Relationship Between Computational and Critical Thinking Towards Modelling Competency Among Pre-Service Mathematics Teachers

Pavitra Kannadass [1], Riyan Hidayat [2], Pariang Sonang Siregar [3], Alma Pratiwi Husain [4]

[1]*Universiti Pendidikan Sultan Idris, 35900, Perak, Malaysia*
[2]*Universiti Putra Malaysia, 43400, Selangor, Malaysia*
[3]*Universitas Rokania, Rokan Hulu, Riau, Indonesia*
[4]*Institut Agama Islam Negeri Fattahul Muluk Papua, Papua, Indonesia*

***Abstract* – Participation in modelling activities significantly facilitates the development of mathematical skills. By utilizing the concept of mathematical modelling, students may be able to develop a more grounded understanding of mathematics. The objective of this research was to explore how computational thinking and critical thinking are connected to the mathematical modelling proficiency of pre-service teachers. Correlational quantitative research was conducted on 140 pre-service mathematics teachers from the Institute of Teacher Education, Penang and the Institute of Teacher Education, Ipoh, using a correlational research design. Using cluster random sampling, the Institute of Teacher Education was selected at random. The results revealed that pre-service mathematics teachers exhibited a strong aptitude for computational and critical thinking, but demonstrated a limited level of proficiency in mathematical modelling. In terms of modelling proficiency, the results indicated a significant correlation between computational thinking and critical thinking.**

The findings from this research demonstrated a significant correlation between critical thinking, computational thinking, and proficiency in modelling. Therefore, computational thinking and critical thinking improve prospective mathematics teachers' modelling skills.

Keywords – Computational thinking, correlational quantitative research, critical thinking, mathematical modelling, pre-service mathematics teachers.

DOI: 10.18421/TEM123-17
https://doi.org/10.18421/TEM123-17

Corresponding author: Riyan Hidayat
Universiti Putra Malaysia, 43400, Selangor, Malaysia
Email: riyan@upm.edu.my

Received: 11 April 2023.
Revised: 26 July 2023.
Accepted: 02 August 2023.
Published: 28 August 2023.

1. Introduction

Mathematical skills develop through modelling. Before assigning them, teachers must understand the task and its challenges [1]. Mathematical modelling may help students grasp maths [2]. Many studies suggest that modelling competencies help teachers implement lessons and improve teaching and learning [4]. According to the study conducted by Leong and Tan [1], the fundamental competencies of modelling in secondary education include the formulation of assumptions, computation and interpretation of solutions, and the application of mathematical reasoning. They stated that some students were tested for basic mathematical modelling. Some assumed that most students were unable to draw conclusions from these factors. For the computing and interpreting solution, one group made many mistakes and showed an error in their model, while the other did not link their model's development to a concept or make an assumption. Researchers found an inappropriate mathematical concept, which led to a wrong interpretation [1]. Hidayat et al. [4] suggested that mathematical modelling competency should be defined in more than one way. Mathematical modelling requires critical and computational thinking. Critical thinking and problem-solving help students' model competency [5].

Modelling competencies are defined as the capacity to comprehend and address intricate problems [6]. Learning mathematics can be a vehicle for students to develop their models and develop their expertise in applying math [1]. Four essential tasks that a modeller must complete to accurately represent a real problem are listed. Durandt et al. [7] wrote that structuring a model helps students understand real problems. However, some countries, including Malaysia, struggle to implement mathematical modelling competencies [1], [8], [9]. Prospective teachers were trained to solve word problems with correct answers [8]. However, they struggled to create a winning strategy due to their mathematical modelling ignorance. According to Schukajlow's research [3], students encountered greater difficulty when attempting to solve modelling and intra-mathematical problems under both the multiple-solutions and one-solution conditions. Students struggle with math, especially in problem-solving [10]. Pre-service mathematics teachers exhibited insufficient pedagogical content knowledge in relation to modelling tasks, conceptions, and dimensions [11]. Maaß [12] found that students cannot estimate the body-head relationship in a problem.

For the computing and interpreting solution, some students made many mistakes and showed a model error, while others did not link their model's development to a concept or assumption. Students use incorrect mathematical concepts for mathematical reasoning, which leads to misinterpretation [1]. Overall, it would appear that secondary school students do not understand mathematical modelling. This problem stems from unrealistic mathematical reasoning [1]. Despite improving critical thinking skills, students still fail non-routine questions [12]. Mathematical modelling can spark creativity and thinking in students. Many studies found critical thinking difficulties in students [13], [14]. Palavan and Ozcan [14] found that pre-service teachers have a low understanding of the problem in self-confidence and truth-seeking, but moderate understanding in being analytical, open-minded, inquisitive, and systematic.

Students obtained the lowest scores in the sub-dimensions of critical openness, as well as reflective and analyticity, within the realm of critical thinking [15]. Students struggle to apply computational thinking [16], [17]. Computational thinking instruction is poorly researched [18]. Computational thinking, especially problem-solving, challenges students [19]. Students struggle with problem-solving and algorithms [20].

The primary focus of this study is to examine the correlation between computational thinking, critical thinking, and the level of mathematical modelling competency among pre-service teachers. In the Malaysian education field, there has not yet been a study on the relationship between critical and computational thinking and learning modelling competency.

