers, which may have prevented access to crucial resources. As a result, important books or book chapters may have been overlooked, potentially impacting the findings. The researchers believed that there were currently enough high-quality books on mathematical modelling instruction available. Moreover, another limitation of this study is the publication date, as mathematical modelling is an evolving field. It was challenging to collect the most recent articles, meaning that some of the latest developments may not be fully represented. Finally, they removed publications which did not develop a new framework or model that contributed to mathematical modelling instruction in teaching.

In order to deal with the SLR limitations, future scholars may utilize additional databases such as ProQuest, Springer, and SCCI to enable a more comprehensive inclusion of relevant studies. They should also adhere to clearly defined inclusion and exclusion criteria and expand their data collection process. Additionally, more precise keywords should be used during searches to yield more relevant and accurate results. Future researchers could also consider analyzing a wider range of sources, such as thesis, dissertations, and conference papers, to uncover additional knowledge about the development of mathematical modelling instruction in education. When it comes to paid documents, researchers have the option to utilize alternative databases that are free of charge, containing approved articles that have undergone verification by supervisors. Considering the authors' geographical spread, more research is needed in the Asian context to enhance mathematical modelling instruction. This happens because modelling tasks are real-life tasks that require a detailed understanding of the context before creating a new model. In other words, the task should be aligned with the environment and experiences of the students. Ultimately, this SLR focuses on five key research questions: the dimensions and sub-dimensions in developing mathematical modelling instruction, the targeted institutional levels, the mathematical topics involved, and the geographical distribution of authors contributing to the development of mathematical modelling instruction. Examining the impact of the implemented frameworks on teachers' instructional effectiveness would provide a valuable contribution to the future SLR.

The implication of this SLR not only highlights the current reviews on the development of mathematical modelling instruction but also underscores the growing body of research and the potential for future implementation of mathematical modelling in education worldwide. This review was primarily conducted to summarize research on key dimensions of mathematical modelling instruction and provide an overview of existing frameworks for teaching mathematical modelling to students in schools. Based on the findings, the research shows that there are numerous effective frameworks for designing mathematical modelling tasks, delivering instruction for modelling lessons, and assessing students' work. Teachers should integrate these frameworks to foster a more engaging classroom atmosphere in mathematics. Furthermore, teachers must grasp the distinctions among the various dimensions of a framework and understand its sub-dimensions to enhance their teaching. If educators lack the necessary understanding of the skills required for modelling activities, they will struggle to effectively integrate modelling into their teaching and learning environments. The results on the sub-dimensions of the frameworks offer valuable insights, helping educators consider key criteria when designing activities to achieve their objectives, without being restricted to specific topics. This study is particularly significant for those who lack confidence due to insufficient training and the skills required to conduct effective modelling lessons.

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