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Pre-service mathematics teachers' modelling processes within model eliciting activity through digital technologies

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ABSTRACT

This study examines the modelling approaches of high school pre-service mathematics teachers (PSTs) and the types and purposes of digital technologies they use at different stages of the mathematical modelling process. Conducted during the 2018–2019 academic year, the study involved 26 PSTs working in eight groups as part of a course on computer technologies in mathematics education. The participants engaged in a model eliciting activity (MEA) focused on the obesity problem, integrating digital technologies and mathematical content knowledge. Findings indicate that while PSTs effectively utilized the internet, spreadsheets, calculators, and mathematical software for problem-solving, three distinct purposes of technology use emerged. However, challenges included overreliance on technological outputs, limiting critical evaluation and validation of models, and difficulties in transferring mathematical content knowledge to the modelling process. These results highlight the need for explicit instructional support in teacher education programs to enhance PSTs' critical engagement with digital tools and strengthen their ability to integrate mathematical knowledge in real-world problem-solving.

1. Introduction

Unlike structured school-related problems, real-world and business challenges are often ill-defined, complex, and multidimensional, involving multiple disciplines and rarely offering straightforward solutions (Jonassen et al., 2006). Addressing these problems effectively requires individuals with advanced technological skills, creative thinking, and flexibility (Borba, 2021; Friedman, 2005; Mulenga & Marbán, 2020; Soto-Acosta, 2020). To cultivate such problem-solving abilities, individuals must be trained to tackle mathematical and real-life problems effectively (NCTM, 2000). The process of applying mathematics to solve real-world issues is known as mathematical modelling (Pollak, 2016), which bridges real-world knowledge with mathematical understanding (Niss et al., 2007). It involves translating real-world problems into mathematical language, manipulating mathematical representations to derive solutions, and interpreting those solutions in the real-world context (Gravemeijer, 2004; Molina-Toro et al., 2019, 2022). Mathematical modelling serves as a means of mathematization, enabling students to establish meaningful connections between real-life situations and mathematical concepts (Steen et al., 2007). Engaging students in modelling real-world scenarios provides valuable learning experiences by immersing them in diverse social, mathematical, and communicative processes (Daher & Shahbari, 2015).

Mathematical modelling plays a crucial role in mathematics education by enhancing students' ability to solve real-world problems using mathematical methods (Niss & Blum, 2020). Integrating innovative, technology-rich approaches into modelling education introduces new perspectives and creates valuable opportunities for both teaching and learning (Cevikbas et al., 2023; Kaiser, 2020). Technology facilitates visualization, mathematization, editing, and problem-solving, simplifying calculations and enabling more reliable results. Additionally, it provides more time for conceptual understanding (Daher & Shahbari, 2015; Geiger, 2011; Niss et al., 2007; Santos-Trigo & Reyes-Rodríguez, 2011). However, effectively incorporating technology into the modelling process remains challenging, and research on its full educational potential is still limited. While several studies have examined digital technologies in modelling education, few have investigated their role during the modelling process (Cevikbas et al., 2023; Siller et al., 2022).

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This study explores how and for what purposes PSTs utilize different technologies (e.g., internet, spreadsheets, calculators, and dynamic geometry software) during a MEA in mathematical modelling. Additionally, it examines how pre-service teachers apply their algebraic content knowledge throughout the modelling process. Based on these objectives, the study is guided by the following research aims/questions:

Despite the growing interest in mathematical modelling, limited research has examined how pre-service teachers (PSTs) integrate technology into modelling activities and how their algebraic content knowledge influences this process. Most existing studies focus on students' modelling experiences, with little attention given to future teachers who will implement these strategies in classrooms (Cevikbas et al., 2023; Siller et al., 2022). Additionally, while technology is widely recognized as a tool for enhancing modelling activities, its role in supporting conceptual understanding and problem-solving within teacher education remains underexplored (Kaiser, 2020; Geiger, 2011). This study addresses these gaps by investigating how PSTs utilize technology during mathematical modelling, how different technological tools influence the modelling process, and how algebraic content knowledge shapes technology use in problem-solving.

1. How do pre-service mathematics teachers (PSTs) utilize technology in the mathematical modelling process, and how does it influence their modelling strategies at different stages?
2. In what ways does pre-service teachers' Mathematical Content Knowledge (MCK) shape their use of technology during the mathematical modelling process?

2. Theoretical framework

This section presents the theoretical foundation underpinning the study by outlining key concepts, models, and perspectives related to mathematical modelling, with a particular focus on Model-Eliciting Activities (MEAs) and cognitive modelling frameworks. Drawing on prior research in mathematics education, the section explores how MEAs function as pedagogical tools for fostering mathematical thinking, and how Ang's (2006, 2010) modelling cycle serves as an analytical lens for examining learners' engagement in the modelling process. It further considers the role of technology and algebraic content knowledge in shaping pre-service teachers' modelling strategies. By integrating these elements, the framework provides a basis for analyzing both the pedagogical and cognitive dimensions of pre-service teachers' participation in modelling tasks.

2.1.1. *The role of model-eliciting activities and the cognitive perspective in mathematical modelling*

Modelling in mathematics education has been a matter of interest in the last few decades. It has played an important role in the development of programs in mathematics education (Burkhardt & Pollak, 2006; Lesh & Yoon, 2007; NCTM, 2000; Niss, 2012). Modelling can be used as a tool to develop the mathematical skills required for the solution of the problems encountered in the daily life of students (Blum & Ferri, 2009; Maiorca & Stohlmann, 2016).

Model-eliciting activities (MEAs) develop and strengthen students' mathematical thinking skills by engaging them in authentic and meaningful real-world problem-solving tasks (William & Goos, 2013). They contribute to mathematical literacy, improve mathematical connection and communication skills, provide in-depth and conceptual understanding, allow high-level mathematical learning, promote positive attitudes towards mathematics, contribute to social skills, and improve problem-solving skills (Bonotto, 2007; Chamberlin & Moon, 2005; English et al., 2005; Lehrer & Schauble, 2007; Lesh & Yoon, 2007; Lesh et al., 2008; Steen et al., 2007).

Any application that connects mathematics to real-life situations can be categorized as mathematical modelling. However, modelling approaches vary depending on theoretical frameworks (Erbas et al., 2014). Researchers' beliefs influence how mathematical modelling is perceived and applied (Ferri, 2013). To date, no universal definition of mathematical modelling has been established. Different interpretations of modelling have led to the development of multiple types of model-eliciting activities (Kaiser et al., 2011). Kaiser and Schwarz (2006) categorized the model-eliciting activities under six different perspectives according to their primary objectives. Those are "realistic or applied modelling," "contextual modelling," "educational modelling," "socio-critical modelling," "epistemological or theoretical modelling," and "cognitive or model-eliciting modelling."

The present study adopts a cognitive perspective to analyze how pre-service teachers engage with MEAs in mathematical modelling. A cognitive perspective is appropriate because it focuses on how learners process, interpret, and refine mathematical models while engaging with real-world problem-solving tasks. The cognitive perspective framework enables a detailed analysis of how pre-service teachers reason, make decisions, and refine their mathematical models during the modelling process.

