INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 13, Issue 3, (2024) E-ISSN: 2226-6348

Literature Review on the Factors Affecting Mathematical Modelling Competency

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To Link this Article: http://dx.doi.org/10.6007/IJARPED/v13-i3/22018 DOI:10.6007/IJARPED/v13-i3/22018

Published Online: 06 August 2024

Abstract

The significance of mathematical modelling is increasing in the field of mathematics education. Moreover, in recent decades, there has been a significant focus on the mathematical modelling competency in research concerning the teaching and learning of mathematical modelling and its practical uses. However, the performance on mathematical modelling competency is not ideal. There are many issues and challenges when students conduct the mathematical modelling. This literature review aims to identify the factors that affect mathematical modelling competency. The relevant articles were identified using the Narrative Literature Review method. The literature review mainly revealed that metacognition, reading comprehension, computational and critical thinking, self-efficacy, gender, academic year could affect students' mathematical modelling competency.

Keywords: Mathematical Modelling Competency, Metacognition, Reading Comprehension, Thinking, Self-efficacy.

Introduction

The importance of mathematical modelling is growing within the realm of mathematics education (Niss & Blum, 2020). Solving modelling problems is a crucial ability in mathematics education (Niss, Blum, Galbraith, & Henn, 2007). Mathematical modelling offers a pathway for advancing research in problem-solving and developing curricula (Sriraman & English, 2010). It has the potential to improve problem-solving abilities and link mathematics to real-life contexts, thereby making it pertinent to students' present and future experiences (Hidayat & Wardat, 2023; Hidayat & Ying, 2023).

Numerous scholars and educational experts have highlighted the vital importance of mathematical modelling competency, stressing its advantages in tackling complexities across diverse fields, particularly in modern science and social sciences like economics, information systems, finance, business, education, and the arts (English, 2008; Gainsburg, 2006; Hidayat et al., 2021; Hidayat, Zulnaidi, & Zamri, 2018; Kartal et al., 2016). Moreover, the importance of having mathematical modelling competency is emphasized as a crucial factor in comprehending complexity, particularly in the fields of science, technology, engineering, and mathematics (STEM), amidst the rapidly evolving and emerging areas of study. This involves creating and adjusting mathematical models to tackle challenges in complex settings, such as nanotechnology and molecular cell biology (Kartal et al., 2016).

However, integrating a mathematical modelling process in mathematics classrooms presents a new obstacle at every educational stage, notably for students enrolled in mathematics education programs (Delice & Kertil, 2015; Hidayat & Ying, 2023; Hidayat et al., 2018; Kannadass et al., 2023; Widjaja, 2013; Yew & Zamri, 2016). Both pre-service and in-service mathematics teachers possess limited understanding and familiarity with mathematical modelling (Biembengut & Faria, 2011; Julie & Mudaly, 2007; Kaiser, 2007; Schukajlow, Kaiser, & Stillman, 2018; Zeytun, Çetinkaya, & Erbaş, 2017), and they also encounter challenges when tackling and resolving modelling tasks (Anhalt & Cortez, 2016; Biembengut & Faria, 2011; Eraslan, 2012; Ferri & Blum, 2010; Kaiser, 2007).

The prevailing opinion is that the modelling process is difficult (Hidayat et al., 2020; Kartal et al., 2016; Wijaya et al., 2014; Yew & Zamri, 2016). The findings from Jankvist and Niss (2020), indicated a notable number of students struggle with comprehending, accepting modelling tasks and making appropriate assumptions and specifications necessary for modelling tasks. Moreover, pre-mathematisation emerges as a significant obstacle in modelling, contributing to the well-established challenge of mathematisation in the field of mathematical modelling. Similarly, according to Frejd and Ärlebäck (2011), the initial phase of the modelling process is commonly acknowledged as the most challenging stage. Students often struggle to comprehend and organize the problem scenario, involving the identification of crucial elements and subsequently formulating relevant assumptions to simplify the scenario and render it more manageable (Berry, 2002; Zeytun, Cetinkaya, & Erbas, 2023; Giménez, & Rosich, 2011). In a research undertaken by Blomhøj and Kjeldsen (2013), who studied a specific problem, students faced challenges in mathematically representing the phrase 'proportional to the square of population size' prior to discovering the equation $N' = kN^2$.

Therefore, it is essential to investigate the factors that affect students' mathematical modelling competency. This literature review aims to identify these factors. By identifying these factors, educators can tailor their teaching methods to better support students in acquiring and mastering mathematical modelling competency.

