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Review Article

# Systematic Literature Review on The Evaluation of Mathematical Modeling Competencies

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**Abstract**

This article presents a systematic review of the national and international literature on mathematical modeling competencies. The research explores the differences and commonalities between the two literatures by examining the trends in the assessment of modeling competencies in detail. A comprehensive search of ERIC, Web of Science, Scopus, and TR Index databases yielded 32 studies that met the inclusion criteria. The selected studies span the years 2011-2023 and demonstrate a concurrent focus in both national and international literature. The studies in the national literature are predominantly qualitative, whereas quantitative research designs are more prevalent in the international literature. In both literatures, the participants are mainly preservice teachers and middle school students. In particular, the tools used to assess mathematical modeling activities differ between the national and international literature. The national literature employs written student responses and video recordings, whereas the international literature utilizes student responses and modeling competency scales. When the aims of studies in the national and international literature on mathematical modeling competencies are examined, it becomes clear that research on the effect of applications such as GeoGebra and STEM on modeling competencies emphasizes the supportive role of these applications in enhancing students' competencies. The article also shows that the national literature tends towards holistic and micro assessments.

**Keywords:** Mathematical modeling, modeling competencies, systematic literature review, competency assessment.

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## INTRODUCTION

Mathematics, which is shaped around the daily needs of human beings and has been used in many different fields in the historical process, is generally perceived by many students as a discipline that is far from real life, surrounded by strict rules, and is handled on an abstract plane without establishing a relationship with real life (Erdem Çavuş & Gürbüz, 2018). This perspective overlooks the fact that mathematics is a vital component of life and has a profound impact on people. Research shows that students often perceive the mathematical ideas they encounter in daily life and the mathematical knowledge they learn in school as distinct entities, having difficulty making connections between the two (Magajna & Monaghan, 2003; Lesh & Zawojeski, 2007). Therefore, emphasizing the connection between mathematics and real-world situations is necessary to give mathematics a more profound meaning and increase its comprehensibility (Şahin et al., 2018). The mathematical modeling approach is one of the most effective ways to demonstrate the interrelationship between mathematics and real-world situations (Ferri, 2018; Gürbüz et al., 2018). The primary purpose of mathematical modeling is to apply mathematical concepts to real-world problems and derive suitable solutions.

According to the mathematical modeling approach, people use mathematical solutions to solve practical problems and then interpret these answers in the light of the real world. However, they may encounter cognitive difficulties in this process. Specific skills are necessary to overcome these challenges (Aydın Güç & Baki, 2019). According to the literature, these skills are referred to as mathematical modeling competencies. Mathematical modeling competence is an individual's conscious and deep openness to deal with the challenges that arise in the mathematical modeling process in a given scenario (Jensen, 2007). Likewise, Blomhøj and Jensen (2003) defined mathematical modeling competence as a person's in-depth readiness to carry out the mathematical modeling process in a given scenario in all its steps. Maaß (2006) also defines mathematical modeling competencies as the combination of skills and abilities needed to carry out the mathematical modeling process purposefully and efficiently. Maaß (2006) also emphasizes that these competencies include a person's intentional and comprehensive willingness to apply these abilities throughout the process.

Establishing a clear relationship between the competencies and the mathematical modeling process itself is important for understanding mathematical modeling competencies in their entirety (Maaß, 2006). In this context, Blum and Kaiser (1997) defined mathematical modeling competencies in relation to the mathematical modeling process, making sense of it and elaborating on these competencies. They identified the sub-competencies that each competency encompasses. These competencies are defined by Maaß (2006) as follows:

> "Understanding the real problem and creating a model based on reality: A1. Competence to make assumptions for the problem and simplify the situation, A2. Competence to identify quantities affecting the situation, name them, and identify key variables, A3. Competence to form relationships between variables, A4. Competence to find appropriate/accessible information to solve the problem and distinguish between relevant/irrelevant information, "B. Constructing a mathematical model from a real model: B.1. Competence to mathematize relevant quantities and relationships between them, B2. Competence to simplify relevant quantities and relationships between them when necessary, B3. Competence to choose appropriate mathematical representations and represent situations graphically"," C. Solving mathematical problems with a mathematical model: C1. the ability to divide the problem into smaller parts, to relate to similar problems, to express the problem in another way, C2. the ability to use mathematical knowledge to solve the problem", "D. Interpreting mathematical results in real situations: D1. Competence to interpret mathematical results in non-mathematical contexts, D2. Competence to generalize solutions developed for a specific situation, D3. Competence to examine the solution of a problem using appropriate mathematical language and communicating about solutions, "E. Verifying solutions: E1. Reflecting on and critically checking the solutions found, E2. Revising parts of the model if the solutions are not consistent, E3. Considering other ways to solve the problem or considering whether the result could have been generated differently, E4. Questioning the model in general" (p.547). “

In literature, various approaches are used to measure mathematical modeling competencies. The most commonly used measurement approaches are: "micro-level approach", "holistic approach", and "mixed approach" (Blomhoej & Jensen, 2003). In the micro-level approach, each step of the modeling process is evaluated separately. The holistic approach emphasizes the interconnectedness of the steps and considers the entire modeling process. The approach that combines micro-level and holistic approaches in balance is called a mixed approach (Aydın Güç, 2019). In the literature, examples of holistic assessment (Henning & Keune, 2007; Niss & Højgaard, 2011; Tekin-Dede & Bukova-Güzel, 2018) and micro-level assessment (Haines & Crouch, 2001; Hanklen et al., 2019; Houston, 2007) are found. The number of studies examining mixed evaluation approaches is relatively small compared to other approaches (Turner et al., 2021; Turner et al., 2022).

Numerous studies have been conducted to assess mathematical modeling competencies (Gürel Çakmak & Işık, 2022; Derin & Aydın, 2020; Latifi et al., 2022; Hagena, 2017; Anhalt et al., 2018). One of these studies is the systematic literature review conducted by Hidayat et al.