MEAs are named as "construct-eliciting activities" and "thought-revealing activities" (Lesh et al., 2000). MEAs require students to apply mathematical concepts to real problems that promote conceptual understanding. In MEAs, students are asked to think about a meaningful, real-life situation and create a symbolic model to be used in this situation (Lesh & Doerr, 2003). "For MEAs, the heart of the problem is for students themselves to develop an explicit mathematical interpretation of situations" (Lesh et al., 2000, p. 593). Research suggests that MEAs encourage students to engage with realistic, challenging, open-ended, and creative problems, allowing them to test and refine their models (Hjalmarson & Lesh, 2010; Lesh & Doerr, 2003; Lesh & Zawojewski, 2007; Lesh et al., 2000). Therefore, MEAs are problem-solving activities in which students are encouraged to develop and produce useful solutions (i.e., conceptual systems or models) to real-world problems by reviewing, testing, improving, reconstructing, and expanding their thoughts (Doerr & Lesh, 2003; Lesh et al., 2000). MEAs are designed to simulate real-life situations. As students are involved in collaborative efforts in small groups to transfer the real-life problem to mathematics (Doerr & Lesh, 2003), each team member can use others' knowledge and expertise to discover various solutions to a problem beyond the limits of their own experience (Huxham & Vangen, 2013). More than one solution can be developed to solve the problem presented in MEAs (Lesh et al., 2000; Lesh & Doerr, 2003). Thus, students can use more than one mathematical modelling process.

MEAs are pedagogical tools to reveal students' reasoning and explanation skills regarding mathematics while dealing with the activity (Doerr & Lesh, 2011; Mentzer et al., 2014). These pedagogical tools can be developed and designed under six principles: the model construction principle, the reality principle, the self-assessment principle, the model documentation principle, the generalizability principle, and the effective (simple) prototype principle. Explanations about modelling principles are given respectively (Lesh et al., 2000):

- The model construction principle: The problem situation should be in a way that students can create and develop meaningful mathematical structures. With the problem situation, students should need to come up with a model and develop it.
- The reality principle: The problem in MEA must be logical and take place in the real world. The problem situation should be both meaningful for students and related to previous knowledge, experience, and daily life.
- The self-assessment principle: The purpose of the problem should be clearly stated. The problem situation should give opportunities to students for evaluating the models they create.

- The model documentation principle: This principle means that the activity is not only model-creating but also thought-describing. Students should create a document regarding their thoughts, which reveal mathematical and non-mathematical interpretations of the problem situation.
- The generalizability principle: During the activity, students must produce models that are useful and can be easily changed, shared, and applied to situations similar to the problem being studied.
- The effective (simple) prototype principle: Students use the concepts underlying the activity to create simple yet powerful models for complex situations. The solution to the problem should provide a prototype or metaphor to interpret other situations.

These six principles collectively guide students through the iterative process of mathematical modelling, ensuring they construct, evaluate, and refine their models effectively. While the Reality Principle grounds the task in real-world contexts, the Self-Assessment and Documentation Principles encourage reflection and justification of mathematical reasoning. Together, these principles create a structured yet flexible framework, enabling students to develop adaptable and conceptually meaningful models.

2.1.2. Mathematical modelling cycle

Although the mathematical modelling process is often described as linear progress, it can also be defined as a cycle in which students can move back and forth between stages (Blomhøj & Jensen, 2003; Confrey & Maloney, 2007). Borromeo-Ferri (2006) structured the modelling cycle from a cognitive perspective as a complex cycle between mathematics and the real world (See Fig. 1). The modelling cycle consists of six stages. Students are given real-life problems. They form the real model by simplifying the problem and defining the key variables. The transition from the real model to the mathematical model is provided through mathematization. The mathematical model allows working mathematically, providing mathematical results. Whether the mathematical results are valid in the real world is interpreted under real-world conditions. In this study, cognitive processes (e.g., interpreting, discussing, translating, validating) in which learners are involved were also investigated.

The use of technology affects the mathematical modelling process. According to Siller and Greefrath (2010), the role of technology in modelling is not depicted in traditional modelling cycles. They defined the "Extended Modelling Cycle" by adding a "technological world" dimension to the mathematical world, where problems are solved with technology. After the mathematical model is created, the result is obtained using computers and technology, and then the mathematical result is achieved. In their following studies, Greefrath et al. (2011) argued that technological tools do not appear to be a "third field" to construct a model that only contains complex formulas, structures, and comments. They concluded that technology affects every stage of the cycle. Greefrath (2011) stated that technology may have a central role in the mathematical modelling process. Rodríguez Gallegos and Quiroz Rivera (2016) also determined that technology is used for different purposes at different stages of the modelling process. Ang (2010) examined the understanding of learners in the technology-assisted modelling process by structuring a mathematical modelling cycle model (See Fig. 2) and found that students used technology at the formulation, interpretation, and refinement stages. The mathematical modelling process takes place through the interaction of the real world, the math world, and the world of technology. In the present study, how pre-service teachers used different technologies during the stages of modelling was examined with the mathematical modelling cycle designed by Ang (2006, 2010).

2.1.3. The role of mathematical modelling in pre-service teachers' education

Successful implementation of mathematical modelling in classrooms depends on teachers' ability to facilitate and guide students through the modelling process (Niss et al., 2007; Kaiser & Sriraman, 2006). Despite the increasing emphasis on modelling in K-16 mathematics curricula, teacher education programs often lack structured training on how to integrate modelling into instruction (Blum & Leiβ, 2007; Zbiek, 2016). Many pre-service teachers struggle with understanding the iterative nature of modelling, selecting appropriate tasks, and incorporating modelling into their teaching practices (Pollak, 2016). Research highlights the importance of MEAs in providing pre-service teachers with opportunities to engage in real-world problem-solving, refine their mathematical reasoning, and develop effective instructional strategies (Doerr, 2007; Villarreal et al., 2018).

Integrating technology-enhanced modelling activities into teacher education programs can further strengthen pre-service teachers' confidence in using digital tools for mathematical problem-solving (Molina-Toro et al., 2019; Geiger & Frejd, 2015). Technology supports visualization, exploration, and validation in the modelling process, allowing pre-service teachers to make deeper connections between mathematics and real-world contexts. The present study expands on these perspectives by investigating how pre-service teachers integrate technology into mathematical modelling through MEAs. Using the mathematical modelling cycle framework, we analyze their decision-making, challenges, and technology use at different stages of the modelling process, providing insights into their learning and instructional approaches.

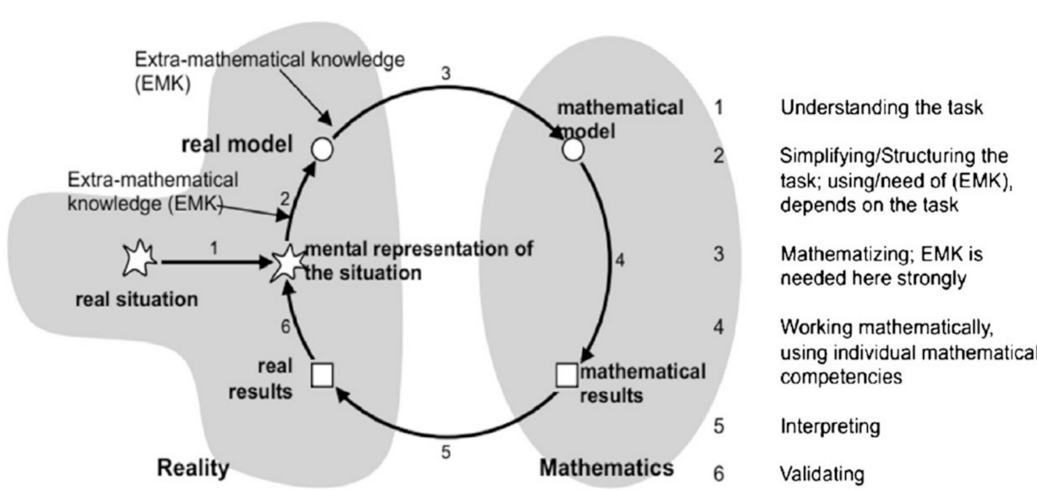

Fig. 1. Modelling cycle under the cognitive perspective by Blum and Leiβ (2007) as adapted by Borromeo-Ferri (2006), p.92).