Methodology

This research was conducted using the Narrative Literature Review (NLR) method as classified by (Rother, 2007). Through Google Scholar search, the researchers identified articles that studied the impact factors of mathematical modelling competency.

Factors Affecting Mathematical Modelling Competency

Because there are no established approaches for using mathematical modelling to solve real-world problems, numerous cognitive and affective obstacles need to be addressed (Cevikbas, Kaiser, & Schukajlow, 2021). Research on mathematical modelling has also focused on exploring cognitive and affective aspects, as indicated by systematic literature reviews conducted by (Hidayat, Adnan, and Abdullah 2022; and Schukajlow et al., 2018). Moreover, Zimmerman and Campillo (2003), also posited that for students to tackle complex problems, they need more than just adequate knowledge, and they also require robust motivation and individual resilience to face the task. Accordingly, the factors affecting mathematical modelling competency can be divided into cognitive factors (e.g., metacognition, reading comprehension, computational and critical thinking), affective factors (e.g., self-efficacy), and some demographic factors (e.g., gender, academic year). These factors will be discussed in detail below.

Metacognition

Metacognition, encompassing psychological and cognitive principles (Papaleontiou-Louca, 2008), pertains to individuals' understanding or cognitive engagement with their own mental processes and outcomes, along with anything related to them (Flavell, 1976, 1977). It involves the ability to monitor and control cognitive processes such as problem-solving, decision-making, and learning (Padmanabha, 2020). In simpler terms, metacognition entails the process of "thinking about thinking" or our ability to know what we know and what we do not know (Costa & Kallick, 2009; Livingston, 2003; Mahdavi, 2014). O'Neil and Abedi (1996), defined metacognition components to include awareness, planning, cognitive strategy, and self-checking.

Metacognition plays a crucial role in higher order thinking (Zohar & Ben-Ari, 2022). Metacognition is an important strategy linked to mathematics achievement (Muncer et al., 2022). It is also associated with the development of problem-solving skills (Güner & Erbay, 2021). Izzati and Mahmudi (2018), stressed that students who possess strong metacognitive skills often excel in problem-solving. This viewpoint was supported by Mokos and Kafoussi (2013), who discussed how procedural knowledge, along with specific strategies, plays a crucial role in solving open-ended mathematical problems. Moreover, metacognitive strategies plays a crucial role in understanding problems, devising learning strategies, and maintaining awareness of the problem-solving process (Sahin & Kendir, 2013).

Metacognition has been acknowledged as essential in tackling complex tasks, such as modelling tasks (Wilson & Clarke, 2004). Metacognitive knowledge and regulation are strong predictors of success in mathematical modelling and problem-solving (Arum, Widjajanti, & Retnawati, 2019). Individuals who possess a high degree of cognitive regulation are more likely to navigate through the problem-solving process effectively compared to those with moderate regulation levels. As a result, individuals lacking metacognitive awareness often struggle, experiencing difficulties in comprehending problems, selecting suitable strategies, and arriving at correct solutions (Güner & Erbay, 2021).

Numerous studies have supported the positive impact of metacognition on mathematical modelling competency. Hidayat and his colleagues have conducted abundant studies related to metacognition and mathematical modelling competency. Hidayat, Zamri, and Zulnaidi (2018), discovered that metacognition has a positive impact on students' mathematical modelling competency, with mastery goal components playing a mediating role. Hidayat et al (2020), demonstrated that metacognition positively influences mathematical modelling competency, with performance goal components acting as a mediator. Hidayat et al (2021), confirmed that there is a statistically significant direct relationship between metacognition and mathematical modelling competency, with academic year level serving as a partial moderator. Hidayat et al (2018), highlighted the mediating role played by various dimensions of metacognition. Specifically, awareness, planning, cognitive strategy, and self-checking were found to significantly mediate the impact of achievement goals on mathematical modelling competency. Hidayat and Ying (2023), investigated the four components of metacognition and their influence on mathematical modelling competency. They discovered that cognitive strategy, planning and self-checking positively impacted the horizontal mathematisation and only self-checking significantly affected the vertical mathematisation. Moreover, Oficiar, Ibañez, and Pentang (2024), found that metacognitive awareness could predict mathematical modelling competency among pre-service elementary teachers.