(2022), who examined the evaluation of mathematical modeling in the context of mathematics education. In this study, only studies conducted with preservice teachers in the last five years were examined, and a total of eighteen articles were analyzed. The researchers concluded that the most common instruments for assessing mathematical modeling were written exams, questionnaires, and reports. Upon examining this study, which was conducted through a systematic literature review, it becomes apparent that it had limitations in terms of sampling and timeframe. This situation reveals the limitations of this study.

This article aims to review previous studies on mathematical modeling competencies systematically. In addition, it aims to reveal the similarities and differences between the two literatures by examining trends in national and international literature in detail within the scope of assessing modeling competencies, and to improve the existing literature. In this systematic literature review, all studies involving mathematical modeling competencies were examined without any limitation based on sample and year. In this context, a systematic literature review on the assessment of mathematical modeling competencies is helpful as it has the potential to contribute to the modeling literature and guide researchers interested in working in this field. In line with the purpose determined within the scope of this study, answers to the following problems were sought:

A. How are the studies on the assessment of mathematical modeling competencies in national and international literature distributed according to years and databases?
B. How are the studies on the assessment of mathematical modeling competencies in national and international literature distributed according to research designs?
    a. How are the studies on the assessment of mathematical modeling competencies in national and international literature distributed according to study groups?
    b. How are the studies on the assessment of mathematical modeling competencies in national and international literature distributed according to data analysis methods?
    c. How are the studies on the assessment of mathematical modeling competencies in national and international literature distributed according to their purposes?
    d. What kind of tools are used to assess mathematical modeling competencies in studies on the assessment of mathematical modeling competencies in national and international literature?
    e. What kind of approaches (micro-holistic-mixed) are used to assess mathematical modeling competencies in national and international literature?

## METHOD

In this study, a systematic review method was used to examine the studies on mathematical modeling competencies. A systematic literature review is an approach to identifying, evaluating, and understanding all research related to a specific research question, topic, or phenomenon of interest (Kitchenham, 2004). In the systematic review process, Daniel and Harland's (2017) triple model approach was adapted and used in accordance with the specific aims of the review. The tripartite model consists of three main components: descriptive systematic review (provides a summary of the literature), synthesis systematic review (categorizes the research logically according to relevant ideas, connections, and rationales), and critical systematic review (provides evidence to support, infer, or present new ideas about the literature).

This review focuses primarily on the synthesis and descriptive systematic review steps of the model. As part of the descriptive systematic review, a literature summary was created, presenting the distribution of included studies by year. During the systematic review of the synthesis, studies were examined within the categories specified by the Publication Classification Forum (see Appendix).

Furthermore, following the systematic review approach, the steps suggested by Newman and Gough (2020) for the systematic review process were followed:

In line with the guidelines proposed by Newman and Gough (2020), these steps:

- Formulate a research question,
- To create a conceptual framework,
- Identify inclusion and exclusion criteria,
- Design a search strategy,
- Conduct a comprehensive search for relevant studies,
- Screening and selecting studies,
- Assessing study quality, extracting data,
- Synthesize information and
- It includes reporting findings.

The studies on mathematical modeling competencies were accessed by searching ERIC, Web of Science, Scopus, and TR Index databases. Detailed explanations of how the studies to be included in the study were selected are provided under the titles' Data Search Protocol' and

'Data Evaluation'. The systematic review stages of the studies included in the research are outlined in the section titled 'Systematic Review Process'.

**Data search protocol and data evaluation**

The data search protocol included identifying the keywords "mathematical modeling competence", "mathematical modeling competencies", and "mathematical modeling competencies" in line with the study's objectives. While searching with these keywords, the specific search formats of each database were taken into account, and the syntax specific to each database was used. Following the assessments, only articles that met the predefined search criteria were included in the systematic review. The inclusion criteria were determined as follows:

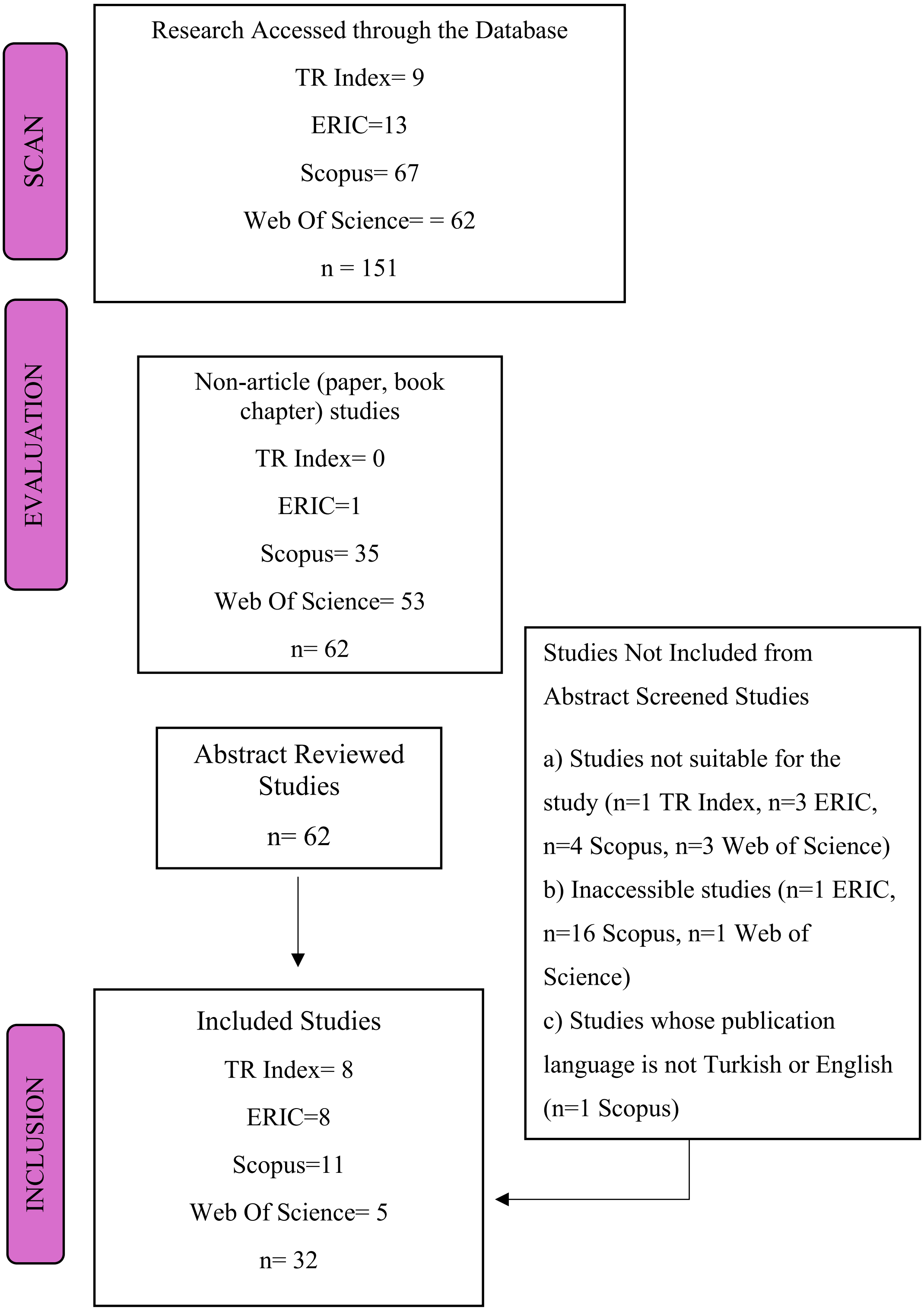
a. The study is open access
b. Full text of the study
c. The study is an article
d. The study deals with mathematical modeling
e. The study is in the field of mathematics education
f. The study includes mathematical modeling competencies

The results of data evaluation in line with the data search protocol and inclusion criteria are presented in Figure 1. Following this process, a total of 32 studies were selected for inclusion in the systematic review.

**Systematic review process**

The first stage of the systematic review process involved evaluating the results obtained. The selection of relevant studies was based on the inclusion and exclusion criteria established by the researchers. In this section, the selection of studies to be included and excluded from the study is presented in Table 2 and Figure 1.

**Figure 1**. below illustrates the inclusion process for the analyzed articles.



In the second stage of the systematic review process, the included studies were evaluated in terms of their subject areas and methodologies. The findings from this review are then presented within the framework of a systematic review synthesis.

**Reliability and validity**

To ensure the reliability of the study, all databases were searched according to the criteria determined by the two researchers who conducted the study. A data search protocol was developed in accordance with the search format of each database to ensure consistency in searches and prevent data loss. The researchers evaluated the data according to this protocol and regularly verified that the search results met the criteria. The studies on which the two researchers were undecided were examined in detail with two field experts, and a consensus was reached among the researchers.

In systematic reviews, predetermined inclusion criteria are crucial for ensuring the validity of the study (Calvo-Morata et al., 2020). Therefore, in this study, the inclusion criteria were determined at the beginning of the systematic review process, and all researchers contributed to the overall validity of the study by conducting their research in accordance with these criteria. Additionally, the entire research process was supported by two field experts. In this study, both data collection and data analysis processes were explained in detail to ensure reliability. Document analysis using a similar approach may show similar results.

**Data Collection Tool**

The data obtained in this study were collected with the revised version of the Publication Classification Form developed by Yıldız et al. (2021). The researchers adapted the form in accordance with the study's purpose, and the original version was updated and organized into ten sections. Three sections related to the evaluation of modeling competencies were added for the study. Section A of the Publication Classification Form provides data for the first and second research problems, and the remaining three sections provide data for the third, fourth, and fifth problems. The revised Publication Classification Form is presented in Appendix 2.

**Data Analysis**

Using the Publication Classification Form, the data obtained from the studies were analyzed using descriptive statistics. The results from the classifications were then presented visually through tables and graphs as part of a comprehensive systematic review. In cases where a study met more than one criterion simultaneously, the analysis included the study in all relevant criteria.

Two researchers independently started the study analysis by examining five studies and extracting codes from each of them. The consistency between the researchers in terms of the extracted codes was calculated, yielding a rate of 88%. The remaining studies planned for analysis were then divided among the researchers, who continued their individual analyses. Frequency values of each extracted code were determined and represented as "M1," "M2," etc., to indicate the source statement. After all the data had been collected, a pool containing the items was created. The categorizations were created by two experts in the field of mathematical modeling prior to the commencement of the study, and these experts subsequently cross-checked the coding and categorizations. Inaccuracies in the groupings were corrected, and finally, the codes and categories were agreed upon.

## FINDINGS

This study aims to systematically review the national and international literature on mathematical modeling competencies and examine the trends in modeling competency assessment. The study's findings comprise eight studies from the national literature and 24 studies from the international literature. The analysis of the findings was conducted in line with the research questions. The first research problem is related to the bibliographic analysis of the studies.

### Distribution of research in national and international literature according to years and databases

The distribution of studies on the assessment of mathematical modeling competencies in the national and international literature, by year, is given in Figure 2 below.