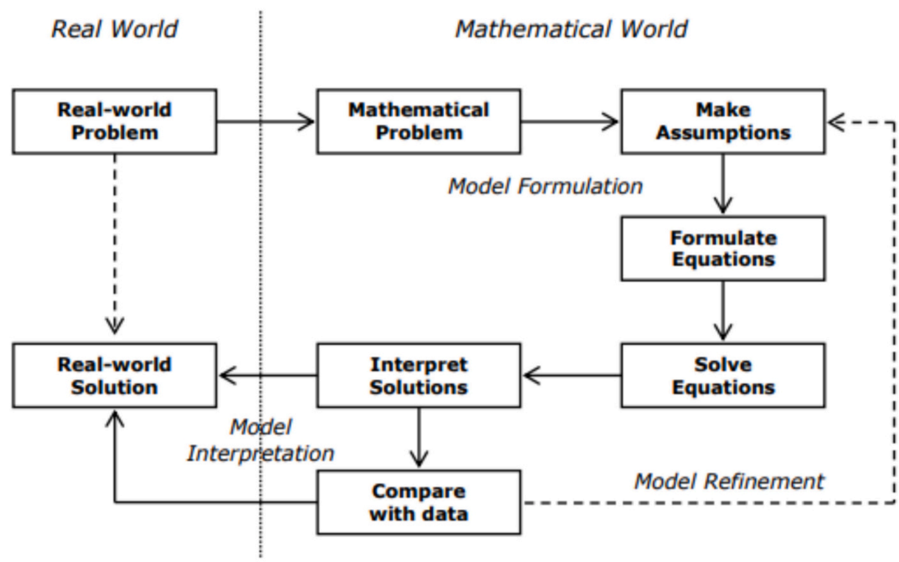

Fig. 2. Mathematical Modelling Process (Ang, 2006).

2.1.4. Clarifying the dual framework: Meas and ang's modelling cycle

MEAs and mathematical modelling cycles provide complementary perspectives on the mathematical modelling process. MEAs focus on authentic problem-solving scenarios that require learners to construct and refine mathematical models based on real-world problems (Lesh & Doerr, 2003). These activities are designed to promote deep mathematical thinking, collaborative learning, and self-assessment, following the six fundamental principles of modelling (Lesh et al., 2000). The MEA framework ensures that learners engage in meaningful, real-world problem-solving while developing generalizable mathematical models.

While MEAs provide the pedagogical foundation for engaging learners in modelling activities, Ang's (2006, 2010) Mathematical Modelling Cycle serves as a process-oriented framework that describes how learners transition between different stages of modelling. Ang's cycle outlines a structured but flexible sequence where learners (1) interpret real-world problems, (2) translate them into mathematical representations, (3) solve mathematical models, (4) validate results, and (5) refine their models using iterative feedback. This framework is particularly useful for analyzing how learners engage with modelling cognitively and how they use technology to support modelling processes (Ang, 2010).

In this study, MEAs provide the learning environment and task structure, while Ang's modelling cycle is used as the analytical framework to examine how pre-service teachers engage with different modelling stages. Specifically, the study investigates how pre-service teachers navigate Ang's modelling cycle while participating in an MEA-based task that requires them to apply mathematical content knowledge and digital tools. This dual approach enables a comprehensive examination of both pedagogical aspects (MEA principles) and cognitive processes (modelling cycle stages), ensuring a deeper understanding of pre-service teachers' mathematical thinking and technology use in modelling.

2.1.5. Framing the study's contribution: Technology and algebraic knowledge in PST modelling

Recent studies emphasize the importance of integrating technology into mathematical modelling education. Koyunkaya and Dede (2024) demonstrated that PSTs can effectively design and solve mathematical modelling problems using multiple digital tools when technology integration is embedded into the teacher education curriculum. Their findings align with research suggesting that the strategic use of technology supports visualization, exploration, and refinement of mathematical models (Daher & Shahbari, 2015; Geiger, 2011). In this study, we extend this perspective by examining how and when pre-service teachers integrate different technologies during the modelling process, particularly focusing on the role of assumptions, equation formulation, and result validation.

Previous research has examined the integration of technology in mathematical modelling; however, these studies primarily focus on students rather than pre-service teachers (Borba, 2021; Cevikbas et al., 2023). The role of PSTs' algebraic content knowledge in shaping their modelling processes remains largely unexplored, despite its potential impact on problem formulation, technology use, and solution validation (Siller et al., 2022). Additionally, Johnson (2001) and Menzel (2001) found that many teachers struggle to articulate the nature of algebraic concepts, particularly fundamental topics such as limits, integrals, and functions. These difficulties may influence how pre-service teachers construct models and apply their mathematical knowledge in real-world contexts, necessitating a deeper exploration of their algebraic reasoning within mathematical modelling tasks. Additionally, while technology is widely used in mathematics instruction, there is limited research on its application during model-eliciting activities (Geiger, 2011; Kaiser, 2020). This study bridges these gaps by examining how PSTs integrate technology in mathematical modelling, how technology influences their modelling strategies, and how their algebraic content knowledge interacts with technology use.

3. Methodology

3.1. Research model

This qualitative study explores pre-service high school mathematics teachers' mathematical modelling processes and their use of technology during a MEA. Given the need for an in-depth examination of how these teachers engage with technology in modelling, a multiple-case study approach was adopted. Each group of pre-service teachers constitutes an individual case, allowing for a comparative analysis of their problem-solving approaches, use of digital tools, and application of mathematical knowledge.

The case in this research is the mathematical modelling process undertaken by pre-service teachers in small groups, within the structured context of an MEA. This case was chosen because model eliciting activities simulate real-world problem-solving scenarios, making them ideal for investigating how pre-service teachers conceptualize, develop, and refine mathematical models using technology. The case study method is particularly well-suited for capturing the complexities of technology integration in mathematical modelling, as it allows for an in-depth exploration of participants' reasoning, decision-making, and collaborative interactions (Simons, 2009).

3.2. The context of the study

3.2.1. Participants

The study group consisted of 26 pre-service mathematics teachers (PSTs) (16 female, 10 male) selected from a larger cohort of 122 PSTs enrolled in a high school mathematics education program at a Turkish state university. They were taking a computer applications course during the spring and summer semesters of the 2018–2019 academic year. Participants were selected through purposeful sampling, ensuring they had relevant knowledge in mathematics, technology, and pedagogy while lacking prior training in mathematical modelling.