2. Research Questions

This study sought to address the following research question:

1. What is the extent of critical thinking abilities among pre-service mathematics teachers?
2. What is the degree of computational thinking proficiency among pre-service mathematics teachers?
3. What is the extent of mathematical modelling competency among pre-service mathematics teachers?
4. Does a significant correlation exist between critical thinking and modelling competency among pre-service mathematics teachers?
5. Is there a significant relationship between computational thinking and modelling competency among pre-service mathematics teachers?
6. Does a significant correlation exist between critical thinking and computational thinking among pre-service mathematics teachers?

3. Literature Review

Previous researchers defined mathematical modelling competency as not only the process of mathematical modelling itself, but also the ability to complete tasks as well as goal-oriented [12], [19], [35], [60] whereas critical thinking for analysis and decision making and computational thinking enables problems to be overcome, conditions to be better understood, and results to be expressed [31].

a. Mathematical Modelling

Mathematical modelling competence has been defined by researchers as the aptitude to accomplish tasks and exhibit goal-oriented behavior [12], [19], while critical thinking for analysis and decision making and computational thinking enable one to solve problems, gain a deeper understanding of their context, and communicate their findings. Here, the Social Cognitive Theory (SCT) and the Theory of Models and Modelling Perspective (MMP) provide the theoretical framework for the investigation.

Mathematical modelling involves translating real-world problems into a mathematical language to understand and solve them [20]. Mathematical modelling connects mathematics to daily life in the classroom. Thus, mathematical modelling allows students to apply maths to real-world problems [21]. [22]. Students must solve or create daily problems in the mathematical modelling task. Modelling competencies can be described as the skills and abilities required to effectively engage in modelling processes with a clear goal in mind, along with the motivation and readiness to put these competencies into practice [12]. Modelling skills depend on physical-mathematical interactions. Maaß [12] outlined several essential skill sets in modelling, which encompass comprehending the problem and constructing a practical model, transforming the practical model into a mathematical representation, solving mathematical problems within the model, interpreting outcomes within the real-world context, and verifying the validity of the solution. Benefits include enhanced critical thinking and problem-solving [1].

Teaching modelling can be divided into two categories: content area modelling and knowledge construction through modelling [7]. Niss et al. [6] stressed mathematical and modelling interdependence. To put it another way, modelling competence depends on and improves mathematical competence [24]. The undergraduate mathematics education program prepares teachers for schools [23]. This paradigm of training partial competencies for learners ensures long-term modelling competency mastery [25].

b. The Correlation Between Critical Thinking and Mathematical Modelling

Knowledge of the many different modelling challenges does not always ensure that one has an understanding of the process [11]. Students were reminded of the significance of acquiring additional skills, such as critical thinking, in order to better prepare them for life and the workplace [3]. Two of the most important principles that schools should take into consideration when designing learning environments are the development of effective teaching and learning environments that encourage students to make use of strategies and develop critical thinking and problem-solving skills. Introducing critical thinking at an early stage during a student's higher education experience not only provides them with a comprehensive understanding of critical thinking but also enhances their metacognitive abilities.

Moreover, it ensures a structured and fair approach to these essential concepts, promoting equity among students [25]. The findings of the study indicate that student’s capacity for independent work was affected by the manner in which their critical thinking skills developed while they were developing mathematical models [26].

c. The Association Between Computational Thinking and Mathematical Modelling

Computational reasoning is the use of logic and computation to address problems, make choices, and influence one's surroundings [27]. Scientific practices are founded on the principle of computational thinking, which suggests that computational thinking is an essential cognitive trait that bridges the gap between the real world and one's own mental models of it [28]. Abstraction, decomposition, algorithmic design, generalization, evaluation, and iteration are concepts and approaches derived from computer and information science that have broad applicability in various disciplines such as the humanities, sciences, arts, and social sciences [27]. It turns out that mathematical modelling is an excellent arena for using, improving, and developing computational thinking abilities [20]. The abilities of computational thinking, such as the ability to collect relevant information, examine problems for patterns, decompose them, and develop step-by-step solutions, are fundamental to mathematical modelling [20]. The ability to think computationally is correlated with enhanced reasoning and problem-solving abilities, which in turn benefits learning in virtually every domain. Two additional reasons why Angeli [29] emphasises the educational benefits of computational thinking are that it encourages the use of abstractions and reasoning skills, which in turn strengthen and support intellectual abilities and are therefore transferable across domains. The ability of a student to solve a problem using a model is directly related to their proficiency in the various aspects of computational thinking [30].

d. Relationship Between Critical Thinking and Computational Thinking

Researchers have previously defined computational thinking as the capacity to reason computationally about problems, improve one's comprehension of context, and effectively convey one's findings. Also, they said that critical thinking is the capacity to evaluate data and choose appropriate courses of action [31]. Attempts have been made to explore the overlap between computational and critical ways of thinking in the academic literature. Both are essential for finding workable solutions to difficult technological issues.

Analysing, evaluating, inferring, predicting, and generalising are all forms of critical thinking that are essential for understanding, learning, decision-making, and problem-solving [27]. Computational thinking can be studied and taught by employing broader critical concepts, methods, and attitudes [27]. By recommending critical approaches that are not typically highlighted in programming courses, teachers can help students develop their programming skills while also making explicit connections between critical and computational abilities [32].

Critical thinking skills are now considered fundamental, on par with literacy, numeracy, and the ability to use language effectively. Critical thinking, which is at the pinnacle of the hierarchy of thinking abilities in the field of computation, can solve any problem [28]. An important component of critical thinking that helps future educators hone their computational abilities is reflective scepticism and openness. They have the capacity to articulate a problem and reason it out. It helps students analyse and predict current and future events, which strengthens their intellectual abilities [33].

