International Journal of Management, IT & Engineering
Vol. 14Issue 11, November 2024,
ISSN: 2249-0558 Impact Factor: 7.119
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gate as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Trends and Developments in Mathematical Modeling Research: A Descriptive Study

Dr. Santosh Kumar Singh Bhadauria
Associate professor
Department of Mathematics
Pt. J.L.N. College Banda

Abstract

Recently, mathematical models and modeling practices have become popular in associating mathematics with real-life problems and thus enhancing understanding of this relationship. Accordingly, mathematical modeling skills have been adopted in standards and by researchers across mathematics education. Understanding the use of mathematical modeling in the teaching–learning processes of mathematics will contribute significantly to the future of the field. This study aimed to review trends in mathematical modeling literature using leading research studies. Research articles indexed in the Web of Science database between 2000 and 2021 were examined to evaluate how they addressed modeling. The review included the types of mathematical modeling approaches employed, along with key characteristics such as publication year, sample, and research method. Data were analyzed through a descriptive content analysis approach using a coding form developed by the researchers. Findings indicated a steady increase in the number of modeling studies over the years, with a strong focus on pre-service teachers. Moreover, many studies employed small samples to closely monitor the modeling process. This descriptive review highlights the growth of mathematical modeling research and points toward areas requiring further empirical exploration.

Keywords: mathematical modeling, mathematics education, descriptive content analysis, teaching and learning, research trends

Introduction

Over the past two decades, mathematical modeling in education has attracted growing scholarly attention. One of the central aims of mathematics education is to cultivate learners who can apply mathematical knowledge in real-world contexts (Kaiser, 2005) and thereby develop problem-solving competencies relevant to everyday life (English & Watters, 2005). Unlike traditional exercises, mathematical modeling tasks encourage deeper mathematical thinking and enhance learners' ability to reason, generalize, and solve authentic problems (English & Watters, 2005).

The significance of mathematical modeling has been further emphasized in international assessments such as PISA, which highlight the importance of mathematical literacy and the application of school mathematics to daily life situations (OECD, 2013). As a result, mathematical modeling has been increasingly integrated into curricula across different countries, from primary to higher education (NCTM, 2000; Ministry of Education Singapore, 2007; Australian Ministry of Education, 2008; Common Core State Standards, 2011).

This curricular emphasis has inspired both reforms in school mathematics and a surge of scholarly interest in modeling as a pedagogical and research focus. The limited progress in developing students' higher-order problem-solving skills (Lesh & Zawojewski, 2007), together with the recognition of modeling as a means of preparing students for real-world problem-solving in a competency-driven economy, has shifted attention from routine problem-solving to mathematical modeling (Chan, 2013). Researchers have highlighted modeling not only as a vehicle for teaching mathematical concepts but also as a means of improving students' dispositions toward mathematics (Blum & Ferri, 2009). Consequently, recent years have witnessed an increase in publications addressing various dimensions of mathematical modeling within mathematics education (Blum & Ferri, 2009).

With the growth of technology and modern learning theories, mathematical modeling studies have expanded to include higher-order cognitive skills supported by digital tools and simulations (Siller & Greefrath, 2010; Lingefjärd, 2013; Çekmez, 2020). Today, modeling is embedded across mathematics curricula worldwide, from primary and secondary levels to higher education, where mathematics often functions as a service subject for disciplines such as engineering, economics, and the sciences (Niss & Blum, 2020; Durandt et al., 2021; Çevikbaş et al., 2022). Beyond mathematics education, modeling has also been widely applied in diverse domains such as applied mathematics, physics, biology, engineering, and even social sciences (Damlamian et al., 2013; Ferruzzi & Almeida, 2013; Laudares & Lachini, 2005).

Despite its growing prominence, research on mathematical modeling is still not fully developed and remains fragmented in several respects (Ferri & Blum, 2013; Stillman et al., 2015). Scholars have not reached a consensus on the precise meaning, scope, and application of modeling (Aztekin & Taşpınar-Şener, 2015), even though there is agreement on the centrality of modeling competencies and the modeling cycle. Furthermore, limited research has systematically examined the distinct contributions of short- and long-term modeling approaches across different levels of education (Çevikbaş et al., 2022). This gap highlights the need for comprehensive studies that synthesize and critically analyze existing research on mathematical modeling.

In this context, the present study seeks to map the current state of mathematical modeling research in mathematics education by conducting a descriptive content analysis of published studies. By categorizing and systematizing different approaches, types, and theoretical perspectives, this review aims to provide a holistic picture of how mathematical modeling is conceptualized, studied, and applied, while identifying gaps that require future scholarly attention.