Within the course framework, pre-service teachers were introduced to dynamic applications (e.g., GeoGebra) and spreadsheets (e.g., Excel) as digital tools for mathematics education. As part of their coursework, they received mathematical modelling training, enabling them to integrate these tools effectively into the teaching process. Throughout the course, they engaged in four MEAs to develop hands-on experience. The final MEA, which forms the basis of this study, was assigned as a project task (obesity problem see in the Fig. X), extending their coursework and providing data for research. The real-world problem presented in Fig. X is adapted from the IM2C-Teacher-and-Student Guide to Mathematical Modelling (p. 51).

To facilitate collaborative problem-solving, the 26 pre-service teachers were divided into eight groups (G1–G8), each consisting of three or four members. Group assignments were determined by the instructor, ensuring a balanced distribution of competencies.

3.3. Mathematical model eliciting activity

As part of the study, the groups of pre-service teachers engaged in a mathematical MEA, where they were tasked with solving the obesity problem (Big Size Me, Galbraith & Holton, 2018). Each group utilized dynamic software (GeoGebra) or spreadsheets (Excel) to develop and analyze their mathematical models, systematically recording their solution process and producing a detailed report. The MEA was selected due to its effectiveness in fostering deep mathematical understanding and problem-solving skills (Lesh & Doerr, 2003). Through this activity, pre-service teachers identified key factors influencing weight change, formulated mathematical models, and interpreted their implications. The non-linear nature of weight change, where weight gain is dependent on current weight rather than being constant, allowed participants to engage with first-order equations, exponential functions, and limit concepts. The mathematical modelling process not only strengthened their conceptual and procedural mathematical knowledge but also enhanced their pedagogical content knowledge, as they had to critically reflect on how to teach such modelling concepts effectively.

The problem aligns with the six fundamental principles of model-eliciting activities (Lesh et al., 2000), ensuring that participants experienced an authentic and structured modelling process. The reality principle ensures that the problem is relatable and meaningful to the participants, as it reflects a real-world issue. The model construction principle requires them to develop a mathematical model based on given data and their own assumptions, while the self-assessment principle encourages continuous evaluation and refinement of their models to improve accuracy and validity. Additionally, the model documentation principle ensures that participants explicitly record their assumptions, modelling strategies, solutions, and interpretations. The generalizability principle enables them to extend their models beyond the initial problem, applying them to different individuals or scenarios, whereas the effective prototype principle helps participants transfer their problem-solving strategies to structurally similar mathematical modelling tasks.

By engaging in this MEA, pre-service teachers were immersed in an authentic mathematical modelling experience, reinforcing both their technological competencies and mathematical reasoning skills. This structured approach ensured that they not only solved a real-world problem but also gained insight into the complexities of mathematical modelling and technology integration in education.

This real-world scenario provided pre-service teachers with an opportunity to mathematically model weight change by analyzing caloric intake, basal metabolic rate (BMR), and physical activity levels. The task required them to develop equations, make assumptions, and explore how different factors influence weight gain over time using various digital technologies.

To create a meaningful and engaging modelling task, we based the problem scenario on real-world data from the documentary *Super-Size Me* (2004) by Spurlock & Spurlock. The film follows Morgan Spurlock, who consumed only McDonald's meals for 30 days, averaging 5000 cal daily while maintaining a sedentary lifestyle. His weight increased from 84.1 kg to 95.2 kg, providing a concrete example for participants to analyze weight gain, caloric intake, and physical activity levels through mathematical modelling.


Describe the real-world problem

Australian obesity a big problem

29 May, 2014. Worldwide adult obesity rates have jumped nearly 30 per cent in the last 30 years, according to new analysis from the Global Burden of Disease Study 2013, published in medical journal *The Lancet*. Adult obesity rates in Australia are climbing faster than anywhere else in the world, and are only slightly less than those of the United States. In Australia, 63 per cent of adults are overweight or obese. In response to the study, health experts have called on the governments in Australia to commit to a national strategy to address overweight and obesity.

Commenting on the implications of the study, Professor Klim McPherson from Oxford University in the UK stated that an appropriate global response to the worldwide obesity rates would focus on 'curtailing many aspects of production and marketing for food industries'.

This kind of public concern is not new. In America in 2004, concern over a perceived link between obesity and food industries led to the making of the documentary film *Super Size Me* (2004). For 30 consecutive days, the film's creator Morgan Spurlock Morgan ate three meals daily consisting of nothing but McDonald's food and beverages (consuming approximately 5000 calories daily). If offered an 'upsize' he always took it, and limited his daily exercise to that of the average American office worker. He ate everything on the McDonald's menu at least once. Spurlock, a 32-year-old male who was 188 cm tall and weighed 84.1 kg at the start of the experiment, documented as his weight increased by 11.1 kg. There were other damaging effects to his body.

Fig. X. The Obesity Problem in IM2C-Teacher-and-Student Guide to Mathematical Modelling (p. 51).

3.4. Data collection tools

The groups were given 90 to 120 min to solve the problem in a quiet environment outside of class hours, recording their discussions using audio recordings. The study utilized group reports, audio recordings, and transcripts from electronic documents as data collection tools.

In this study, direct observation of the groups was not conducted while they solved the problem. Instead, participants worked independently in a quiet environment outside class hours, and their discussions were audio-recorded to ensure an authentic and uninfluenced problem-solving process. The decision not to observe was made to allow participants to engage naturally without external influence, preserving the integrity of their modelling processes. However, the study utilized group reports, audio transcripts, and electronic documents, which provided a comprehensive view of their reasoning, collaboration, and use of technology.

As part of the data collection process, multiple sources were used to capture the pre-service teachers' modelling processes. Group reports served as written records detailing the solution processes, including tables, notes, evaluations, explanations, and final reflections, resulting in a 42-page report. Additionally, electronic documents were collected, as groups utilized dynamic software for modelling—three groups developed models using GeoGebra, while the remaining five used Excel. To further document the modelling process, groups audio-recorded their discussions, which were later transcribed by the researcher, yielding an 87-page transcript for analysis.

3.5. Data analysis

Mathematical modelling involves translating real-world problems into mathematical representations, solving them, and interpreting the results within a given context (Ang, 2006, Fig. 2). Ang's (2006) Mathematical Modelling Process outlines key stages: problem formulation, making assumptions, developing mathematical representations, solving the model, and validating results. This structured approach provides a systematic framework for understanding how learners engage with mathematical modelling.

One of the key contributions of Ang (2006) is his emphasis on technology as an integral part of the modelling process. He argues that technological tools, such as graphing calculators and computer software, facilitate visualization, simulation, and computation, ultimately enhancing students' ability to develop and refine models. Ang (2006) provides concrete examples, such as using graphical solutions for the logistic equation and modelling epidemics, demonstrating how technology aids in conceptualizing complex mathematical relationships.

Despite these advantages, Ang (2006) also highlights challenges in technology integration in mathematical modelling education. He notes that teacher preparedness, restrictions on technology use in formal assessments, and students' over-reliance on computational tools can limit its effectiveness. These concerns are particularly relevant in contexts where traditional assessment methods do not fully accommodate the exploratory and dynamic nature of technology-supported modelling.

Given these insights, Ang's (2006, 2010) framework serves as a valuable foundation for analyzing pre-service teachers' engagement with technology in mathematical modelling. This study adopts Ang's Mathematical Modelling Process as an analytical framework, providing a structured lens to examine how PSTs utilize digital tools, formulate models, and validate their solutions. To minimize this complexity, using technology is important and necessary in some cases. Themes, codes, and an exemplary approach for mathematical modelling stages are given in Table 1.