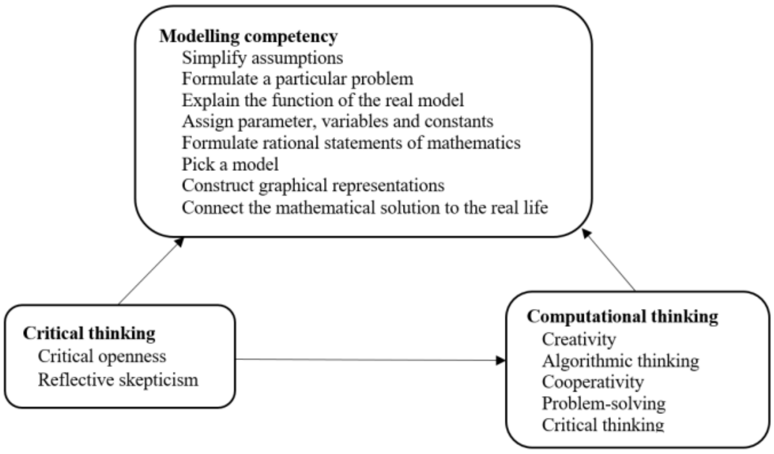

Figure 1. Conceptual framework

4. Methodology

This chapter examines the study's research methodology. It covers research design, population, sample, data collection, and procedure. The chapter also discusses research instruments, validity, reliability, and data analysis on the relationship between computational and critical thinking and modelling competency in pre-service mathematics teachers.

a. Research Design

A study design should be flexible to meet research needs [36]. The research design involves data collection, analysis, and reporting [35], [59]. The study design allows for various methods to improve study efficacy [34]. This research uses quantitative methods and correlational design [35], [36]. Quantitative research allows data analysis and hypothesis creation. This method analyses data statistically [37]. Non-experimental correlational research design examines the relationship between two or more variables [37]. Correlational studies allow researchers to share the benefits of their findings with the population [38].

The correlational design was chosen to quickly administer upwards samples.

They can also gather a lot of data at once [39]. Finally, they can examine variable relationships [40]. Correlation studies have drawbacks. Since it is unclear which factor causes the other, correlation studies cannot prove causality. Computational and critical thinking and pre-service mathematics teachers' modelling competency were examined in this study using correlation studies. In a correlational research design, the researcher does not directly control or manipulate any variables. This study used precise correlation studies to identify critical and computational thinking factors that affect pre-service teachers' modelling competency. This study's theoretical framework [35] allowed mathematics education pre-service teachers to model and question their maths skills. It also linked critical and computational thinking.

This study examines how these factors affect mathematical modelling skills in pre-service teachers at two teacher-training institutes in Penang and Ipoh, Perak, who were enrolled in mathematics education programs. This study used self-questionnaires and self-tests to assess mathematical modelling skills. Questionnaires are easy to administer because respondent data is collected before the data analysis [41]. Questionnaires allow data from all respondents to be analysed using predetermined scale measurements.

Rating exercises and checklists can accomplish this [36]. Participants must complete online surveys, unlike face-to-face interviews. Structured surveys have no more questions. By examining existing questionnaires before starting a new survey, it will improve the result’s reliability and validity [37].

b. Population and Sample

The participants in this study were pre-service teachers who were undergraduate students enrolled in a teacher education program at the Institute of Teacher Education in Malaysia. The decision to focus on pre-service mathematics teachers was driven by the aim of enhancing teacher preparation programs. In Malaysia, there are 27 Teacher Education Institutes.

For this study, we selected the Institutes of Teacher Education from the North Zone. The objective of this study was to gather data regarding the experiences of pre-service mathematics teachers who were enrolled in courses focusing on gender, critical thinking, computational thinking, and modelling competency. Pre-service teachers have advanced mathematics course experience [42]. Pre-service teachers, for instance, enrol in advanced courses like geometry, algebra, probability, and calculus. It is assumed that students who enrol in advanced mathematics courses have already studied the modelling process.

In this study, a cluster random sampling method was used to select the teacher training institutes at random. Cluster sampling is a statistical sampling method that divides the entire population under study into groups called clusters that appear identical on the outside but differ on the inside [42]. Cluster sampling is more practical because it requires fewer resources. One disadvantage of cluster sampling is biased samples [43]. The primary goals of cluster sampling in this study can be cited as cost reduction and increased levels of sampling efficiency. A group of people is divided into smaller groups called "clusters" in cluster sampling. Then, at random, a sample is selected from each of these groups.

Cluster sampling is a type of probability sampling that is frequently used to study large populations, particularly those that live in multiple locations. Researchers frequently use pre-existing groups as clusters, such as cities or institutions [44]. In the northern region, there are six teacher training institutes, but only two offer a mathematics education program. As a result, teacher training institutions from Perak and Penang were chosen. We selected at random from the sample size table created by Krejcie and Morgan in 1970 [44]. 140 aspiring maths educators from Year Three and Four were chosen, as shown in table 1. The researchers were able to gather more precise and intricate data because of the larger sample size. Additionally, this assisted in lowering the likelihood of error [36].

c. Instrument

This survey-style research study employs feedback in the form of a questionnaire and a set of multiple-choice questions as instruments. Respondent demography, a critical thinking questionnaire, a computational thinking items questionnaire, and a mathematical modelling test comprise the questionnaire instrument. Part A of this study examined the demographics of the respondents. They were divided into two categories: gender studies and age studies, with Sections B, C, and D serving as the study's main sections.