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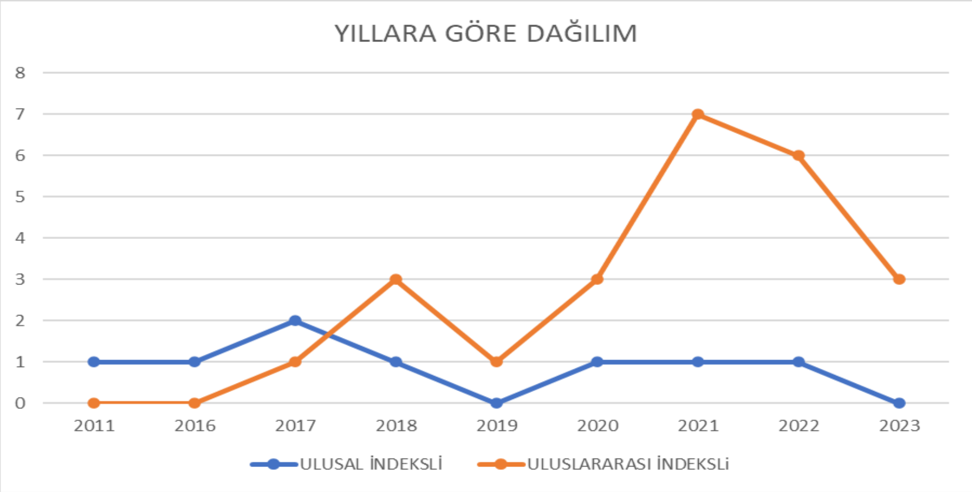
**Figure 2.** Distribution of studies on the assessment of mathematical modeling competencies in national and international literature by years




When Figure 2 above is examined, it is evident that the studies in both literatures span the period from 2011 to 2023. Figure 2 shows the increase in research on mathematical modeling competencies from 2011 to 2023. The majority of the studies were conducted in 2017 in the national literature and in 2021 in the international literature.

The distribution of studies on the assessment of mathematical modeling competencies in national and international literature, as per the databases, is presented in Table 1 below.

**Table 1.** Databases where the analyzed articles were found

| Article Code | Databases where the analyzed articles were found | Frequency |
|---|---|---|
| M1, M2, M3, M4, M5, M6, M7, M8 | TR Index | 8 |
| M9, M10, M11, M12, M13, M14, M15, M16 | ERIC | 8 |
| M17, M18, M19, M20, M21, M22, M23, M24, M25, M26, M27 | Scopus | 11 |
| M28, M29, M30, M31, M32 | Web of Science | 5 |

When Table 1 above is examined, it is evident that there are the highest number of studies in the Scopus database, an equal number of studies in the ERIC and TR Index databases, and fewer studies in the Web of Science database compared to the other databases. Table 1 shows that

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research on mathematical modeling competencies is more prevalent in the international literature (75%) than in the national literature (25%).

## Research Designs

The distribution of studies on the evaluation of mathematical modeling competencies in the national and international literature, according to research design, is presented in Table 2 below.

**Table 2.** Research Designs Used in the Analyzed Articles

| **Research Designs** | | **National Literature Frequency (TR Index)** | **International Literature Frequency (Scopus-ERIC- Web of Science)** |
|---|---|---|---|
| Quantitative Pattern | Causal Comparison | M4 | - |
| | Relational (Correlational) | M2 | M11, M15, M17, M19, M25, M26, M28, M31 |
| | Fully Experimental | - | M18 |
| | Quasi-Experimental | - | M14 |
| | Scanning | - | M21 |
| | Interim Total | 2 | 11 |
| Qualitative Design | Descriptive | - | M12, M32 |
| | Case Study | M1, M6, M7 | - |
| | Action Research | M8 | - |
| | Teaching Experiment | - | M16, M24 |
| | Unspecified | M5 | M13, M19, M20, M22, M30 |
| | Interim Total | 5 | 9 |
| | Mixed Pattern | M3 | M9, M10, M23, M27 |
| General Total | | 8 | 24 |

**Note:** The data presented in the table have been organized by adhering to the statements in the relevant studies

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When Table 2 above is examined, it is evident that the quantitative method was employed in thirteen studies, the qualitative method in fourteen studies, and the mixed method in five studies. In the national literature, qualitative studies (n = 5) are more preferred than quantitative (n = 2) and mixed (n = 1) designs. In the international literature, it is observed that quantitative studies (n = 11) are preferred over qualitative (n = 9) and mixed (n = 4) designs. Table 2 shows that studies on mathematical modeling competencies are primarily qualitative in the national literature and quantitative in the international literature.

**Examination of the working groups of the studies**

The distribution of studies on the assessment of mathematical modeling competencies in the national and international literature, according to the study groups, is presented in Table 3 below.

**Table 3.** Types of Study Groups in the Analyzed Articles

| **Sample Type in the Analyzed Articles** | **National Literature Frequency (TR Index)** | **International Literature Frequency (Scopus- ERIC- Web of Science)** |
|---|---|---|
| Primary School Student | -- | M11, M16 |
| Secondary School Student | M1, M2, M3, M6 | M10, M12, M13, M15, M17, M17, M23, M23, M26, M27, M31, M32 |
| High School Student | -- | M14, M18, M24, |
| Undergraduate Student | - | M9 |
| Teacher Candidate | M4, M5, M7, M8 | M19, M20, M21, M22,<br>M25, M28, M29, M30 |

Upon analyzing Table 3 above, it becomes evident that the participants consisted of preservice teachers in eleven studies and students in twenty-one studies. It is noted that studies in the national literature were conducted with middle school students (n = 4) and preservice teachers (n = 4). In the sample of these studies, the number of preservice teachers and middle school students is equal. The studies in the international literature were conducted with middle school students (n = 7), preservice teachers (n = 7), high school students (n = 4), primary school students (n = 2), and university students (n = 1). In the sample of these studies, the number of preservice teachers and middle school students was equal to, or greater than, the other sample selections. Table 3 shows that studies on mathematical modeling competencies primarily involve preservice teachers and middle school students in the national literature, as well as in the international literature.