The PSTs were not explicitly required to follow Ang's (2006) Mathematical Modelling Process as a step-by-step framework while solving the problem. Instead, they were encouraged to engage in an open-ended modelling process, allowing them to explore and construct their own mathematical representations naturally. However, their

Table 1
Theme-Codes-Exemplary approach for Mathematical Modelling Stages (Ang, 2010).

Theme (Modelling Stages)	Codes	An exemplary approach
Real-world Problem	Reading and recognizing the problem	Spurlock, who ate an average of 5000 cal per day, gained 11.1 k after 30 days. What is the most suitable model for this situation?
Mathematical Problem	Defining the problem mathematically Determining variables Determining relationships between variables	84.1 kg + 11.1 kg = 95.2 kg Variables and the relationship: Weight gain is related to Calorie Intake – [Calorie Burning + Basal Metabolic Rate (BMR)]
Make Assumptions	Determining the basic framework and assumptions for the model	The basic framework: The calorie intake for weight gain should be more than the calorie burning. Assumptions: a) Calories are taken from meals, b) Spurlock has a sedentary lifestyle, c) Daily Burned Calories = BMR + Calories burned during an activity
Formulate Equations	Creating models based on assumptions (Equation, Rule, Function, Graph etc.)	BMR is searched on the internet and Mifflin formula is found: 10w + 6.25 h - 5a + 5 for males w: weight in kilograms, h: height in centimeters and a: age in years BMR = 10w + 1020 for Spurlock But Spurlock has a sedentary lifestyle then his daily BMR is 1.2BMR = 12w + 1224 W=84.1 kg (initial), $I = 5000$ (daily calorie intake) and E = 12w + 1224 (daily calorie burning) $\text{Today's weight} = \text{Yesterday's weight} + \frac{I - E}{7700}$ 1st day = 84.1 + [5000–(12 × 84.1 + 1224)]/7700 = 84.459 2nd day =84.46 + [5000–(12 × 84.459 + 1224)]/7700 = 84.818 As solving the mathematical operations manually will be long and tiring, the operations are carried out with a calculator. Accordingly, the 30th day weight is 94.53.
Solve Equations	Solving the model with mathematical techniques and tools	The formula developed is limited to 30 days. For general formula, the day-weight table is created in Excel and calculations are done on programs or applications. t is the time and w_0 is the initial weight, Δt is the elapsed time and Δw is the weight gain If $\Delta w = \frac{[I - (12w_0 + 1244)].\Delta t}{7700}$, we get: $\ln(3776–12\,w_0) = -0.00156\,t + c$ $(3776 - 12w_0) = A.e^{-0.00156t}$ as $t = 0$, $w_0 = 84.1$, A = 2767 the weight at the desired time is $w = \frac{3776 - 2767.e^{-0.00156t}}{12}$. So, for the 30th day ($t = 30$), w = 94.63
Interpret Solutions	Interpreting the solution or results of the model	With the developed model, the 30th day weight was found different from the one given in the problem. This difference is thought to be due to calculating the average calorie intake and energy use.

(continued on next page)

Table 1 (*continued*)

Theme (Modelling Stages)	Codes	An exemplary approach
Compare with Data	Comparing the solutions obtained from the model with the data initially given or collected Making the corrections by reviewing the assumptions if necessary.	The calculated 30th day weight is 5 % lower than that given in the problem (calculated with the calculator). The model is accepted when the assumptions are taken into account, since the weight gain is logical and consistent, and the result obtained is close to the information given in the problem.
Real-world Solution	Proposing a solution for real life based on the problem	Weight gain decreases the quality of life after a certain point. For this reason, we can balance our weight gain by paying attention to the calories we take and by increasing our activity level. Thus, we should care about our health.

problem-solving approaches were later analyzed using Ang's (2006) framework to systematically examine how they navigated different stages of modelling, including problem formulation, making assumptions, developing mathematical representations, solving the model, and validating results. This approach provided insights into the extent to which PSTs' modelling strategies aligned with established theoretical perspectives on mathematical modelling.

Today, the use of technology has become inevitable to access and process information. When the content of the problem is examined, it is seen that full information about BMR is not given and there is no guidance on the model. As can be understood from the sample solution given above, additional information and practical calculation possibilities are needed in the modelling process. In the problem, the model can be developed without using technology, but this is probably a tiring process and yields inadequate solutions.

The collected data—including group reports, audio transcripts, and electronic documents—were analyzed using thematic analysis, following the six-step framework proposed by Braun and Clarke (2006, 2021). Thematic analysis was chosen for its flexibility in identifying, analyzing, and interpreting patterns (themes) within qualitative data. The process involved the following steps:

1. Familiarization with Data – All data sources were reviewed multiple times to gain a comprehensive understanding of the pre-service teachers' modelling processes and technology use.
2. Generating Initial Codes – The data were systematically coded to identify key aspects of the mathematical modelling process, focusing on problem formulation, assumptions, mathematical representations, solution strategies, and validation.
3. Searching for Themes – The initial codes were grouped into overarching themes based on Ang's (2006) Mathematical Modelling Process, ensuring alignment with the theoretical framework.
4. Reviewing Themes – The themes were refined by checking for coherence within and across themes, ensuring that they accurately reflected the PSTs' modelling processes.
5. Defining and Naming Themes – Each theme was clearly defined, and an exemplar coding structure was developed to illustrate how the pre-service teachers navigated different stages of modelling.
6. Writing the Report – The finalized themes and codes were structured into Table 1, providing an explicit overview of the modelling stages and coding framework.

To ensure trustworthiness and reliability, the thematic coding was conducted independently by two researchers, and any discrepancies were discussed and resolved through a negotiated coding approach (Miles & Huberman, 1994). Inter-coder agreement was assessed using Cohen's Kappa, which yielded a value of 0.82, indicating a strong level of agreement (Landis & Koch, 1977). The finalized coding was further reviewed and validated by an external expert in mathematics education research.

By adopting Braun and Clarke's (2006, 2021) rigorous thematic analysis framework, this study ensures methodological transparency in identifying how pre-service teachers engage with technology during mathematical modelling.

4. Findings

In this section, the findings are reported according to the research questions (RQs). The first part presents how pre-service teachers used technology in the modelling process (RQ1), while the second part describes how these technological tools were utilized at different stages of the modelling cycle (RQ2). To enhance clarity and avoid redundancy, modelling approaches are described according to specific stages, with variations and differences highlighted separately after presenting the general approaches. The technologies used include the internet, GeoGebra dynamic software, Excel, and calculators. Based on the findings, the coding of the technology types and their objectives in the modelling process is presented in Table 2.

RQ 1. Technology Use in the Modelling Process.

RQ 2. Findings by Modelling Stage

4.1. Stage 1: Real-world problem & mathematical problem formulation

The groups did not use technology at the first two stages. In the real-world problem stage, the problem was read by one of the group members and the problem situation was summarized in verbal expressions. In the mathematical problem stage, the addition process was preferred for the mathematical problem and the 'calorie intake' and 'calorie burning' variables were determined for weight gain. In Fig. 3, G6's statement regarding the mathematical problem is given while G8's association the mathematical symbols with the variables are presented in Fig. 4. The calorie intake is represented by + as it contributes weight gain, while exercises are represented by - because exercises and BMR prevent weight gain. (See Fig. 5.)