The mathematical competency modelling test was developed by Haines et al. [45]. It was used to assess students' abilities in the area of mathematical modelling. Using 22 questions, the test assesses six mathematical modelling competencies. They incorporated various components into their study, including the formulation of goals, identification of variables, formulation of mathematical statements, model selection, assumption-making, and problem formulation [45]. The mathematical modelling competencies are then extended to include representations of mathematical solutions to real-world problems. This does not imply that they should be capable of solving complex problems [4]. The purpose of this study was to assess students' ability to perform mathematical modelling. The students were required to answer 22 multiple-choice questions. A pre-service teacher who answered multiple-choice questions received a score of two in this study. The test's 22 questions will yield a maximum score of 44 points. One disadvantage of multiple-choice formats is that the respondent's chances of getting the correct answer are significantly reduced if they only guess. The constructs and sub-dimensions of the mathematical modelling competency test are described in Table 1 below.

Table 1. Construction and sub-dimension of the mathematical modelling competency test

Construct	Sub-dimension	Questions
Mathematical modelling competency	Simplify assumptions	Q1, Q2, Q3
	Explain the function of the real model	Q4, Q5, Q6
	Formulate a particular problem	Q7, Q8, Q9
	Assign parameters, variables, and constants	Q10, Q11, Q12
	Formulate rational statements of mathematics	Q13, Q14, Q15
	Pick a model	Q16, Q17, Q18
	Construct graphical representations	Q19, Q20
	Connect the mathematical solution to the real-life	Q21, Q22

The assessment of the two sub-dimensions of critical thinking, namely critical openness and reflective scepticism, was conducted in this study through the administration of a questionnaire adapted from Hernandez et al. [46] and Sosu [47]. The questionnaire contains 11 items in total, seven on critical openness and four on reflective scepticism, all of which are measured using a 5-point Likert scale ranging from (1= strongly disagree) to (5= strongly agree). The Likert scale is a straightforward and efficient method for measuring and managing survey responses. It is quicker to complete and is suitable for both administrators and respondents [49]. The constructs and sub-dimensions of critical thinking are described in Table 2 below.

Table 2. Critical thinking dispositions

Construct	Dispositions	Number of items
Critical thinking	Critical openness	Q1, Q2, Q3, Q4, Q5, Q6, Q7
	Reflective skepticism	Q8, Q9, Q10, Q11

This study focused on investigating five specific sub-dimensions of computational thinking skills, namely creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. A questionnaire developed by Korkmaz and Bai [49] was utilised for this study. The questionnaire contains 20 questions, including three on creativity, four on algorithmic thinking, four on cooperation, four on critical thinking, and five on problem solving. The survey questions were assessed using a 5-point Likert scale, where respondents could indicate their level of agreement or disagreement, ranging from 1 (strong disagreement) to 5 (strong agreement). The Likert scale is a simple and effective tool for managing survey responses. It is quick to complete and ideal for both respondents and administrators [48]. Table 3 describes the constructs and sub-dimensions of computational thinking.

Table 3. Sub-dimensions of computational thinking

Construct	Sub-dimension	Number of items
Computational thinking	Creativity	C1, C4, C5
	Algorithmic thinking	A1, A3, A4, A6
	Cooperativity	O1, O2, O3, O4
	Critical thinking	T1, T2, T3, T5
	Problem solving	P1, P2, P3, P4, P5

d. Data Collection Process

A letter confirming the researcher's status as a student at *University Pendidikan Sultan Idris* (UPSI) is attached to the request for permission from the Institute of Teacher Education in Ipoh and Penang before beginning the research. After obtaining approval from the Institute of Teacher Education in Ipoh and Penang, permission was granted to contact the targeted respondent by calling the head of the mathematics department at the Teaching Institute of Ipoh and Penang. The researcher then coordinated with the specific mathematics lecturer for Year Three and Four to set up a time for administering the modelling competency test and the questionnaire. The researcher took the time to provide a concise explanation of the instruction to the respondent. A series of questionnaires and questions with multiple-choice responses were sent to the selected samples via Google Forms. For convenience, both the link to the questionnaire and the multiple-choice questions were provided. The time allotted to complete the questionnaire and multiple-choice questions were unrestricted. The entirety of the respondents' responses was entered into a spreadsheet and uploaded to Google Drive for further analysis. Using SPSS software, responses to questionnaire items were processed and analysed to determine the reliability of the items used. The collection of specific respondent data commenced. After data collection, SPSS 26 was used to examine the relationship between critical thinking and computational thinking among pre-service teachers. After analysing the data, the researcher reached the conclusions and made some recommendations.

e. Validity and reliability

Validity is defined as the accuracy, significance, and applicability of a researcher's findings [50]. Validity is also defined as the assurance that the data used to support a researcher's conclusions are trustworthy [35], [50]. Validity is determined by the evidence that an instrument accurately measures what should be included in a conclusion. In 2005, Cohen and colleagues proposed a number of enhancements for the instrument's reliability. Both face validity and content validity are assessed in this study. Validity refers to the extent to which test questions reflect the instrument's content accurately [35].

To ensure validity, all items and domains should be represented [36]. The researcher did not omit any questions from the questionnaire to ensure the content's accuracy. Three specialists examined the content of the instruments. This study employs CVI to evaluate the data collected from experts.