Reading Comprehension

Reading comprehension refers to the active process of constructing a sufficient mental representation of a text (Kintsch, 1986). Reading comprehension plays a crucial role in mathematical modelling. Reading comprehension may also be viewed as a subsidiary skill essential for the construction of real-world models, as the organization and simplification of provided information are directly contingent upon a sufficient grasp of the material (Krawitz et al., 2022). To be more specific, the essence of mathematical modelling lies in translating a real-world scenario into a mathematical representation. The translation process demands a sufficient understanding, structuring, and simplification of the original real-world context (Krawitz et al., 2017). And the real-world scenario is predominantly depicted in written format (Verschaffel, Greer, & Corte, 2000). That means the modelers need reading comprehension from the text to extract relevant information, identify key variables, and comprehend the underlying relationships between different elements of the problem.

Empirical findings have demonstrated the positive relation between reading comprehension and mathematical modelling competency. The study by Leiss et al (2010), showed a connection between overall reading skills and constructing a mental representation of a scenario when tackling a task based on real-world situations. Krawitz et al (2017), discovered a positive relationship between students' ability to answer reading comprehension questions successfully and their enjoyment of and performance in modelling tasks. Moreover, Vilenius-Tuohimaa, Aunola, and Nurmi (2008), found that the performance on mathematics problems remained significantly positively related to reading comprehension even after accounting for technical reading skills.

Computational and Critical Thinking

Computational thinking encompasses a combination of cognitive processes used to tackle problems of differing complexity, including algorithmic thinking, decomposition, pattern recognition, abstraction, and debugging (Wing, 2006). Computational thinking promotes abstraction and reasoning skills that enhance and support intelligence and enable transfer across domains (Angeli, 2022). The skills associated with computational thinking are crucial for mathematical modelling, such as gathering relevant information, identifying patterns in problems, breaking them down, and creating step-by-step solutions (Ang, 2012).

Critical thinking involves skills such as evaluating arguments, drawing conclusions through inductive or deductive reasoning, assessing or judging situations, and making decisions or addressing issues (Lai, 2011). Critical thinking is important for the process of producing a model, especially for interpreting the results in the real word (Lopes, 2023). Producing a model requires not only mathematical skills but also the critical, social and technological abilities to assess the practicality and validity of the constructed model (Frejd & Vos, 2021).

Kannadass et al (2023), conducted a correlational research design to explore the relationship among critical thinking, computational thinking, and mathematical modelling competency. The results of this study showed a significant relationship among critical thinking, computational thinking, and mathematical modelling competency. The development of computational thinking and critical thinking enhances the mathematical modelling abilities of pre-service mathematics teachers. Moreover, Goodsett and Schmillen (2022), assert that teachers with strong critical thinking skills are adept at mathematical modelling. This is supported by Salha and Qatanani (2021), indicating that the growth of students' critical thinking abilities while creating mathematical models affects their capacity for independent work. In addition, Chen (2013), demonstrated a significant correlation between computational thinking and mathematical modelling abilities among pre-service mathematics teachers.

Self-efficacy

Self-efficacy refers to the belief in one's ability to influence both present and future situations, along with having the necessary resources to achieve set objectives (Bandura, 1977). Self-efficacy influences every stage of setting goals, striving towards them, persevering, and exerting effort, particularly concerning anticipated results (Bandura, 2006), and it has been particularly identified as a determinant in opting for mathematics classes and pursuing a career in science (Betz & Hackett, 1983). Moreover, there are many studies showed that self-efficacy is an important predictor of mathematics achievement (Prabawanto, 2018; Schunk, 1983; Schunk & Cox, 1986).

Empirical research underscores the importance of self-efficacy plays a significant role in predicting success in mathematical modelling. Sharma (2013), investigated the connection between self-efficacy and mathematical modelling among high school students. The finding showed that self-efficacy beliefs directly and positively predicted students' performance in solving modelling problems. Schukajlow, Achmetli, and Rakoczy (2019), observed that interventions employing particular modelling techniques aimed at improving self-efficacy in perceived competence revealed that students, particularly those who generated multiple solutions, benefited from increased self-efficacy. To be more specific, self-beliefs could impact mathematical modelling at various stages, depending on when they are triggered, such as when students construct the situation model, perform calculations, or even at the initial stage of approaching the task. Hence, self-beliefs make a distinct and significant contribution to mathematical modelling Stanislaw Schukajlow et al., 2019). Meanwhile, Czocher, Melhuish, and Kandasamy (2019), demonstrated through an intervention study that participation in a mathematical modelling competition had the potential to enhance one's confidence in mathematical abilities.