**Data analysis methods of the studies conducted**

The distribution of studies on the assessment of mathematical modeling competencies in the national and international literature, according to data analysis methods, is presented in Table 4 below.

| **Data Analysis Methods of Research** | | **National Literature Frequency (TR Index)** | **International Literature Frequency (Scopus-ERIC- Web of Science)** |
|---|---|---|---|
| **Quantitative** | Descriptive | - | - |
| | Relational (Correlational) | M2 | M10, M11, M15, M17, M17, M18, M19, M25, M26, M28, M31 |
| | t-test | M4 | M14 |
| | ANOVA/ANCOVA | - | M27 |
| | Nonparametric tests | - | M21, M23 |
| | **Interim Total** | **2** | **14** |
| **Qualitative Design** | Descriptive Analysis | M1, M5 | M10, M12 |
| | Content Analysis | M3, M8 | M16, M20, M30, M32 |
| | Qualitative Data Analysis | M6, M7 | M9, M13, M22, M24, M29 |
| | **Interim Total** | **6** | **11** |
| **General Total** | | **8** | **25** |

**Note:** Since more than one data analysis method was used in some studies, the total number exceeds the number of studies.

When Table 4 above is examined, it is evident that quantitative data analysis methods were used in sixteen studies, and qualitative data analysis methods were used in seventeen studies.

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In the national literature, it is observed that qualitative data analysis studies (n = 6) are more frequently preferred than quantitative data analysis studies (n = 2). In the international literature, it is observed that studies with quantitative data analysis (n = 14) are more frequently preferred than those with qualitative data analysis (n = 11). Table 4 shows that studies employing qualitative data analysis are more prevalent in the national and international research on mathematical modeling competencies.

**Aims of The Studies Conducted**

The distribution of studies on the assessment of mathematical modeling competencies in the national and international literature, according to their purposes, is presented in Table 5 below.

**Table 5.** Distribution of the Analyzed Studies According to Their Purposes

| Objectives | National Indexed | International Indexed |
|---|---|---|
| Developing a mathematical modeling competence scale | | M12 |
| Assess mathematical modeling competencies | M2, M3, M4 | M11, M13, M16, M21, M30 |
| Develop mathematical modeling competencies | | M20 |
| To examine the effect of modeling applications (GeoGebra, STEM, Gamification, etc.) on modeling competencies | M1, M5, M6, M7, M8 | M9, M10, M14, M15, M17, M18, M22, M24, M27, M29, M32 |
| To examine the relationship between mathematical modeling competencies and some skills (Metacognition, Reflective thinking, Creativity) | | M19, M23, M25, M26, M28 |
| To design an assessment approach for mathematical modeling competencies | | M31 |

When Table 5 above is examined, it is seen that studies have been conducted for various purposes. In the national and international literature, there are more studies evaluating modelling competencies (n = 8) and examining the effects of various applications on modelling competencies (n = 9). In the international literature, unlike the national literature, there are studies conducted to develop modelling competencies (n = 1) and to investigate the relationship between mathematical modelling competencies and skills such as metacognition, reflective thinking, and creativity (n = 5). Additionally, there are studies aimed at designing an assessment approach for mathematical modelling competencies (n=1) and developing a mathematical modelling competency scale (n=1).

**What kind of tools are used to assess mathematical modelling competencies**

The distribution of studies on the assessment of mathematical modeling competencies in the national and international literature, according to the tools used in assessing modeling activities, is presented in Table 6 below.

**Table 6.** Tools Used to Evaluate Modeling Activities in the Reviewed Articles

| Tools Used to Evaluate Modeling Activities in the Reviewed Articles | National Literature Frequency (TR Index) | International Literature Frequency (Scopus- ERIC- Web of Science) |
|---|---|---|
| Performance Evaluation Table (Rubric) | - | M9, M11, M26 |
| Multiple Choice Modeling Questions | M5 | M21 |
| Written Student Answers | M1, M2, M3, M6, M7, M8 | M13, M14, M15, M16, M17, M17, M18, M19, M20, M22, M23, M29, M30, M31, M32 |
| Modeling Proficiency Scale | M4 | M10, M12, M25, M27, M28 |
| Semi-structured Interview | M3 | M22, M24, M32 |
| Video Recordings | M1, M6, M8 | M13, M16 |

**Note:** Since more than one assessment tool was used in some studies, the total number exceeds the number of studies.

When Table 6 above is examined, it is evident that the tools used to evaluate mathematical modelling activities comprise a performance evaluation table, multiple-choice modelling questions, written student answers, a modelling proficiency scale, semi-structured interviews, and videos. In the studies reviewed in the national literature, the tools used to evaluate modelling activities included written student responses (n=5), video recordings (n=3), a modelling proficiency scale (n=1), semi-structured interviews (n=1), and multiple-choice modelling questions (n=1). In the studies reviewed in the international literature, the tools used to evaluate modelling activities included written student responses (n=15), a modelling proficiency scale (n=5), video recordings (n=2), semi-structured interviews (n=2), multiple-choice modelling questions (n=1), and a performance evaluation table (n=1). Table 6 shows that the tools used in studies evaluating mathematical modelling activities are written student responses and video recordings in the national literature, and student responses and a modelling proficiency scale in the international literature.

**Approaches used in the assessment of mathematical modelling competencies**

The distribution of studies on the assessment of mathematical modelling competencies in the national and international literature, according to the approaches used to assess these competencies, is presented in Table 7 below.