Combining scale and item measurements, the CVI and the S-CVI are the two forms used for this type of evaluation. The I-CVI is calculated using the proportion of items that score 3 or 4 on the relevance scale and the average score of all items on the scale. S-CVI/UA achieve a satisfactory level, thereby achieving a satisfactory level of content validity for the questionnaire.

f. Data Analysis

The data collected in this study were processed and analyzed utilizing the Statistical Package for the Social Sciences (SPSS) software, specifically version 26. Descriptive statistics and correlation analysis were employed to analyze the data. The percentage was based on the social and demographic data of the people who took part. The goal of this study was to conduct a descriptive analysis, which was done by reporting descriptive statistics and correlations for each construct. In this research, the mean and standard deviation were utilised as elements of the descriptive analysis for each construct. For critical thinking, computational thinking, and modelling competency, the mean and standard deviation of each answer would be calculated. The calculated score would then be compared to each factor to see which one provided the highest mean. Each score would be shown in the form of a table. The study scale of Section 29 Educational policy planning and research was used to figure out what the mean values meant. On a mean scale, a score between 1.0 and 1.8 is very low, 1.9 to 2.6 is low, 2.7 to 3.4 is medium, 3.5 to 4.2 is high, and 4.3 to 5.0 is very high.

Correlation is a numerical value that indicates the direction and strength of the relationship between two or more variables. As indicated by the value 0.00 – 0.29, the relationship's strength was very low. When the value falls between 0.30 and 0.49, the strength of the relationship is considered low. The relationship is moderately strong, with a value between 0.50 and 0.69. When the value is between 0.70 and 0.89, the relationship is deemed to be strong. When the value is between 0.90 and 1.00, the relationship's strength is very strong. The relationship between critical thinking and modelling competency, the relationship between computational thinking and modelling competency, and the relationship between critical thinking and computational thinking will be determined by correlation coefficient interpretation guidelines.

5. Results

This study's population of pre-service teachers consisted of undergraduate students at the Institute of Teacher Education, Malaysia. These included third- and fourth-year pre-service mathematics teachers who were currently enrolled in mathematics education programmes. The purpose of the study was to collect information about the experiences of pre-service mathematics teachers who had taken courses on gender, critical thinking, computational thinking, and modelling competency. Undergraduates are familiar with advanced mathematics courses. Pre-service teachers, for instance, enrol in advanced courses like geometry, algebra, probability, and calculus. It is assumed that students who enrol in advanced mathematics courses have already studied the modelling process. Consequently, these students from the mentioned educational institutions from the states of Perak and Penang were chosen. A total of 140 third- and fourth-year mathematics pre-service teachers participated in this study. Table 4 displays the respondents' demographic information.

Table 4. The demographic information (N = 140)

Item		Frequency	Percentage
Gender	Male	51	36.4
	Female	89	63.6
Race	Malay	81	57.9
	Chinese		16.4
	Indians	24	17.1
	Others	12	8.6

There were 89 mathematics education majors (63.6% women) and 51 (36.4% men) enrolled in the pre-service programmes. In addition, there were 81 Malay respondents (57.9%), 23 Chinese respondents (16.4%), 24 Indian respondents (17.1%), and 12 respondents from other races (8.2%).

a. Descriptive Analysis

The descriptive analysis examines pre-service mathematics teachers' levels of critical thinking, computational thinking, and mathematical modelling based on data collected from a total of 140 respondents. In this section, the level of critical thinking of teachers was examined using mean and standard deviation analysis per construct. Critical openness and reflective scepticism are two sub-constructs of critical thinking. Table 5 presents the findings of the analysis.

Table 5. Descriptive statistics of critical thinking

Construct	Sub-constructs	Mean	Standard Deviation	Level
Critical Thinking	Critical openness	3.91	0.53	High
	Reflective skepticism	4.07	0.68	High
Overall mean		3.99	0.56	High

Table 5 reveals that the mean values for the sub-construct critical openness were (M = 3.91, SD = 0.53) and the mean values for the sub-construct reflective scepticism were (M = 4.07, SD = 0.68), indicating that reflective scepticism was the most prevalent and critical openness was the least prevalent. Overall, pre-service teachers assigned a mean value of M=3.99 and a standard deviation of 0.56 to the level of critical thinking. This indicates that a large proportion of pre-service mathematics teachers had strong critical thinking skills which enabled them to get to the root of problems and find reasonable solutions for modelling problems. The five sub-constructs of computational thinking were creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. The findings of the analysis are presented in Table 6.

Table 6. Descriptive analysis of computational thinking

Construct	Sub-constructs	Mean	Standard Deviation	Level
Computational Thinking	Creativity	4.00	0.77	High
	Algorithmic thinking	4.09	0.62	High
	Cooperativity	3.85	0.57	High
	Critical thinking	4.04	0.60	High
	Problem solving	3.97	0.53	High
Overall mean		3.99	0.44	High

The mean values for creativity were (M = 4.00, SD = 0.77) and for algorithmic thinking were (M = 4.09, SD = 0.62). Cooperation showed a mean of (M= 3.85, SD= 0.57), critical thinking showed a mean of (M= 4.04, SD= 0.60), and problem-solving showed a mean of (M=3.97, SD=0.44). The sub-construct with the highest mean was algorithmic thinking, and the sub-construct with the lowest mean was cooperativity. Overall, computational reasoning was rated positively by pre-service teachers (M = 3.99, SD = 0.44). Pre-service mathematics teachers rated themselves as having a high level of computational thinking, according to the findings [51], [52]. This section examines the teachers' level of mathematical modelling by analysing each construct using mean and standard deviation. The findings of the analysis are presented in Table 7.