Mathematical Modeling

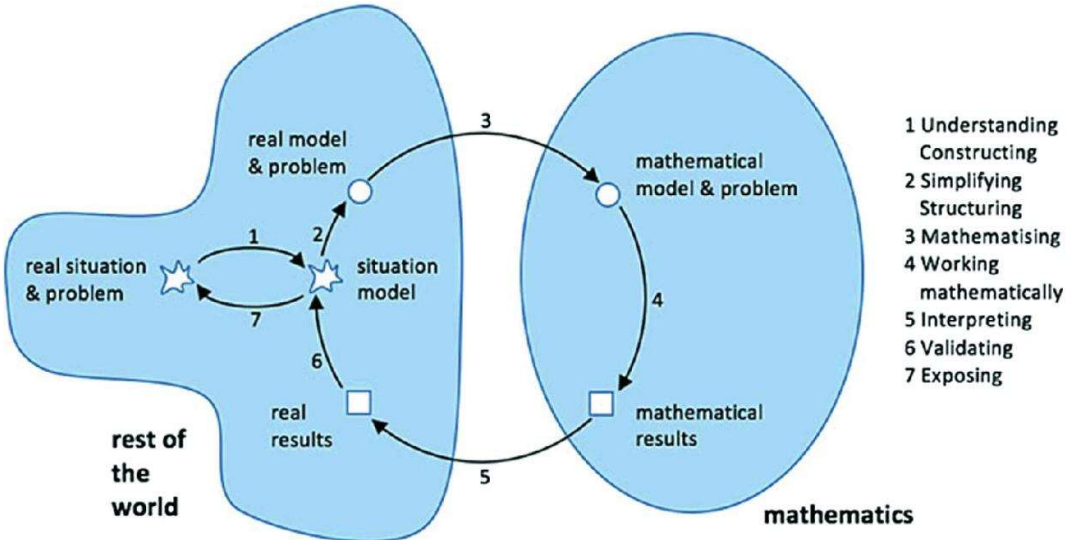
The concept of *mathematical modeling* has been defined in diverse ways in the literature, reflecting researchers' perspectives and the emphasis they place on different aspects of the process (Bukova Güzel, 2016). While some definitions highlight the stages of the modeling cycle, others stress its broader purpose and characteristics (Çavuş Erdem, 2018).

One of the earliest definitions, proposed by Pollak (1979), describes mathematical modeling as the interaction between the real world and mathematics. This perspective laid the foundation for integrating real-life contexts into mathematics education. Building on this, Lesh and Doerr (2003) conceptualized modeling as the transformation of a real-world problem into a mathematical form, the development of appropriate mathematical models to solve it, and the interpretation of results in relation to the original situation. In this view, modeling becomes a tool to explain and make sense of reality through mathematics.

Borromeo-Ferri (2006) expanded this understanding by describing mathematical modeling as a *complex and cyclical process* that involves continuous transitions between real-world phenomena and mathematical structures. Similarly, Galbraith and Clatworthy emphasized modeling as the application of mathematics to solve unstructured, real-life problems. Taken together, these definitions suggest that modeling is not a linear activity but a recursive cycle in which problems are contextualized, mathematized, analyzed, and then reconnected with the original context through interpretation and validation.

Central to this process are *modeling competencies*, which encompass the knowledge, skills, attitudes, and metacognitive abilities required to carry out modeling effectively (Maaß, 2006). While modeling skills refer to the ability to translate real-world situations into mathematical representations and connect outcomes back to reality, modeling competencies involve a broader set of dispositions—including creativity, adaptability, and reflective thinking—that enable individuals to engage meaningfully with modeling tasks.

Over the years, numerous scholars have contributed to refining both the definition of modeling and the competencies required for it (Pollak, 1979; Kapur, 1982; Berry & Houston, 1995; Lesh & Doerr, 2003; Borromeo-Ferri, 2006; Schwarz et al., 2008; Blum & Leiß, 2007). Among these, Borromeo-Ferri's (2006) modeling process and the associated competencies are widely cited as a comprehensive framework for understanding how learners navigate between mathematical and real-world domains. This framework, often



represented in cyclical models (see Figure 1), continues to serve as a foundation for research and practice in mathematics education.

Figure 1 Mathematical Modeling Process (Borromeo-Ferri, 2006)

The mathematical modeling process, as shown in Figure 1, is represented in a cyclical structure comprising seven interconnected sub-processes. These include: (i) understanding the problem or task, (ii) simplifying and organizing it by drawing on additional non-mathematical knowledge, (iii) mathematizing the situation, (iv) applying mathematical reasoning and competencies, (v) interpreting the results, (vi) validating the outcomes, and (vii) presenting the findings. In this sense, the modeling cycle begins with a real-world context or problem, initially expressed in everyday, non-mathematical terms. Importantly, the task should remain open-ended and unstructured so that it encourages learners to engage in critical and creative thinking.

In the second stage of the modeling cycle, students engage in activities such as reading, visualizing, sketching, and organizing information in tables to make sense of the given task or problem. They then identify and analyze the necessary data, establish relationships, and formulate hypotheses and assumptions. At this point, students begin to recognize associations among variables. Using relevant mathematical concepts and rules, they test these associations, assumptions, and hypotheses against the available data. This step represents the phase where the model is most mathematically oriented, as students attempt to solve the problem through mathematical procedures.

The final stage involves evaluating the validity of the model and judging its accuracy. If the model is mathematically sound and the process appears appropriate, the results are interpreted in real-life terms and then reported. However, if the outcomes are found to be unreasonable or inaccurate, the modeling cycle recommences, requiring students to refine their approach until a suitable and accurate solution is achieved.

The competencies required in modeling overlap partly with problem-solving skills, yet modeling problems represent a distinct dimension of problem-solving. Galbraith and Catworthy (1990) define mathematical modeling as the application of mathematics to unstructured, real-life problems. In this sense, modeling tasks are typically open-ended and non-routine, whereas problem-solving includes both routine and non-routine problems. Routine, textbook-style verbal problems do not qualify as modeling problems because modeling requires the integration of extra-mathematical knowledge to address ambiguous or complex conditions (Schukajlow et al., 2018).