**Table 7.** Evaluation Approach Used in the Reviewed Articles

| Evaluation Approach Used in the Reviewed Articles | National Literature Frequency (TR Index) | International Literature Frequency (Scopus- ERIC- Web of Science) |
|---|---|---|
| Holistic | M3, M6, M8 | M15, M16, M17, M18, M19, M19, M20, M21, M22, M23, M24, M25, M26, M27, M28, M29, M30 |
| Micro | M1, M2, M4, M5, M7 | M9, M10, M12,<br>M13, M14, M32 |
| Karma | --- | M11, M31 |
| **Total** | **8** | **24** |

Table 7 above shows that the studies using a holistic evaluation approach (n = 20), a micro evaluation approach (n = 10), and a mixed evaluation approach (n = 2) are categorized into three groups. It is observed that studies in the national literature were conducted using either a holistic evaluation approach (n=4) or a micro evaluation approach (n=4). In the evaluation approach of these studies, the number of holistic and micro selections is equal. It is observed that studies in the international literature employed a holistic evaluation approach (n=16), a micro evaluation approach (n=6), and a mixed evaluation approach (n=2). In the assessment approaches of these studies, the holistic approach is more common than other assessment approaches. Table 7 shows that studies on mathematical modeling competencies have been conducted using holistic and micro approaches in the national literature, as well as holistic, micro, and mixed approaches in the international literature.

## DISCUSSION AND CONCLUSION

This article systematically examines research on assessing mathematical modeling competencies in national and international literature. Between 2011 and 2023, the study included eight articles from the national literature and 24 articles from the international literature. The majority of studies were conducted in 2017 in the national literature and in 2021 in the international literature, with a decrease in the number of studies conducted in subsequent years observed.

When the participant groups of studies evaluating mathematical modeling competencies in national (M4, M5, M7, M8) and international literature (M19, M20, M21, M22) are examined, it is seen that the studies focusing on preservice teachers outnumber those involving other types of participants. This finding suggests that preservice teachers are generally preferred, as revealed by studies such as Aztekin and Taşpınar-Şener (2015), Albayrak and Çiltaş (2017), and Yıldız and Yenilmez (2019) in the national literature, as well as Hidayat et al. This trend indicates that studies conducted with preservice teachers share a common focus in the national and international literature. The adaptation of teacher education programs to changing educational needs is critical for successful innovations in education (Akça et al., 2023). Since the predominant focus in these studies is on preservice teachers, who are at the center of educational systems and reforms, it is noteworthy that they comprise a larger proportion of participants than other groups. Articles published in internationally indexed journals encompass various sample types, including gifted students, primary school students, high school students, and engineering students, unlike studies in national indexed journals. This indicates that the sample diversity in the national literature is limited.

It is observed that studies evaluating mathematical modeling competencies in the national literature (M1, M5, M6...) are generally designed using qualitative research designs, whereas studies in the international literature (M11, M15, M17...) are primarily designed using quantitative research designs. It was determined that studies in the international literature generally aimed to evaluate mathematical modeling competencies or to examine the effect of an applied teaching method on modeling competencies. For this reason, they benefited from quantitative research methods in accordance with their research objectives. In addition, it was concluded that most studies in the national literature employed the case study model (M1, M6, M7), while those in the international literature primarily used the correlational model (M25, M26, M28). This study aligns with previous studies, such as Aztekin and Taşpınar-Şener (2015), Albayrak and Çiltaş (2017), and Yıldız and Yenilmez (2019), which indicate that research on modeling in Turkey is predominantly designed using qualitative approaches and case studies. This result can be attributed to the fact that the case study offers an opportunity to examine the researched topic in depth (Yıldırım & Şimşek, 2008). However, few in number, action research, causal comparison, and action research designs were found in both literatures (M4, M8).

When the purposes of studies conducted in national and international literature are examined, the study (M20), which aimed to improve mathematical modeling competencies in each literature, emphasized the importance of using various teaching methods and materials to strengthen students' modeling skills. In addition, studies examining the effect of modeling applications (GeoGebra, STEM, gamification, etc.) on modeling competencies (M5, M6, M17, M18, M22) have shown that these applications are practical tools for strengthening students' modeling skills. In addition, in the international literature, studies (M19, M23, M25, M26, M28) conducted to examine the relationship between mathematical modeling competencies and specific skills (metacognition, reflective thinking, creativity) revealed that modeling skills are related not only to mathematical knowledge but also to cognitive and creative abilities. In this respect, similar studies can be conducted in the national literature.

In both literatures, the use of students' written answers stands out as a widely preferred tool for assessing mathematical modeling competencies. This indicates that written answers are a commonly used assessment tool for evaluating modeling competencies (M1, M2, M14, M15, etc.). These findings are supported by the studies conducted by Fredj (2013) and Hidayat et al. While it was observed that the assessment approach with rubrics (performance evaluation tables) was frequently used in the international literature, it was determined that this method was not included in the national literature. This difference may be related to the usefulness of rubrics in evaluating modeling activities. In fact, Kertil (2021) states that rubrics do not help evaluate modeling competencies in classroom applications of modeling activities. However, it was observed that more than one assessment tool was used in some studies, both in the national and international literature. The use of multiple data collection tools can positively support the reliability of the studies (Yıldırım & Şimşek, 2008). Therefore, it can be considered that more than one data collection tool was used in these studies.

In both national (M3, M6, M8) and international literature (M15, M16, M17, M18...), it is generally observed that a holistic approach is adopted to assess mathematical modeling competence. This finding is consistent with studies that use a holistic assessment approach to assess students' modeling skills (Kreckler, 2017; Rellensmann et al., 2017). The literature emphasizes that the holistic approach is an effective way to create a learning environment that fosters the development of mathematical modeling competencies (Grünewald, 2012). For this reason, it is believed that the holistic approach is more commonly employed in national and international literature. In the international literature, micro-assessment (M9, M10, M12...) is a method that has been addressed in fewer studies compared to holistic assessment. The number of studies using the mixed assessment approach is quite limited. In the national literature, no study was found that used a mixed-method approach. In the international literature, only two studies (M11 and M31) used this method.