Table 7. Descriptive statistics of mathematical modelling

Construct	Sub-constructs	Mean	Standard Deviation	Level
Mathematical modelling	Simplify assumptions	1.05	0.59	Moderate
	Explain the function of the real model	0.90	0.45	Low
	Formulate a particular problem	0.91	0.51	Low
	Assign parameters, variables, and constants	0.83	0.67	Low
	Formulate rational statements of mathematics	0.81	0.56	Low
	Pick a model	0.97	0.43	Low
	Construct graphical representations	1.21	0.71	Moderate
	Connect the mathematical solution to the real life	0.89	0.50	Low
Overall mean		0.93	0.26	Low

The mean value for the sub-construct "simplify assumptions" was (M= 1.05, SD= 0.59), the mean value for "explain the function of the real model" was (M= 0.90, SD= 0.45), the mean value for "formulate a specific problem" was (M=0.91, SD= 0.51) and the mean value for "assign parameters, variables, and constants" was (M= 0.83, SD= 0.67).The sub-construct with the highest mean value was creating graphical representations, while the sub-construct with the lowest mean value was formulating rational statements about mathematics. It can be seen that, on average, pre-service mathematics teachers rated the level of mathematical modelling as (M=0.93, SD=0.26). This indicates that the level of mathematical modelling was satisfactory to the teachers. It is possible to conclude that pre-service mathematics teachers rated their own mathematical modelling skills as low. This suggests that the majority of teachers rated themselves as having a partial understanding or a complete lack of understanding.

b. *Correlation Analysis*

Correlation analysis is employed to investigate the connection among the three variables being examined: critical thinking, computational thinking, and mathematical modelling within the population of pre-service mathematics teachers. The Table 8 below shows the result of findings obtained.

Table 8. Relationship between variables

		Mathematical modelling
Critical thinking	Pearson correlation (r)	0.207*
	P-value	0.014

The correlation analysis in Table 9 revealed a weak but significant correlation between critical thinking and mathematical modelling (r = 0.207, p 0.014). According to Salha and Qatanani [26], r =

0.207 indicated a significant relationship between pre-service mathematics teachers' critical thinking and mathematical modelling competency. A positive correlation between two variables indicates that as the value of one variable rises, so does the value of the other. Teachers with a high level of critical thinking would be proficient in mathematical modelling in this study [25]. As a result, the null hypothesis that "no significant relationship exists between critical thinking and mathematical modelling competency among pre-service mathematics teachers" was rejected. This suggests that among pre-service mathematics teachers, there was a significant correlation between critical thinking and mathematical modelling ability.

The correlation between computational thinking and mathematical modelling competency was significant but weak among pre-service mathematics teachers (r = 0.183, p 0.030). There was a significant relationship between computational thinking and mathematical modelling competence among pre-service mathematics teachers. A positive correlation between two variables indicates that as the value of one variable rises, so does the value of the other. In this study, pre-service teachers' mathematical modelling competency increased in direct proportion to their level of computational thinking. There was no correlation between computational thinking and mathematical modelling competence among pre-service mathematics teachers, according to the null hypothesis, H0. Based on the evidence, the null hypothesis was rejected (p = 0.030, r = 0.183). This suggests that among pre-service mathematics teachers, there was a significant correlation between computational reasoning and mathematical modelling ability.

To test the validity of the third null hypothesis, which asserts that there is no significant association between critical thinking and computational thinking among pre-service mathematics teachers, the correlation between critical thinking and computational thinking among this specific group was investigated. The results of the analysis are shown in Table 9.

Table 9. Relationship between critical and computational thinking

		Computational thinking
Critical thinking (n=140)	Pearson correlation (r)	0.846**
	P-value	0.000

The correlation analysis in Table 10 revealed that the correlation between critical thinking and computational thinking was statistically significant (r = 0.846, p = 0.000). r = 0.846 indicates a positive or direct high relationship between critical thinking and computational thinking among pre-service mathematics teachers. A positive correlation between two variables indicates that as the value of one variable rises, so does the value of the other. The higher the critical thinking, the higher the computational thinking among pre-service mathematics teachers. The null hypothesis, H0, states that there was no relationship between critical and computational thinking among pre-service mathematics teachers. Based on the findings (p = 0.000, r = 0.846), the null hypothesis was rejected. This suggests that critical and computational thinking had a significant correlation among pre-service mathematics teachers.

6. Discussion

The study unveiled its findings regarding the correlation between critical thinking, computational thinking, and mathematical modelling among pre-service mathematics teachers. Pre-service mathematics teachers demonstrated a high level of critical thinking (RO1), which is consistent with the findings of Zakaria et al. [54]. This finding is consistent with the findings of Abrami et al. [53], who discovered that teachers were able to improve their students' abilities after receiving training in critical thinking. Goodsett and Schmillen [25] assert that the reflective scepticism sub-dimension is a tool that can be used to conduct three interrelated intellectual operations that are essential to critical enquiry. Students can engage in this type of learning when confronted with situations that test their knowledge; for instance, when confronted with an unexpected event, they may need to develop their knowledge of how to deal with it. Moreover, critical openness can help students develop their own critical theory skills and connect with the experiences of others. Consequently, the level of critical thinking found among the pre-service teachers who participated in this study was comparable to that of previous research.

Pre-service mathematics teachers reported a high level of computational thinking (RO2). Pre-service teachers performed poorly on sub-construct cooperation [54]. Pre-service teachers performed well on the sub-constructs of creativity, algorithmic reasoning, problem-solving, and critical thinking [23]. As such, the teacher’s ability to teach computational thinking improved a lot after they used the computational thinking modules, which helped students figure out how to solve problems. The results of this study showed that the pre-service teachers who took part in this study had the same level of computational thinking as the people in other studies.