4.2. Stage 2: Making assumptions

At the making assumptions stage, the groups demonstrated similarity on three assumptions: a) Preferring high-calorie foods and beverages to receive an average of 5000 cal per day, b) Assuming that he does not do enough activity due to being an office worker, and c) accepting daily calorie intake and burning the same. The main frameworks that the groups focused on the model were 'Calorie intake – Calorie burning = Weight gain' and 'Calorie intake > Calories used'. While making predictions about the model, four groups stated that the model to be developed should be an equation and a group remarked that it should be

Table 2
Coding of Technology Types and Objectives in the Modelling Process.

Internet	I1	To gather information / ideas about a situation, event or definition
	I2	To research formulas on the internet to use in the model construction
	I3	To make calculations on the internet by entering data
Excel Software	E1	To create a table by using Excel
	E2	To obtain the result using the automatic calculation feature of the Excel
	E3	To create a line graph with the graph creation, feature of the Excel
GeoGebra Software	G1	To create a line graph with the GeoGebra software
	G2	To obtain the graphical function using the special functions of the GeoGebra software
Calculator	H1	To make calculations to obtain results

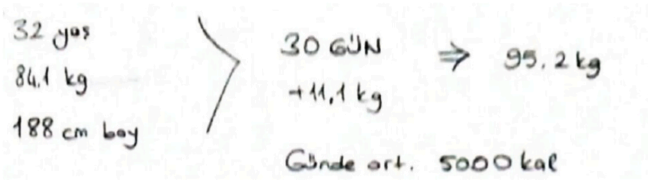

Fig. 3. G6's mathematical problem statement.

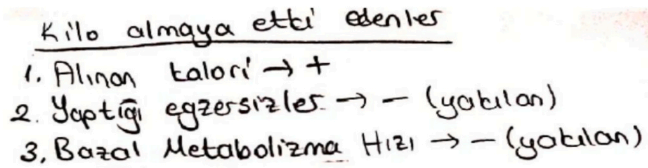

Fig. 4. G8's variables and relationships.

a curve graph. As the groups shaped their assumptions, they conducted research on internet about how the BMR affects weight gain and the working conditions of workers. They also used the calculator for daily calorie-weight assumptions.

4.3. Stage 3: Formulating the equation

At the formulating the equation stage, although the groups knew that BMR is related to the current weight, seven groups took the weight gain as constant by considering it as initial weight and one group calculated BMR based on the current weight. It was observed that five groups constituted the equation model as (Calorie intake - Calorie burning) / 770 = Weight gain, two groups as $y = ax$, one group as $y = a_1x_1 + a_2x_2 + \ldots + a_{10}x_{10}$ and one group as $(\text{Initial weight} + 0,649) - \frac{(\text{BMR}.1,22)(\text{current weight})}{7700} = \text{today's weight}$. When the model development processes were examined, only G4 questioned what BMR means.

B: What does the calorie burn per kg mean? I think we will multiply by weight.

V: Yes, his weight is 84 kg. It is initial.

B: Mmm he will gain a certain weight every day, he will burn those calories then. So, it will be an eq.

V: Yeah. So, it's going to be something like a linear chart.

N: It is not true; I think it will be something different.

V: It will be a slightly curved graphic.

All groups encountered challenges in calculating calorie intake from meals and the number of calories burned through exercise, making it difficult to formulate an accurate weight gain equation. For instance, one group (G4) expressed their struggle, stating: 'We weren't sure how to calculate the exact calories burned because different activities require different energy levels. We just assumed an average value, but we're not sure if that's accurate enough'. They used a calculator to overcome this difficulty and obtain the results easily. The groups investigating BMR found the formula of Mifflin, calculated the BMR value by writing the desired data values, and created the equation with group discussions. Four different Mifflin formulas were used, and one group made the calculation on the internet.

4.4. Stage 4: Solving the equation using technology

At the solving the equation stage, the groups transferred their models from paper to digital platforms for further analysis. Two groups used GeoGebra, five groups used Excel, and one group used both Excel and GeoGebra. Groups using GeoGebra created visual representations of the day-weight relationship, while those using Excel leveraged its automatic calculation and tabulation features to analyze trends over time. However, PSTs were not explicitly asked to explain their rationale for choosing a particular tool. Incorporating their reasoning could further illuminate how technology preferences influence the modelling process and provide additional insights into their decision-making strategies. Groups using GeoGebra added the day-weight table to the program and obtained a graph. Based on the model they developed in the previous stage, groups using Excel defined the formula that made automatic calculations, organized a calorie-intake / burning table and created a day-weight chart based on these tables. When the graphs were analyzed, groups other than G4 obtained a linear day-weight graph, in which the amount of weight gain remained constant. It was observed that this stage was completely technology-intensive, and the groups used expressions such as *drag and drop, right click, select cell* etc. The groups used the technology for automatic calculation, organization, and visual description.

4.5. Stage 5: Interpreting & comparing results

At interpreting the solution stage, the groups made statements that summarize the modelling processes in general and made comments on the correctness or inaccuracy of their solutions. For example, G2 stated that they reached a solution as a result of trial and error and life with exercises and life without exercises models gave different results. G6 found an error in Excel calculation and G4 thought that the model could be improved further. At this stage, preservice teachers did not use technology.

At comparing the data stage, the answers obtained with the values

	A	B	C	D	E	F
14						
15	Gün	Alınan Kalori	Başlangıç Kilosu	Yakılan Kalori	bmh dolayısıyla	Gün Sonu Kalori Farkı
16	1	4624	84,1	120,44	2017,00	2849,00
17	2	4624	84,47	120,435	2017,00	2849,00
18	3	4952	84,84	120,435	2017,00	2849,00
19	4	5121	85,21	120,435	2017,00	2849,00
20	5	5015	85,58	120,435	2017,00	2849,00
21	6	5121	85,95	120,435	2017,00	2849,00
22	7	5015	86,32	120,435	2017,00	2849,00
23	8	5352	86,69	120,435	2017,00	2849,00
24	9	4624	87,06	120,435	2017,00	2849,00
25	10	5230	87,43	120,435	2017,00	2849,00
26	11	4847	87,8	120,435	2017,00	2849,00
27	12	5121	88,17	120,435	2017,00	2849,00
28	13	4952	88,54	120,435	2017,00	2849,00
29	14	5015	88,91	120,435	2017,00	2849,00
30	15	5352	89,28	120,435	2017,00	2849,00
31	16	5352	89,65	120,435	2017,00	2849,00

Fig. 5. Table and Chart Created by G7 in Excel.

given in the problem were compared. The groups realized that their responses were close to the given values and the difference was due to the calculation of the average calorie values. They inferred that their models were correct. G4 and G6 returned to their assumptions after comparison. G4 evaluated the curve graph assumption, marked the regression model exponentially and obtained the equation of (weight) $= 84.1024.e^{-0.0042x}$ considering x (days). The G6 changed some of the assumptions because the calculated weight gain was more than given. That is, they increased working hours and assumed that he walked to work. Using the automatic calculation feature of the formula they defined, the group changed the hours of the activities by trial and error until the weight gain was 11.1. At this stage, the use of technology was limited to the editing possibilities offered by the software.