Several scholars have argued that routine problems alone are insufficient to develop students' problem-solving skills (Blum & Niss, 1991; Lesh & Doerr, 2003; English & Watters, 2004; Henn, 2007). Consequently, emphasis has been placed on open-ended, non-routine modeling activities that lack fixed instructions, thereby encouraging students to make independent decisions. Research findings show that mathematical modeling contributes to students' ability to:

- transfer mathematical concepts to real-life contexts (Lesh & Harel, 2003; Lesh & Doerr, 2003),
- develop positive attitudes toward mathematics (Blum, 2011; Borromeo Ferri, 2009),
- enhance metacognitive knowledge and skills (Maaß, 2006; Blum & Ferri, 2009), and
- strengthen mathematical reasoning (Zawojewski et al., 2003; Chamberlin & Moon, 2008).

Mathematical Modeling Approaches

Research on mathematical modeling has been shaped by multiple perspectives and theoretical frameworks (Kaiser, Blomhøj, & Sriraman, 2006; Niss et al., 2007; Erbaş et al., 2014; Aztekin & Taşpınar-Şener, 2015). Although these perspectives are not entirely distinct, they emphasize different dimensions of modeling in mathematics education. This section outlines key approaches discussed in the literature.

Kaiser and Sriraman (2006) proposed a broad classification of modeling perspectives into six categories:

1. **Realistic and Applied Modeling** – This approach emphasizes the development of problem-solving and modeling skills through real-world applications. It focuses on fostering students' ability to apply mathematics in practical contexts.
2. **Contextual Modeling** – Grounded in psychological goals, this approach provides students with authentic, real-life tasks. The underlying assumption is that

meaningful learning occurs when learners encounter mathematical concepts within relevant contexts.

3. **Educational Modeling** – Often the most commonly applied perspective, educational modeling integrates aspects of both realistic and contextual approaches. It emphasizes structuring learning environments and processes that support mathematical modeling, with the aim of enhancing concept development.
4. **Socio-Critical Modeling** – This perspective highlights the social and cultural dimensions of mathematics. It seeks to cultivate critical thinking by encouraging students to question and reflect on the societal role of mathematics. Through discussions ranging from simple to complex, students develop a more critical stance toward real-life problems.
5. **Epistemological Modeling** – Rooted in philosophical and theoretical considerations, this approach prioritizes mathematical structures and the relationships among concepts. Real-life contexts are secondary; any activity that involves exploring mathematical structures and interpretations is considered a modeling activity.
6. **Cognitive Modeling** – Focused on cognitive and metacognitive processes, this perspective investigates how learners think, reflect, and regulate their reasoning while engaging in modeling tasks (Bukova Güzel, 2016).

A second categorization frames mathematical modeling either as a **goal** or as a **tool**. When viewed as a *goal*, the emphasis is on equipping students with modeling competencies that enable them to solve complex, real-life problems. The aim is to nurture and advance modeling skills themselves (Galbraith, 2012). In contrast, modeling as a *tool* refers to its use in teaching and reinforcing mathematical concepts within the curriculum. In this sense, modeling provides a meaningful context for learning mathematics, supporting conceptual understanding and application (Lesh & Doerr, 2003).

This study synthesizes current literature on mathematical modeling and is intended to serve as a guide for future research. Using a **descriptive content analysis** approach, it systematically reviewed studies on mathematical modeling published in journals indexed in the Web of Science (SSCI). The parameters for inclusion were determined by the researchers, and the themes used for analysis are explained in detail in the methodology section.

In line with the study's purpose, the following research questions were addressed:

- How are mathematical modeling studies in the Web of Science database distributed with respect to characteristics such as publication year, sample level, country, and research method?
- For what purposes and in what ways has mathematical modeling been used in these studies?
- Which mathematical modeling approaches are most commonly adopted in the literature?

Method

Article Selection Process

In systematic review studies, establishing clear selection criteria is essential to ensure the quality and reliability of the data (Hwang & Tsai, 2011). The use of well-defined criteria provides a more accurate representation of the research field (Kitchenham et al., 2009). Such criteria may involve reviewing all articles within a domain or narrowing the scope to databases such as the **Social Sciences Citation Index (SSCI)**, which is widely recognized for indexing high-quality research over an extended period (Zhang & Leung, 2014).

In this study, we focused on articles related to mathematical modeling published in journals indexed in the SSCI database. The SSCI database was accessed through the **Web of Science (WOS)** platform. Using the advanced search option, the query was constructed with logical expressions:

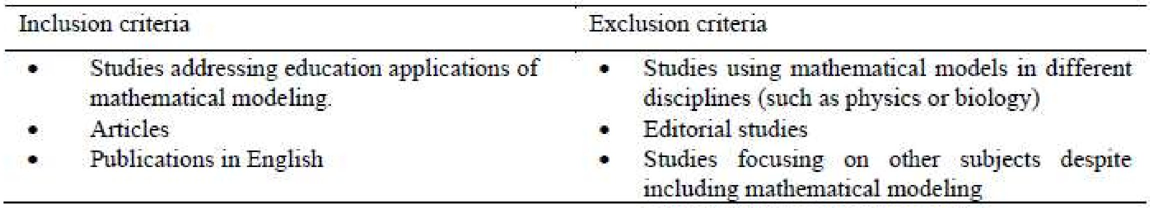
*TS = ("math" AND "education") AND TS = ("modeling" OR "modelling")**

This strategy ensured the inclusion of all relevant studies without overlooking key contributions in mathematical modeling. The publication window was set between **2000** and **5 January 2021**, the date of the final search.