Most of both national (M1, M2, M3...) and international studies (M13, M15, M20, M21...) on the characteristics of mathematical modeling measurement have focused on cognitive measures. These studies generally use a holistic assessment approach that evaluates the cognitive dimension of modeling competencies (M22; Tekin Dede & Bukova Güzel, 2018). In the reviewed studies, it was observed that the holistic assessment approach was employed more frequently. Cognitive measurements may have been included in a large number of studies for this reason. These results align with the findings of Hidayat et al. Two studies (M13 and M14) published in the ERIC database focused on both affective and cognitive measures. This finding aligns with a systematic review by Schukajlow et al. (2018), which demonstrated that affective components were frequently mentioned in the analyzed journal articles on modeling teaching and learning.

As a result of evaluating the studies conducted in the context of the sub-competencies of the mathematical modeling cycle, various findings were obtained. For example, in the study coded M9, the most significant improvement was observed in students' problem understanding, simplification, and mathematization competencies. In the study coded M26, it was stated that the most significant increase in students occurred in the stages of making associations, understanding the problem, and simplifying. In the study coded M4, it was concluded that preservice teachers obtained the highest scores in the interpretation-verification competency, but the lowest value in the mathematical modeling sub-competency. In the study coded M10, it was stated that students' interpretation and verification competencies were particularly low. Upon examining the findings, it is evident that most studies have observed an increase in participants' problem comprehension competence. However, the measurement results for competencies such as mathematization, association, and interpretation-verification differ from one another. These differences are likely due to factors such as sampling and assessment methods.

In the studies, the study group mainly consisted of preservice mathematics teachers. Future studies should be conducted in collaboration with mathematics teachers and primary and secondary school students. Additionally, in the national literature, gifted students can be included in study groups, and their modeling competencies can be examined.

The holistic approach is mainly used in the studies analyzed. Both the holistic approach and the micro approach have strong and convincing arguments. Considering the strengths of these approaches, it is recommended to adopt a mixed approach that combines micro and holistic perspectives. In this way, students' modeling competencies can be examined in more detail.

Finally, although cognitive measurements of modeling competence are mostly made, affective measurements should also be included in future studies because having positive attitudes and beliefs towards modeling practices is an important part of modeling competencies (MaaB, 2006).

## RECOMMENDATIONS

### Recommendations for Teachers

This systematic review highlights that teachers and preservice teachers play a central role in developing and assessing mathematical modeling competencies. Based on the findings, the following recommendations are offered for teachers:

1. **Integrate Modeling into the Curriculum:** Mathematical modeling not only enhances problem-solving abilities but also helps students connect mathematics with real-life contexts. Therefore, teachers should systematically integrate modeling-based activities into their lessons across different mathematical topics.

2. **Adopt a Holistic Approach to Assessment:** The review suggests that holistic approaches are frequently employed, particularly in national studies. Teachers are encouraged to assess students' modeling competencies not only based on the final product but also through the **entire modeling process**, including problem understanding, assumption making, mathematization, interpretation, and validation.

3. **Use Multiple Assessment Tools:** Employing diverse tools such as written student responses, rubrics, video recordings, and observations provides a more reliable and in-depth understanding of students' modeling processes. Teachers should avoid relying on a single assessment method and instead combine different instruments to capture both cognitive and process-oriented aspects of modeling.

4. **Consider the Affective Dimension of Modeling:** The studies reviewed primarily focused on cognitive aspects, while affective components such as students' attitudes, beliefs, and motivation toward modeling received limited attention. Teachers should foster a favorable emotional climate that encourages engagement and persistence during modeling activities.

5. **Utilize Technological and Interdisciplinary Applications Effectively:** The findings indicate that digital tools, such as **GeoGebra**, **STEM-based environments**, and **gamification practices**, positively support the development of modeling competencies. Teachers should integrate these tools not only for visualization but also as a means to enhance exploration, reasoning, and creativity.

6. **Adapt Modeling Activities to Different Student Levels:** While most national studies focus on preservice teachers, modeling activities can be successfully implemented at all grade levels—from primary to secondary education. Teachers should design modeling tasks that are aligned with students' cognitive readiness and their everyday experiences.

7. **Promote Collaborative Learning Environments:** Small-group work, peer discussions, and collaborative reflection allow students to compare different models and reasoning strategies. Teachers are encouraged to create cooperative learning environments that promote interaction and shared problem-solving throughout the modeling process.

8. **Engage in Professional Development Focused on Modeling Pedagogy:** Since effective modeling instruction requires specific pedagogical and assessment skills, teachers should participate in professional development programs focusing on modeling processes, assessment approaches, and the use of technological tools to enhance modeling-based teaching.