4.6. Stage 6: Real-world solution & model refinement

The only group working at the real-world solution stage was G1. The group did not use the technology and commented on the following statements regarding real life:

G: Fat becomes weight. Despite their fast-foot style diet, those who do sports gain less weight.

F: It is seen that those who do sports and have a more active lifestyle and gain less weight than people with a passive lifestyle. These people are healthier.

It was observed that all groups developed models, one group completed the process that started with the real-life problem with a real-life solution, and the two groups returned to the assumptions. Throughout the process, the use of technology can be summarized as internet for *accessing information*, calculator for *calculating*, Excel for *organizing data, automatic calculation and graphing*, and GeoGebra software for *graphing and obtaining functions*. The purposes of technology use at the modelling stages of the groups are shown in Table 3.

The study revealed that pre-service teachers utilized various digital technologies throughout the modelling process. The internet was primarily used for research, such as gathering background information, finding formulas, and verifying calculations. Calculators were employed for manual computations, while Excel played a key role in automating calculations, organizing data, and generating graphical representations. Additionally, GeoGebra was used for graphing and visualizing functions. However, many participants incorrectly assumed a constant weight gain, leading to oversimplified models that did not accurately reflect real-world conditions.

Although some groups refined their models after comparing their results with real-world data, most did not make significant adjustments, highlighting a limited application of critical reflection. Only one group explicitly connected their mathematical model to real-life implications, recognizing the role of physical activity in weight management. This suggests that while pre-service teachers effectively engaged with technology, greater emphasis is needed on model revision and real-world interpretation to enhance their conceptual understanding.

Table 3
The Purposes of Using Technology in the Mathematical Modelling Stages of the Groups.

	Making Assumptions	Formulating the Equation	Solving the Equation	Comparing the data
G1	I1, H1	I2, H1	G1	
G2	H1	H1	E1, E2	
G3	H1	I2, H1	E1, E2, E3, G1	
G4	I1, H1	I2, H1	G1	G2
G5		I2, I3, H1	E1, E2	
G6	I1	I2, H1	E1, E2	E2
G7		I2, H1	E1, E2, E3	
G8		I2, H1	E1, E2	

5. Discussion, conclusion and recommendations

Although the modelling approaches and technology use of pre-service high school mathematics teachers showed slight differences, they were generally similar. When transforming real-world problems into mathematical problems, they primarily focused on the numerical values of weight gain and identified relevant variables through group discussions. Half of the groups used the internet and calculators while making assumptions and developing equation models. While one group calculated weight changes day by day, others developed a proportional model. Groups that created models using tables and graphs in Excel or GeoGebra later evaluated their solutions and models. However, only two groups revised their assumptions after comparing their results with the given models, refining their models using software. As a result, one group edited their data table, while another modified their equation model, transitioning from a linear function to an exponential function based on the current weight. At the end of the process, only one group proposed a real-life solution, demonstrating an attempt to connect their mathematical findings to practical implications.

Previous research by Johnson (2001) and Menzel (2001) found that many teachers struggle to articulate the nature of algebraic concepts. Key topics such as limits, integrals, and functions are fundamental in high school mathematics curricula and essential components of teacher education programs. Despite having prior knowledge of exponential functions and mathematical content knowledge, pre-service teachers in this study initially developed linear equation models during the formulating equations stage. A closer examination of their reasoning and discussions revealed that many groups assumed weight gain was constant or relied on the initial weight instead of the current weight, leading to the development of linear models rather than exponential ones. The findings indicate that pre-service teachers may struggle to conceptualize the dynamic nature of mathematical concepts and effectively apply their field knowledge. To address this gap, MEAs should be more frequently incorporated into teacher education programs, particularly in algebra instruction, to strengthen conceptual understanding, promote flexible thinking, and enhance problem-solving skills.

The use of technology plays a crucial role in enhancing teaching and learning (Lemke et al., 2009; Tamim et al., 2011), and teachers are central to the successful integration of technology into educational environments (Ertmer et al., 2012; Levin & Wadmany, 2008). Consequently, technology has become an essential component of mathematics education, leading to improvements in both the quality (content) and quantity (number of lessons) in courses on technology use in mathematics instruction. In this study, pre-service teachers used various technological tools to gather information online, perform calculations using calculators, organize and visualize models with software, and edit their graphical representations and tables. Their engagement with these digital tools reflects the growing significance of technology in supporting mathematical modelling and problem-solving processes.

The study identified four key roles of technology in mathematical modelling: accessing information, performing numerical calculations, organizing data, and visualizing and analyzing graphical representations. These findings align with those of Daher and Shahbari (2015), who investigated the use of spreadsheets in the modelling process and highlighted their effectiveness in fostering creative and flexible problem-solving approaches. The integration of technology enhances conceptual understanding and improves students' mathematical reasoning and solution skills, making learning more meaningful and dynamic.

The integration of technology into mathematical modelling has been widely explored in recent research. Koyunkaya and Dede (2024) found that pre-service teachers effectively designed and solved mathematical modelling problems by integrating multiple digital tools across different courses. Similarly, our study highlights how PSTs utilized Excel, GeoGebra, calculators, and the internet at various stages of the modelling process. While the pre-service teachers in Koyunkaya and Dede's (2024) study incorporated digital tools as part of a structured instructional framework, our findings indicate that the nature and timing of technology use varied significantly across groups, with some teachers revising their models after initial implementation.

Despite these benefits, technology use in mathematical modelling can lead to challenges such as overconfidence in digital outputs and misinterpretation of results. In this study, groups searched for the Mifflin formula online, but due to variations in formula coefficients, they obtained different results despite using identical weight, height, and age values. Similarly, students relied on software-generated models without critically assessing their accuracy, assuming correctness based on the given values. However, weight gain and basal metabolic rate (BMR) dynamically influence calorie expenditure, meaning weight does not increase proportionally. Similar concerns about over-reliance on technology and misinterpretation of results were reported in studies by Lingefjärd (2000) and Saka and Çelik (2018). These findings emphasize the importance of fostering critical thinking and proper use of technology in mathematical modelling, ensuring that students engage in deep reasoning rather than simply accepting computational outputs at face value.

Pre-service teachers integrated technology into the modelling process in three distinct ways. In the first cycle, three groups summarized the problem, transformed it into a mathematical representation, identified key variables and assumptions through group discussions, and established the initial framework for their models. They then developed both a mathematical model and a corresponding technological model, utilizing technology for calculations and visualizations. After obtaining their results, they interpreted their findings and evaluated the models collaboratively through discussions.

In the second cycle, three groups used technology earlier in the process, employing it to define assumptions and formulate equations before transitioning to constructing the technological model. They relied on group discussions to analyze their solutions and compare the data with the given values. In the third cycle, two groups incorporated technology throughout multiple stages, using it to identify assumptions, formulate and solve equations, and verify their results. These groups, after completing their initial models, realized the need for revisions and refined their models by modifying assumptions and adjusting technological representations. As illustrated in Fig. 6, this revision process led some groups to skip a step in the model refinement cycle, demonstrating how technology influenced the way pre-service teachers structured and modified their models.