The initial search yielded **941 studies**. After applying filters for SSCI-indexed journals, open-access availability, and English-language publications, the number was reduced to **260 studies**. These articles were then examined in detail by researchers with expertise in mathematics education. Following this review, **42 studies** specifically addressing mathematical modeling in mathematics education were selected.

The inclusion criteria required that studies focus on modeling within mathematics education, while studies that applied modeling in other subject areas (e.g., physics, biology) were excluded. Disagreements between researchers were resolved through discussion, and any study lacking consensus was omitted. **Table 1** summarizes the inclusion and exclusion criteria applied in this study.

Table 1 Article Selection Criteria



Inclusion criteria	Exclusion criteria
• Studies addressing education applications of mathematical modeling. • Articles • Publications in English	• Studies using mathematical models in different disciplines (such as physics or biology) • Editorial studies • Studies focusing on other subjects despite including mathematical modeling

Table 2: List of Articles and Journals Accessed in WOS Database

Nr	Articles (Author & Year)	Journal	Publisher	No. of Articles	Impact Value	Category
1	Hidayat et al. (2018); Eraslan & Kant (2015); Bal & Doğanay (2014); Erbaş et al. (2014); Çiltaş & Işık (2013); Eraslan (2012); Doruk (2012)	*Educational Sciences: Theory & Practice*	Codon Publications	7	0.700	Education and education research
2	Urhan & Dost (2017); Niss (2017); Zeytun & Erbaş (2017); Jacops & Durandt (2017); Shahbari & Peled (2015)	*International Journal of Science and Mathematics Education*	Springer	5	1.578	Mathematics and science education
3	Grajales et al. (2018); Krutikhina et al. (2018); Tezer & Cumhur (2017); Karalı & Durmuş (2015)	*Eurasia Journal of Mathematics, Science and*	Modestum	4	0.470	Mathematics, STEM, science and engineering

Nr	**Articles (Author & Year)**	**Journal**	**Publisher**	**No. of Articles**	**Impact Value**	**Category**
		Technology Education				education
4	Paolucci & Wessels (2017)	*Journal of Teacher Education*	Sage	1	3.600	Teacher education and standards
5	Şahin & Eraslan (2016); Aztekin & Taşpınar-Şener (2015)	*Eğitim and Science*	TED	2	0.740	Education and education research
6	Frejd & Bergsten (2015); Wake (2014); Hankeln (2020); Shahbari & Tabach (2020)	*Educational Studies in Mathematics*	Springer	4	1.500	Mathematics education
7	Dewolf et al. (2015)	*Instructional Science*	Springer	1	1.734	Education and education research
8	Mentzer et al. (2014)	*International Journal of Technology and Design Education*	Springer	1	1.326	Technology and design education
9	Gainsburg (2013)	*Mathematical Thinking and Learning*	Taylor & Francis	1	1.393	Education and education research
10	Kjeldsen & Blomhøj (2013)	*Science & Education*	Springer	1	1.266	Mathematics and science education, education history and research
11	Hickendorff (2013)	*Cognition and Instruction*	Taylor & Francis	1	2.516	Education and education research
12	Doruk & Umay (2011)	*Hacettepe University Journal of Faculty of Education*	Hacettepe University	1	0.180	Education and education research
13	Kim & Kim (2010)	*Asia Pacific Education Review*	Springer	1	0.761	Education and education

Nr	**Articles (Author & Year)**	**Journal**	**Publisher**	**No. of Articles**	**Impact Value**	**Category**
						research
14	Schukajlow et al. (2018); Frejd & Bergsten (2018); Galleguillos & Borba (2018); Orey & Rosa (2018); Hernandez-Martinez & Vos (2018); Dawn (2018); Villarreal et al. (2018); Barquero et al. (2018); Sevinc & Lesh (2018); Chang et al. (2020)	*ZDM – Mathematics Education*	Springer	10	1.256	Mathematics education
15	Cekmez (2020)	*Interactive Learning Environments*	Taylor & Francis	1	1.929	Education and education research
16	Asempapa & Brooks (2020)	*Journal of Mathematics Teacher Education*	Springer	1	1.5	

Coding and Data Analysis

All selected articles were systematically coded and analyzed by the researchers. To ensure the reliability of the coding process, an initial pilot test was conducted with 15 randomly selected articles coded independently by each researcher. The outcomes of this initial phase showed a high level of agreement, confirming the consistency of the coding criteria. Following this, the remaining articles were coded independently.

After completing the independent coding, the researchers compared their codes and discussed any discrepancies to reach mutual agreement. The degree of reliability was then calculated using the formula proposed by Miles and Huberman (1994):

$$\text{Reliability} = \text{Consensus} / (\text{Consensus} + \text{Disagreement})$$

A reliability value above 70% is generally considered acceptable (Miles & Huberman, 1994). In this study, the calculated reliability was 92.4%, indicating a high level of consistency between coders.

The researchers utilized standard office software to organize and record the coding process using a structured form aligned with the research questions. Each article was coded according to various criteria such as publication year, participant type (teachers, pre-service teachers, and students—with further subdivisions under students), sample size, and research design (qualitative, quantitative, or mixed methods). Additionally, the way mathematical modeling was addressed within each study was classified into specific categories, which are presented in detail in the findings section.