The study discovered that pre-service mathematics teachers had a low level of mathematical modelling competency (RO3). The current study's findings are similar to those of previous studies [1], [23]. Making rational statements about mathematics is another sub-construct in this study that had the lowest value, which is consistent with Leong and Tan's [1] assertion that study participants had difficulty making rational statements about how to solve problems, make assumptions, and use maths to solve problems. Anhalt [8] explains this by defending the claim that a cohort of pre-service mathematics teachers was prepared to deal with answer-dependent word problems. Regrettably, their inadequate comprehension of mathematical modelling hindered their ability to formulate an effective strategy. Students, in particular, struggled with posing a well-defined mathematical problem. Mathematical education majors in training have been found to be woefully ignorant of the pedagogical content of modelling tasks, conceptions, and dimensions [11]. According to the findings of Maaß [12] study, students had difficulty estimating the connection. One of the duties and responsibilities of the undergraduate mathematics education programme is to prepare teachers for the classroom. This study found that pre-service teachers' mathematical modelling competency was consistent with other studies.

In line with the claim made by Goodsett and Schmillen [25] that teachers with a high level of critical thinking would be skilled at mathematical modelling, pre-service teachers in this study showed a significant relationship between critical thinking and modelling competency (RO4). This assertion is supported by the research [26], which found that students' ability to work independently was influenced by how their critical thinking skills evolved while creating mathematical models. Introducing critical thinking early in a student's higher education experience aids in their understanding of critical thinking, enhances their skills in mathematical modelling competency, and promotes a structured and fair approach to these vital concepts.

The current study found a significant relationship between pre-service mathematics teachers' computational thinking and mathematical modelling (RO5). Chao [55] supports the finding that among pre-service mathematics teachers, computational thinking and mathematical modelling abilities were directly correlated. Computational thinking uses abstractions and reasoning methods that support and strengthen intellectual abilities and are thus applicable across domains. Loops, conditions, and the creation of algorithms are just a few examples of computational thinking elements that can be linked to a student's capacity to solve any modelling problem [55].

The current study found a highly significant correlation between critical thinking and computational thinking (RO6), which is consistent with the findings of study [28]. Students' mathematical abilities can benefit from explicit connections between critical thinking and computational thinking abilities. Students who have honed their critical thinking skills are more likely to think independently and creatively when faced with problems in their daily lives or at school. Furthermore, both critical thinking and computational thinking can be integrated into general education courses, which aids in curriculum development. Pre-service mathematics teachers can improve their computational abilities by practising reflective scepticism and openness, both of which are aspects of critical thinking. They are able to articulate and reason through a problem. As a result, students' analytical and predictive abilities improve, as does their overall intellectual capacity [33].

7. Conclusion

The objective of this study was to examine how pre-service mathematics teachers utilize critical thinking, computational thinking, and mathematical modelling, aiming to provide a contextual understanding and shed light on the implications of these findings for the field. Consequently, the modelling competency of pre-service mathematics teachers is enhanced by both computational thinking and critical thinking. The study's findings have the potential to increase awareness and reform within relevant organisations such as the State Education Department (JPN) and the Ministry of Education (KPM). Pre-service teachers can benefit from critical thinking and computational thinking. As a result, how a teacher teaches and how students learn in the classroom will have the greatest impact on how well they learn and perform in school. It will also improve their knowledge and way of thinking, allowing them to become more competent.

Even though mathematics lecturers instruct students, the study's findings will be useful to them. The lecturer is able to identify the areas of weakness of the pre-service teachers and develop innovative strategies and approaches to ignite the pre-service teachers' application of computational and critical thinking towards modelling competency. This could be a fantastic opportunity for educators to improve the mathematical instruction that their students receive.

8. Limitation of study and future work

Due to some limitations, this study only included participants who were at the beginning of their teaching profession as mathematics educators. Students who did not fall into this category may find the results ineffective. The demographic differences between the sexes were not taken into account in this analysis. We prioritised a candidate's level of competence over their learning philosophy or business savvy when deciding on a modelling approach. This is because students rarely have the opportunity to practise mathematical modelling throughout their academic careers. One way to evaluate the success of mathematical modelling is to examine how well students learned the necessary skills in school. In the future, researchers can add another variable which is modelling as a learning approach, to produce a more accurate analysis. To obtain more reliable data, the researcher can choose samples from universities and colleges that offer mathematics education. Researchers can also compare male and female abilities by including gender demography in their analysis. Another suggestion for future research to include regression analysis.

Acknowledgements

The author expresses gratitude to all those who contributed to this study, but especially to the students of the Teaching Institutes of Ipoh and Penang for their work in the Department of Mathematics Education.

References:

[1]. Leong, K. E. & Tan, J. Y. (2020). Exploring secondary students' modelling competencies. *The Mathematics Enthusiast, 17*(1), 85-107. Doi: 10.54870/1551-3440.1481

[2]. Leong, K. E. (2013). Mathematical modelling in the Malaysian secondary curriculum. *Learning Science and Mathematics Online Journal*, 8, 66-74.

[3]. Schukajlow, S., Kaiser, G., & Stillman, G. (2018). Empirical research on teaching and learning of mathematical modelling: A survey on the current state-of-the-art. *ZDM, 50*, 5-18. Doi: 10.1007/s11858-018-0933-5

[4]. Hidayat, R., Zamri, S. N. A. S., Zulnaidi, H., & Yuanita, P. (2020). Meta-cognitive behaviour and mathematical modelling competency: Mediating effect of performance goals. *Heliyon, 6*(4). Doi: 10.1016/j.heliyon.2020.e03800

[5]. Sriraman, B., & English, L. (2009). Surveying theories and philosophies of mathematics education. In *Theories of mathematics education: Seeking new frontiers*, 7-32. Berlin, Heidelberg: Springer Berlin Heidelberg.