This study reaffirms the central role of technology in mathematical modelling, aligning with Greefrath (2011) and Geiger (2011), who argue that digital tools shape the entire modelling process. Furthermore, findings expand on Ang's (2006, 2010) Mathematical Modelling Cycle, demonstrating that pre-service teachers do not always follow a linear problem-solving trajectory. Instead, their use of technology influenced when and how they revisited assumptions, revised models, and interpreted solutions.

This study contributes to the theoretical understanding of mathematical modelling in teacher education by expanding upon existing frameworks of technology-supported modelling. While prior research (e.g., Geiger, 2011; Greefrath, 2011) has emphasized the role of technology in mathematical problem-solving, our findings demonstrate that pre-service teachers engage with digital tools in non-linear ways, often revising their assumptions and models dynamically. This challenges traditional stepwise modelling perspectives and aligns with Ang's (2006, 2010) Mathematical Modelling Cycle, reinforcing the need to view the modelling process as iterative rather than strictly sequential. Furthermore, this study highlights the cognitive challenges PSTs face in transferring algebraic content knowledge to real-world modelling contexts, suggesting that existing theories on teacher learning in mathematical modelling (e.g., Kaiser & Sriraman, 2006) should more explicitly account for difficulties in conceptualizing exponential relationships. By revealing patterns in technology use, mathematical reasoning, and model revision, this study contributes to a more nuanced theoretical understanding of how digital tools mediate the development of modelling competencies in teacher education.

While this study provides valuable insights, its scope is limited to a single course and 26 pre-service teachers from one institution, which may affect the generalizability of the findings. Future research should investigate larger cohorts across multiple institutions and diverse educational settings to gain a broader understanding of how pre-service teachers engage with technology in mathematical modelling. Additionally, this study does not account for variations in pre-service teachers' prior experiences with digital tools or their levels of technological proficiency, which may influence their modelling approaches. Further studies could explore how different levels of technological proficiency impact the effectiveness of technology integration in modelling. Another important limitation is the short-term nature of this study; future research should assess the long-term effects of technology-based modelling experiences on teachers' instructional practices in real classroom environments. Moreover, examining the role of structured

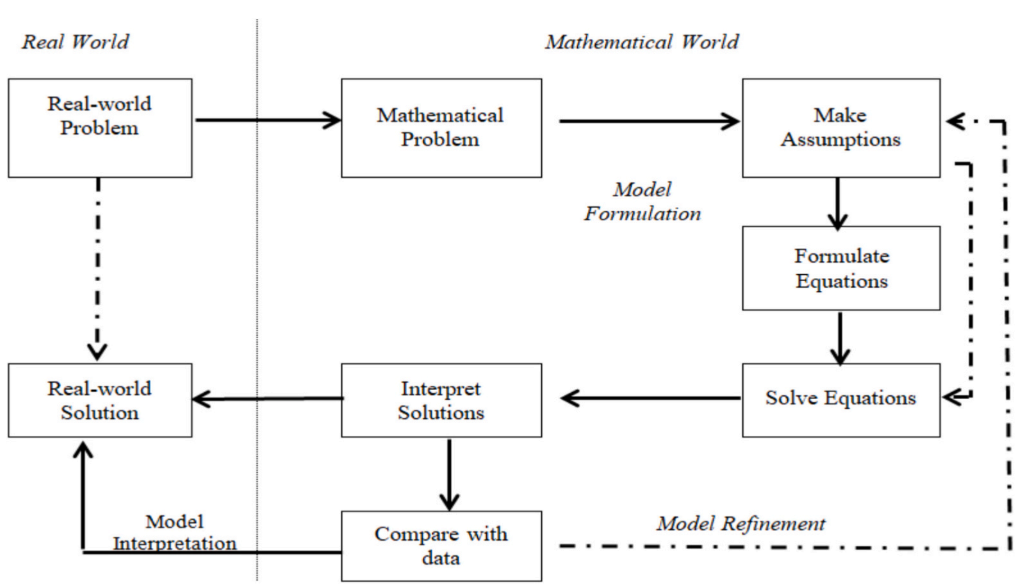

Fig. 6. Mathematical Modelling Process of Two Groups Refining the Model.

pedagogical frameworks in guiding technology use during mathematical modelling could provide deeper insights into how pre-service teachers develop their modelling competencies. Addressing these limitations could lead to more comprehensive strategies for integrating digital tools into mathematics teacher education, ultimately enhancing pre-service teachers' ability to engage students in meaningful mathematical modelling activities.

The findings of this study highlight important implications for teacher training programs and initial teacher education, particularly in integrating mathematical modelling and technology into instruction. Pre-service teachers exhibited difficulties in applying their mathematical content knowledge, especially in conceptualizing weight change as an exponential function, emphasizing the need for stronger algebraic reasoning and real-world application in teacher education programs. Additionally, while they utilized digital tools such as GeoGebra and Excel, their use was often procedural rather than conceptual, underscoring the need for targeted training on leveraging technology for visualization, dynamic graphing, and data interpretation. Furthermore, some pre-service teachers demonstrated overconfidence in technological outputs, assuming correctness without critical evaluation. To address this issue, teacher education should incorporate activities that foster critical thinking about technology-generated results and emphasize the importance of model validation. The study also revealed that only a few groups refined their models after comparing their results, indicating the necessity of embedding iterative problem-solving experiences and structured reflection sessions to reinforce the cyclical nature of mathematical modelling. To ensure future teachers are adequately prepared, initial teacher education programs should integrate modelling activities within mathematics methods courses, providing hands-on experiences that enable them to implement modelling effectively in their classrooms. Addressing these areas will enhance pre-service teachers' content knowledge, pedagogical strategies, and technological proficiency, equipping them to facilitate meaningful mathematical modelling experiences for their students.

CRediT authorship contribution statement

Mehmet Ali Kandemir: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nurullah Eryilmaz:** Writing – review & editing, Validation, Supervision, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare no competing interests that could have influenced the research, authorship, or publication of this article.

Appendix A

Table 1
Energy Used by Activity.

Activity	Energy used (kcal/kg/h)
Sitting quietly	0.4
Writing	0.4
Standing relaxed	0.5
Driving a car	0.9
Vacuuming	2.7
Walking rapidly	3.4
Skateboarding	5.0
Running	7.0
Tennis	7.0
Swimming	7.9

Table 2
Energy Content of Sample Fast Food Items.

Sample Fast Food Items	Energy (kcal)
Plain hamburger: ground beef patty, grilled (40 g), hamburger bun (65 g) and salad	328
Plain hamburger and medium chips: ground beef patty, grilled (40 g), hamburger bun (65 g) and salad	497
Cheeseburger: ground beef patty, grilled (40 g), hamburger bun (65 g), lettuce, sliced tomato and onion, tomato sauce, cheese (16 g)	391
Cheeseburger and large chips: ground beef patty, grilled (40 g), hamburger bun (65 g) and salad, large portion of chips	728
Double hamburger and medium chips: 2 ground beef patties, grilled (80 g), hamburger bun (65 g) and salad, medium portion chips	606
Pizza with cheese, tomato and olives: medium portion (90 g)	223
Pizza with cheese, tomato and olives: large portion (340 g)	844
Lemonade (375 ml)	158
Dry ginger (375 ml)	124
Bundaberg ginger beer (375 ml)	188
Coca Cola (375 ml)	158
Pepsi cola (375 ml)	169
Fanta (375 ml)	210

Data availability

The data that support the findings of this study are available from the author, Mehmet Ali Kandemir, upon reasonable request.

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