Findings and Discussions

Forty-two studies on modeling selected within the scope of the current study were examined in line with the analysis categories. Noteworthy findings in each table are explained below the related tables.

Table 3 Distribution of studies on modeling in terms of sample

Sample	Frequency (f)	Percentage (%)	Articles
Elementary school students	2	4.8	Eraslan & Kant (2015); Şahin & Eraslan (2016)
Lower secondary school students	5	11.9	Tezer & Cumhur, (2017); Shahbari & Peled (2014); Hickendorff (2013); Doruk (2012); Doruk & Umay (2011)
High school students	4	9.5	Grajales et al. (2017); Mentzer et al.(2014); Chang et al. (2020); Hankeln (2020)
University students	5	11.9	Niss (2017); Dewolf et al. (2013); Gainsburg (2013); Kjeldsen & Blomhøj (2013); Hernandez-Martinez & Vos (2018)
Pre-service teachers	9	21.4	Hidayat er al. (2018); English (2017); Zeytun & Erbaş (2017); Karalı & Durmuş (2015); Bal & Doğanay (2014); Çiltaş & Işık (2013); Eraslan (2012); Villarreal et al. (2018); Cekmez (2020)
Teachers	5	11.9	Barquero et al. (2018); Dawn (2018); Sevinc & Lesh (2018); Asempapa & Brooks (2020); Galleguillos & Borba (2018)
Others	12	28.6	Urhan & Dost (2017), Krutikhina et al. (2018); Jacops & Durandt (2017); Freid & Bergsten (2016); Aztekin & Taşpınar-Şener (2015); Wake (2014); Erbaş et al. (2014); Kim & Kim (2010); Orey & Rosa (2018); Schukajlow et al. (2018); Frejd & Bergsten (2018); Shahbari & Tabach (2020)
Total	42	100	

It is observed that studies carried out with pre-service teachers are more frequent among studies on modeling in the literature. In addition, "other" studies of literature review, book review, and studies with mixed participants have a similar percentage in the literature. There are few studies carried out with elementary school and high school students.

Table 4 Distribution of studies on modeling in terms of number of participants

Participants	Frequency (f)	Percentage (%)	Articles
Less than 50	24	57.1	Grajales et al. (2018); Niss (2016); Zeytun & Erbaş (2017); Şahin & Eraslan (2016); Frejd & Bergsten (2015); Karalı & Durmuş (2015); Eraslan & Kant (2015); Aztekin & Taşpınar-Şener (2015); Dewolf et al. (2015); Mentzer et al. (2014); Bal & Doğanay (2014); Gainsburg (2013); Kjeldsen & Blomhøj (2013); Çiltaş & Işık (2013); Eraslan (2012); Hernandez-Martinez & Vos (2018); Barquero et al. (2018); Galleguillos & Borba (2018); Villarreal et al. (2018); Frejd & Bergsten (2018); Sevinc & Lesh (2018); Shahbari & Tabach (2020); Hankeln (2020); Cekmez (2020)
51-99	6	14.3	Paolucci & Wessels (2017); Jacops & Durandt (2017);Shahbari & Peled (2014); Doruk (2012); Kim & Kim (2010); Dawn (2018)
100+	8	19	Hidayat et al. (2018); Tezer & Cumhur (2017); Hickendorff (2013); Doruk & Umay (2011); Orey & Rosa (2018); Schukajlow et al. (2018); Chang et al. (2020); Asempapa & Brooks (2020)
Other	4	9.5	Urhan & Dost (2017); Krutikhina et al. (2018); Wake (2014); Erbaş et al. (2014)
Total	42	100,0	

More than half of the articles (57.1%) worked with participants that were less than 50. This sample size was followed by participant groups of 100 and over (19%) and between 51 and 99 (14.3%) participants. The ‘other’ category includes studies in which the numbers of participants were not stated, and this group has the least frequency (9.5%).

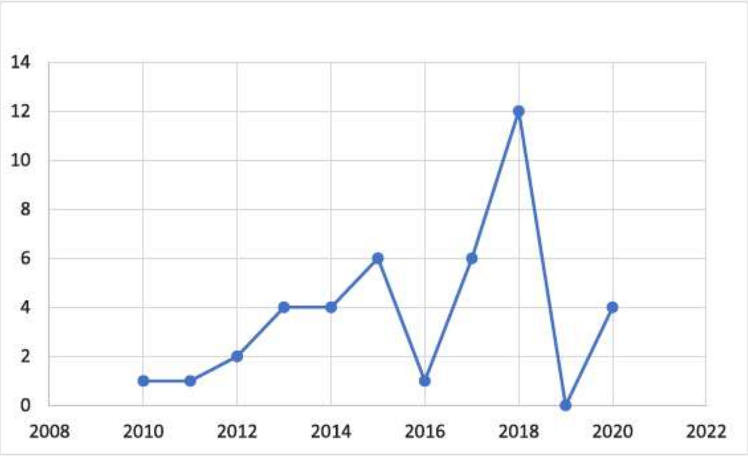


Figure 2 Number of Publications

The number of research studies on mathematical modeling gained pace after 2013. In