Gender

When assessing a student's performance, gender holds the utmost significance (Al Husaini & Shukor, 2022). According to Mehraein and Gatabi (2014), the findings revealed that gender has a relationship with students' mathematical modelling competency. To be more specific, the study examined gender differences in mathematical modelling competency and attitudes among sixth-grade Iranian students through a quasi-experimental design. Findings revealed a shift in attitudes post-intervention, with most students viewing modelling as a math problem and expressing interest in solving such problems. Although girls initially outperformed boys, post-intervention, boys showed significantly better performance. Moreover, boys displayed a more positive attitude towards mathematical modelling problems.

However, most studies, fail to detect gender differences. With the comparing the gender difference of three different modelling tasks, namely peeling a pineapple, tennis racket task, sewing a football, Ludwig and Reit (2013), conluded that in the majority of countries, there are no statistically significant gender differences observed when it comes to problem-solving abilities. There are also no significant gender differences for the study from (Gatabi and Abdolahpour 2013; and Frejd and Ärlebäck 2011).

Numerous studies on academic performance suggest that boys tend to outperform girls in terms of mathematical knowledge (Co-operation & Development, 2009; Mullis et al., 2000). As Ellis, Fosdick, and Rasmussen (2016), found, a woman entering college calculus is 1.5 times less likely than a man to enroll in Calculus 2, indicating that these disparities increase over time. Moreover, Villalobos (2009), asserts that women typically achieve lower results in STEM and math-related classes. This tendency arises from women's heightened anxiety surrounding mathematics or science exams, influenced by the stereotype threat they encounter in these domains (Al-Tameemi et al., 2023; Ganley & Vasilyeva, 2014; Karakolidis, Pitsia, & Emvalotis, 2016). Of course, some studies suggest that girls are more successful in academic achievement. For example, Houtte* (2004) investigated differences in academic achievements based on gender and discovered that boys consistently performed less successfully academically compared to girls.

Therefore, although there are some sort of gender difference in academic achievement, more research showed there is no significant gender difference in mathematical modelling competency from quantitative research, it will need more in-depth qualitative research for discovering this differences.

Academic Year

Through successive years of education, thought processes and mathematical modelling may improve through exposure to the potential effects of different learning environments in mathematics education, thereby enhancing metacognition and mathematical modelling skills (English, Ärlebäck, & Mousoulides, 2016). Oficiar et al (2024), found that participants in higher academic years show enhanced metacognitive awareness and mathematical modelling competency, irrespective of their gender. These findings align with R. Hidayat et al. (2018), which suggests that students in advanced academic years demonstrate a heightened awareness of metacognitive strategies and typically display enhanced competence in mathematical modelling. In addition, Hidayat, Zamri et al (2021), highlighted the moderating role of academic year between the metacognition and mathematical modelling competency, with a stronger effect observed in the second-year group compared to the first and third years.

Discussion

Research on mathematical modelling competency has gained much attention. In terms of the research on its factors, it involves not only cognitive aspects, but also affective aspects, as well as demographic aspects. This review mainly discusses metacognition, reading comprehension, computational and critical thinking, self-efficacy, gender, academic year. Among them, the abundant research is on metacognition and mathematical modelling competency. There are studies on metacognition as an independent variable and as a mediating variable. There are also studies on the four dimensions of metacognition and the impact of metacognitive awareness on mathematical modelling competency. However, there are fewer studies on the impact of thinking on mathematical modelling competency. In addition, more empirical research is needed to explore the impact of gender on mathematical modelling competency.

According to this literature review, a practical suggestion for educators is that they should assist students by using suitable teaching methods and creating a conducive learning environment to enhance their metacognition in tackling complex problems related to mathematical modelling competency. For example, educators can encourage students to reflect on their thinking processes and strategies and provide opportunities for them to evaluate and adjust their approaches to problem-solving. Additionally, it is essential to foster students' self-efficacy by providing positive reinforcement and setting tasks that are challenging yet achievable.

Conclusion

This literature review identifies the factors influencing students' mathematical modelling competency and presents several theoretical and practical research implications. To begin with, this study raises awareness of factors impacting students’ mathematical modelling competency. In addition, by analyzing how these variables interact and influence students’ mathematical modelling competency, it will also assist teachers, lecturers, administration and decision makers in gaining insights into teaching methods and interventions that promote effective mathematical modelling.

There are some limitations in this study. Initially, the researchers exclusively considered studies reported in English for this review. For future studies, it is important to also explore reviewed journals published in languages other than English. In addition, this study only selected some representative factors, and other factors such as achievement goals were not discussed in detail. Moreover, the research on these factors has not been differentiated by stages, such as elementary school, middle school, and university. More detailed and targeted analysis is needed in future research.

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