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## APPENDIX 1: ARTICLE LIST

| Database | Paper | Authors | Year | Code |
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| TR Dizin | Ortaokul 3.Sınıf Öğrencilerinin Okuma Yarışması Problemi Üzerinde Bilişsel Modelleme Yeterlikleri | Neslihan ŞAHİN, Ali ERASLAN | 2017 | M1 |
| TR Dizin | Modelleme Yeterlikleri ile Sınıf Düzeyi ve Matematik Başarısı Arasındaki İlişkinin İncelenme | Ayşe Tekin Dede | 2017 | M2 |
| TR Dizin | Altıncı Sınıf Öğrencilerinin Matematiksel Modellemede Oluşturdukları Gerçek Yaşam Problem Durumu Modelleri | Çağlar Naci HIDIROĞLU; Yeliz ÖZKAN HIDIROĞLU | 2017 | M3 |
| TR Dizin | Ortaokul Matematik Öğretmen Adaylarının Matematiksel Modelleme Yeterliklerinin Cinsiyete Göre İncelenmesi: Çok Boyutlu Madde Tepki Kuramı | Yüksel Dede; Veysel Akçakın; Gürcan Kaya | 2018 | M4 |
| TR Dizin | Matematik Öğretmeni Eğitiminde STEM - Matematiksel Modelleme Birlikteliğinin Problem Çözme ve Modelleme Becerilerine Etkisi | Gökhan Derin; Emin Aydın | 2020 | M5 |
| TR Dizin | Argümantasyon Kalitesinin Matematiksel Modelleme Sürecine Yansıması | Funda AYDIN GÜÇ; Handan KULEYİN | 2021 | M6 |
| TR Dizin | Cognitive Mathematical Modeling Competencies of Primary School Teacher Candidates | Damla Koç; Aysun Nuket ELCI | 2022 | M7 |
| TR Dizin | Applications Based on an Atomic-Supported Holistic Approach Fostering The Modeling Competencies of Preservice Mathematics Teachers | Zeynep Çakmak Gürel; Ahmet Işık | 2022 | M8 |
| ERİC | Strengthening an Educational Innovation Strategy: Processes to Improve Gamification in Calculus Course through Performance Assessment and Meta-evaluation | Elvira G. Rincon-Flores , Katherina Gallardo , Juana María de la Fuente | 2018 | M9 |
| ERİC | Investigating the Change in Middle School Students' Mathematical Modeling Competencies according to Their Reading Comprehension Skills Levels | Yasemin ALKAN; Mehmet Aydın | 2021 | M10 |
| ERİC | Validating a student assessment of mathematical modeling at the elementary school level | Erin E. Turner Mei-Kuang Chen Amy Roth McDuffie James E. Smith Julia Aguirre Mary Q. Foote Amy Been Bennett | 2021 | M11 |
| ERİC | Matematiksel Modelleme Yeterlikleri Ölçeği'nin Geliştirilmesi ve Psikometrik Özelliklerinin Belirlenmesi: Özel Yetenekliler Örneklemi | Gülnur Özbek; Erdoğan Köse | 2022 | M12 |
| ERİC | Group Modeling Competencies of Seventh Grade Mathematics Students | Özlem Kalaycı; Özge Gün | 2022 | M13 |
| ERİC | Modeling with Differential Equations and GeoGebra in High School Mathematics Education | Mohamed Latifi; Abdelhak Eseghir; Abdelouahed Elmaroufi; Khalid Hattaf; Naceur Achtaich | 2022 | M14 |
| ERİC | Using heuristic worked examples to promote solving of reality-based tasks in mathematics in lower secondary school | Martin Hänze; Dominik Leiss | 2022 | M15 |
| ERİC | Investigating mathematical modeling competencies of primary school students: Reflections from a model eliciting activity | İsmail Kaygısız; Emine Aysın Şenel | 2023 | M16 |
| SCOPUS | Using Reading Strategy Training to Foster Students' Mathematical Modelling Competencies: Results of a Quasi-Experimental Control Trial | Maike Hagena; Dominik Leiss; Knut Schwippert | 2017 | M17 |
| SCOPUS | Developing the Competency of Mathematical Modelling: A Case Study of Teaching the Cosine and Sine Theorems | Duong Huu Tong, Nguyen Phu Loc, Bui Phuong Uyen; Le Thi Giang | 2019 | M18 |

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| SCOPUS | Meta-cognitive behaviour and mathematical modelling competency: Mediating effect of performance goals | Riyan Hidayat; Sharifah Norul Akmar Syed Zamri; Hutkemri Zulnaidi; Putri Yuanita | 2020 | M19 |
| SCOPUS | Strategic support to students' competency development in the mathematical modelling process: A qualitative study | Rina Durandt; Geoffrey Lautenbach | 2020 | M20 |
| SCOPUS | Modelling competencies of school learners in the beginning and final year of secondary school mathematics | Cyril Julie | 2020 | M21 |
| SCOPUS | Development of prospective elementary teachers' mathematical modelling competencies and conceptions | W. Tidwell, C. O. Anhalt, R. Cortez B. R. Kohler | 2021 | M22 |
| SCOPUS | Creativity in students' modelling competencies: Conceptualisation and measurement | Xiaoli Lu; Gabriele Kaiser | 2021 | M23 |
| SCOPUS | Developing a task design and implementation A framework for fostering mathematical modelling competencies | Vince Geiger; Peter Galbraith; Mogens Niss; Catherine Delzoppo | 2021 | M24 |
| SCOPUS | The Interrelationships between Metacognition and Modeling Competency: The Moderating Role of the Academic Year | Hidayat, R., Syed Zamri, S. N. A., Zulnaidi, H., Abdullah, M. F. N. L., Adnan, M. | 2021 | M25 |
| SCOPUS | Effects of mathematical modelling-based project production and management program on gifted students<br><br>Mathematical Modelling and reflective thinking for real-life problem solving | Gülnur Özbek; Seokhee Cho | 2022 | M26 |
| SCOPUS | Gifted youths' mathematical modelling-based project production: Structure, triggers, and contributing factors | Gülnur Özbek; Erdoğan Köse; Seokhee Cho | 2023 | M27 |
| WOS | Roles of metacognition and achievement goals in mathematical modeling competency: A structural equation modeling analysis | Riyan HidayatID; Hutkemri Zulnaidi; Sharifah Norul Akmar Syed Zamri | 2018 | M28 |
| WOS | The Emergence of Mathematical Modeling Competencies: An Investigation of Prospective Secondary Mathematics Teachers | Cynthia Oropesa Anhalt, Ricardo Cortez Amy Been Bennett | 2018 | M29 |
| WOS | Preservice mathematics teachers' professional modeling competencies: a comparative study between Germany, Mainland China, and Hong Kong | Xinrong Yang; Björn Schwarz; Issic K. C. Leung | 2021 | M30 |
| WOS | Mathematical Modeling in the Elementary Grades: Developing and Testing an Assessment | Erin E. Turner Amy Roth McDuffie Amy Been Bennett Julia Aguirre Mei-Kuang Chen Mary Q. Foote James E. Smith | 2022 | M31 |
| WOS | Examining students' mathematical modeling competences in video-based modeling tasks | Hande Aytemiz ; Zeynep Çakmak Gürel | 2023 | M32 |