International Journal of Management, IT & Engineering
Vol. 14Issue 11, November 2024,
ISSN: 2249-0558 Impact Factor: 7.119
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
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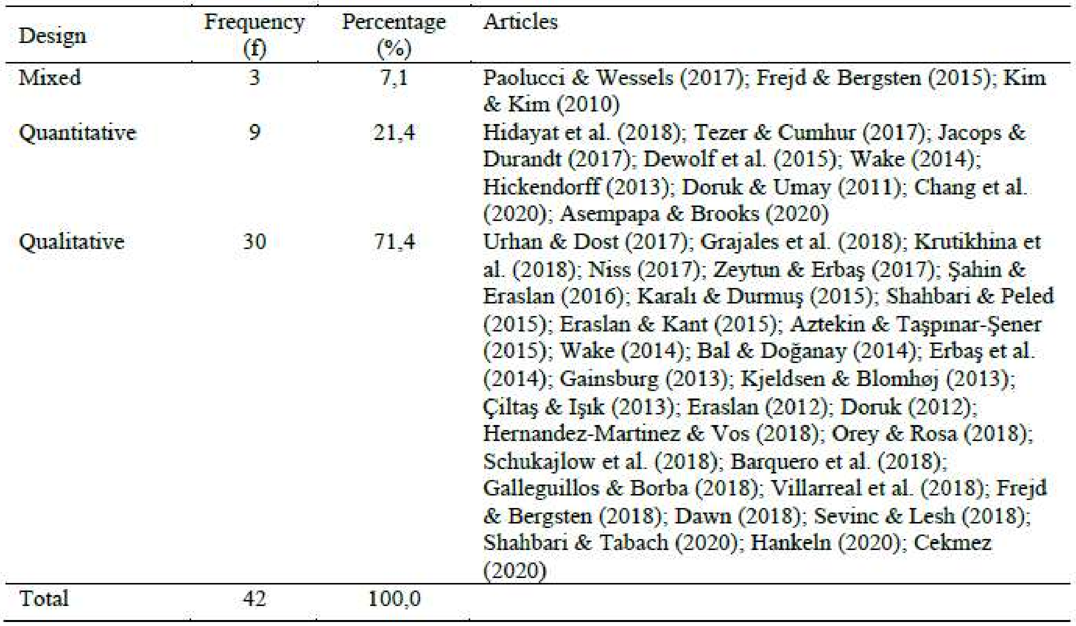
other words, there was a limited number of studies before 2013, and the number of studies increased rapidly in 2015 and afterwards.

Table 5 Distribution of studies on modeling in terms of research designs



Design	Frequency (f)	Percentage (%)	Articles
Mixed	3	7,1	Paolucci & Wessels (2017); Frejd & Bergsten (2015); Kim & Kim (2010)
Quantitative	9	21,4	Hidayat et al. (2018); Tezer & Cumhur (2017); Jacops & Durandt (2017); Dewolf et al. (2015); Wake (2014); Hickendorff (2013); Doruk & Umay (2011); Chang et al. (2020); Asempapa & Brooks (2020)
Qualitative	30	71,4	Urhan & Dost (2017); Grajales et al. (2018); Krutikhina et al. (2018); Niss (2017); Zeytun & Erbaş (2017); Şahin & Eraslan (2016); Karalı & Durmuş (2015); Shahbari & Peled (2015); Eraslan & Kant (2015); Aztekin & Taşpınar-Şener (2015); Wake (2014); Bal & Doğanay (2014); Erbaş et al. (2014); Gainsburg (2013); Kjeldsen & Blomhøj (2013); Çiltaş & Işık (2013); Eraslan (2012); Doruk (2012); Hernandez-Martinez & Vos (2018); Orey & Rosa (2018); Schukajlow et al. (2018); Barquero et al. (2018); Galleguillos & Borba (2018); Villarreal et al. (2018); Frejd & Bergsten (2018); Dawn (2018); Sevinc & Lesh (2018); Shahbari & Tabach (2020); Hankeln (2020); Cekmez (2020)
Total	42	100,0	

the dominant paradigm in mathematical modeling research is the qualitative paradigm.

Table 6 Distribution of studies on modeling in terms of countries

Country	Frequency (f)	Percentage (%)	Articles
The U.S.A.	2	6,9	Fang & Guo (2016); Mentzer et al. (2014)
The U.K.	1	3,4	Wake (2014)
Belgium	1	3,4	Dewolf et al. (2015)
Denmark	2	6,9	Niss (2017); Kjeldsen & Blomhøj (2013)
Indonesia	1	3,4	Hidayat et al. (2018)
South Africa	2	6,9	Paolucci & Wessels (2017); Jacops & Durandt (2017)
Holland	1	3,4	Hickendorff (2013);
Israel	1	3,4	Shahbari & Peled (2015)
Sweden	1	3,4	Frejd & Bergsten (2015)
California	1	3,4	Gainsburg (2013)
Cyprus	1	3,4	Tezer & Cumhur (2017)
Columbia	1	3,4	Grajales et al. (2018)
Korea	1	3,4	Kim & Kim (2010)
Russia	1	3,4	Krutikhina et al. (2018)
Turkey	12	41,4	Urhan & Dost (2017); Zeytun & Erbaş (2017); Şahin & Eraslan (2016); Karalı & Durmuş (2015); Eraslan & Kant (2015); Aztekin & Taşpınar-Şener (2015); Bal & Doğanay (2014); Erbaş et al. (2014); Çiltaş & Işık (2013); Eraslan (2012); Doruk (2012); Doruk & Umay (2011)
Total	42	100,0	

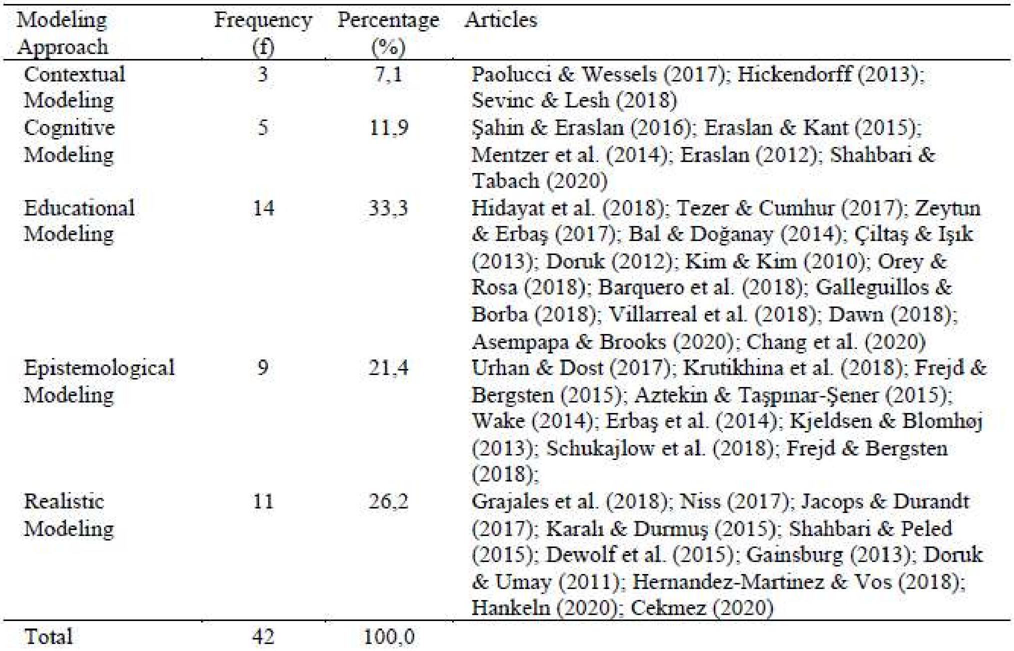
The distribution of the articles in terms of countries demonstrates that the studies conducted in Turkey constituted 41% of all studies in the sample. The studies conducted in the U.S.A., Denmark, and South Africa corresponded to 21% of all studies. Other countries had just one study on mathematical modeling.

Table 7 Distribution of studies on modeling in terms of how modeling is addressed

Examination of Modeling	Frequency (f)	Percentage (%)	Articles
Modeling as a goal	13	31.0	Urhan & Dost (2017); Grajales et al. (2018); Krutikhina et al. (2018); Şahin & Eraslan (2016); Frejd & Bergsten (2015); Wake (2014); Erbaş et al. (2014); Doruk & Umay (2011); Orey & Rosa (2018); Schukajlow et al. (2018); Frejd & Bergsten (2018); Dawn (2018); Sevinc & Lesh (2018)
Modeling as a tool	29	69.0	Hidayat et al. (2018); Niss (2017); Tezer & Cumhur (2017); Paolucci & Wessels (2017); Zeytun & Erbaş (2017); Jacops & Durandt (2017); Karalı & Durmuş (2015); Shahbari & Peled (2015); Eraslan & Kant (2015); Aztekin & Taşpınar-Şener (2015); Dewolf et al. (2015); Mentzer et al. (2014); Bal & Doğanay (2014); Gainsburg (2013); Kjeldsen & Blomhøj (2013); Hickendorff (2013); Çiltaş & Işık (2013); Eraslan (2012); Doruk (2012); Kim & Kim (2010); Hernandez-Martinez & Vos (2018); Barquero et al. (2018); Galleguillos & Borba (2018); Villarreal et al. (2018); Chang et al. (2020); Shahbari & Tabach (2020); Hankeln (2020); Cekmez (2020); Asempapa & Brooks (2020)
Total	42	100,0	

The studies were also examined in terms of whether modeling was used as a goal or tool in those studies. In 69% of the studies, modeling was examined as a tool. This demonstrates that the use of modeling is more common in learning-teaching processes. In other words, modeling is used to a greater extent with pedagogical purposes such as conceptual learning and arrangement of learning processes.

Table 8 Distribution of studies on modeling in terms of modeling approaches



Modeling Approach	Frequency (f)	Percentage (%)	Articles
Contextual Modeling	3	7,1	Paolucci & Wessels (2017); Hickendorff (2013); Sevinc & Lesh (2018)
Cognitive Modeling	5	11,9	Şahin & Eraslan (2016); Eraslan & Kant (2015); Mentzer et al. (2014); Eraslan (2012); Shahbari & Tabach (2020)
Educational Modeling	14	33,3	Hidayat et al. (2018); Tezer & Cumhur (2017); Zeytun & Erbaş (2017); Bal & Doğanay (2014); Çiltaş & Işık (2013); Doruk (2012); Kim & Kim (2010); Orey & Rosa (2018); Barquero et al. (2018); Galleguillos & Borba (2018); Villarreal et al. (2018); Dawn (2018); Asempapa & Brooks (2020); Chang et al. (2020)
Epistemological Modeling	9	21,4	Urhan & Dost (2017); Krutikhina et al. (2018); Frejd & Bergsten (2015); Aztekin & Taşpınar-Şener (2015); Wake (2014); Erbaş et al. (2014); Kjeldsen & Blomhøj (2013); Schukajlow et al. (2018); Frejd & Bergsten (2018);
Realistic Modeling	11	26,2	Grajales et al. (2018); Niss (2017); Jacops & Durandt (2017); Karalı & Durmuş (2015); Shahbari & Peled (2015); Dewolf et al. (2015); Gainsburg (2013); Doruk & Umay (2011); Hernandez-Martinez & Vos (2018); Hankeln (2020); Cekmez (2020)
Total	42	100,0	

Conclusions and Suggestions

The present study reviewed research on the use of **mathematical modeling in mathematics education** by examining aspects such as publication year, research design, participant characteristics, countries, modeling approaches, and purposes for which modeling was utilized. The findings revealed that studies on mathematical modeling remain **limited at the elementary and secondary school levels**, whereas a majority have been conducted with **pre-service teachers**.

Previous literature supports this trend, noting that **mathematical modeling is insufficiently integrated into elementary mathematics curricula** (Jones, Langrall, Thornton & Nisbet, 2002). Scholars have also emphasized the need to incorporate **technology-based, environment-friendly modeling activities** suitable for various grade levels (Rojano, 2015), and to **prioritize mathematical modeling as a core goal** of mathematics education in the modern era (Amit, 1999; Er-sheng, 1999). Likewise, Çevikbaş et al. (2022) observed that studies on mathematical modeling competencies are predominantly focused on **secondary and high school students**, followed by **teacher education programs**.

One major reason behind this focus on pre-service teachers is the **bureaucratic challenges** associated with conducting research in schools (Aztekin & Taşpınar-Şener, 2015). Pre-service teachers are also **more accessible to researchers** within faculties of education, and most modeling-related research tends to emerge from **courses offered at the university level**. Moreover, researchers often assume that **younger students may struggle to engage effectively** with advanced modeling activities due to their developmental stage and the **complex pedagogical knowledge** such studies demand (Aztekin & Taşpınar-Şener, 2015).

Nevertheless, it is crucial to **support and design resources** that introduce mathematical modeling from **early education onwards** (Paolucci & Wessels, 2017). The study further found only one research instance involving **graduate-level participants** and none with **academic professionals**, indicating **limited sample diversity** (Albayrak & Çiltaş, 2017). Expanding modeling research across **K–12 education** can be beneficial, particularly as **technological tools now enable dynamic visualizations and computational modeling**. Increasing research at this level can help identify students' **difficulties, thought processes, and attitudes** toward mathematical modeling, contributing to its meaningful inclusion in the classroom.

In terms of **sample size**, over half of the reviewed studies included **fewer than 50 participants**, consistent with prior findings (Bayrak & Çiltaş, 2017; Çelik, 2017; Çevikbaş et al., 2022). This is often linked to the **qualitative nature of the research designs**, which constituted about **70% of the reviewed studies**, as well as to **time constraints, ethical procedures, and convenience sampling methods**. Smaller samples are particularly common in **cognitive modeling studies**, which focus on **individual challenges and mental processes** (Eraslan, 2012; Shahbari & Tabach, 2020; Şahin & Eraslan, 2016). Conversely, **educational modeling studies**, which often adopt **experimental or correlational survey methods**, tend to involve larger samples (Hidayat et al., 2018; Kim & Kim, 2010; Tezer & Cumhur, 2017). Hence, the **modeling approach and research design** significantly influence the sample size and scope of such studies.

When analyzed chronologically, the review found that mathematical modeling research **began gaining momentum after 2003** (Çevikbaş et al., 2022). This growth may be attributed to **curricular reforms** in several countries (NCTM, 2000; Ministry of Education Singapore, 2007; CCSM, 2011) that positioned modeling as a **key mathematical competency**. The increasing recognition that **modeling enhances real-world problem-solving skills** (Gürbüz & Doğan, 2019) and the **limitations of traditional instructional methods** (Mousoulides, Christou & Sriraman, 2008) have also contributed to its prominence. Researchers have shifted toward **open-ended, contextual, and real-life modeling tasks** (Blum & Niss, 1991; Lesh & Doerr, 2003; Hickendorff, 2013; Çekmez, 2020), in response to the growing emphasis on **21st-century skills** and **international assessments** such as **TIMSS, PISA, and PIRLS**.

Although the number of studies has not been uniformly distributed across years, there has been a **gradual and steady rise**, particularly influenced by **ICTMA conferences** and increased global collaboration in the field (Çevikbaş et al., 2022). Sustaining this research continuity is essential for improving the **quality and applicability** of mathematical modeling and for reaching **diverse participant groups**.

Overall, the findings suggest a need for:

1. **Expanding research to K–12 classrooms** to explore students' real-life mathematical thinking.
2. **Reducing bureaucratic barriers** to facilitate school-based studies.
3. **Balancing instructional and learning perspectives** by investigating students' skill development during modeling.
4. **Encouraging longitudinal and large-scale research** that captures broader trends in mathematical modeling education.

Through these directions, mathematical modeling can evolve into a more **inclusive, dynamic, and practical component** of mathematics education across all learning stages.

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