[6]. Niss, M., Blum, W., & Galbraith, P. (2007). *Introduction*. In W. Blum, P. Galbraith, H. Henn, & M. Niss (Eds.), *Modeling and Applications in Mathematics Education: The 14th ICMI Study*, 3-32. New York: Springer.

[7]. Durandt, R., & Lautenbach, G. (2020). Strategic support to students' competency development in the mathematical modelling process: A qualitative study. *Perspectives in Education, 38*(1), 211-223. Doi: 10.18820/2519593x/pie.v38i1.15

[8]. Anhalt, C. O., Cortez, R., & Bennett, A. B. (2018). The emergence of mathematical modeling competencies: An investigation of prospective secondary mathematics teachers. *Mathematical Thinking and Learning, 20*(3), 202-221. Doi: 10.1080/10986065.2018.1474532

[9]. Zlatkin-Troitschanskaia, O., Pant, H. A., & Coates, H. (2016). Assessing student learning outcomes in higher education: Challenges and international perspectives. *Assessment & Evaluation in Higher Education, 41*(5), 655-661. Doi: 10.1080/02602938.2016.1169501

[10]. Julie, C. (2020). Modelling competencies of school learners in the beginning and final year of secondary school mathematics. *International Journal of Mathematical Education in Science and Technology, 51*(8), 1181-1195. Doi: 10.1080/0020739x.2020.1725165

[11]. Greefrath, G., Siller, H., Klock, H., & Wess, R. (2021). Pre-service secondary teachers' pedagogical content knowledge for the teaching of mathematical modelling. *Educational Studies in Mathematics, 109*(2), 383-407. Doi: 10.1007/s10649-021-10038-z.

[12]. Maaß, K. (2006). What are modeling competencies? *ZDM, 38*(2), 113-114. Doi: 10.1007/BF02655885.

[13]. Ghadi, I., Alwi, N. H., Abu Bakar, K., & Talib, O. (2012). Construct validity examination of critical thinking dispositions for undergraduate students in University Putra Malaysia. *Higher Education Studies, 2*(2), 138-150. Doi: 10.5539/hes.v2n2p138.

[14]. Palavan, Ö. (2020). The effect of critical thinking education on the critical thinking skills and the critical thinking dispositions of preservice teachers. *Educational Research and Reviews, 15*(10), 606-627. Doi: 10.5897/err2020.4035.

[15]. Lin, K., Yu, K., & Chang, S. (2017). The development and validation of a mechanical critical thinking scale for high school students. *EURASIA Journal of Mathematics, Science and Technology Education, 13*(5). Doi: 10.12973/eurasia.2017.00675a

[16]. Jiang, S., & Wong, G. K. (2019). Primary school students' intrinsic motivation to plugged and unplugged approaches to develop computational thinking. *International Journal of Mobile Learning and Organisation, 13*(4), 336. Doi: 10.1504/ijmlo.2019.10021903.

[17]. Sondakh, D. E., Osman, K., & Zainudin, S. (2020). A pilot study of an instrument to assess undergraduates' computational thinking proficiency. *International Journal of Advanced Computer Science and Applications, 11*(11). Doi: 10.14569/ijacsa.2020.0111134.

[18]. Mindetbay, Y., Bokhove, C., & Woollard, J. (2019). What is the relationship between students' computational thinking performance and school achievement? *International Journal of Computer Science Education in Schools*, *2*(5), 3-19. Doi: 10.21585/ijcses.v0i0.45.

[19]. Kaiser, G., & Schwarz, B. (2006). Mathematical modelling as a bridge between school and university. *ZDM, 38*(2), 196-208. Doi: 10.1007/bf02655889.

[20]. Ang, K. (2012). Mathematical modelling as a learning experience in the classroom. In *Electronic Proceedings of the 17th Asian Technology Conference in Mathematics*, Bangkok, Thailand, 16-20.

[21]. Barbosa, J. C. (2006). Teacher-student interactions in mathematical modelling In C. Haines, P. Galbraith, W. Blum & S. Khan (Eds.) *Mathematical modelling: education, engineering and economics*. Chicheter: Horwood Publishing.

[22]. Lingefjärd, T. (2006). Mathematical modelling in teacher education - Necessity or unnecessarily. In W. Blum, P. L. Galbraith, H.-W. Henn, & M. Niss (Eds.), *Modelling and applications in mathematics education, 10*, 333-340. Boston, MA: Springer US. Doi: 10.1007/978-0-387-29822-1_35.

[23]. Rochmad, Agoestanto, & Kharis, M. (2018). Characteristic of critical and creative thinking of students of mathematics education study program. *Journal of Physics: Conference Series*, *983*, 012076. Doi: 10.1088/1742-6596/983/1/012076.

[24]. Kaiser, G., & Brand, S. (2015). Modelling competencies: Past development and further perspectives. In Stillman, G., Blum, W., Salett Biembengut, M. (eds.) *International perspectives on the teaching and learning of mathematical modeling*, 129-149. Doi: 10.1007/978-3-319-18272-8_10.

[25]. Goodsett, M., & Schmillen, H. (2022). Fostering critical thinking in first-year students through information literacy instruction. *College & Research Libraries, 83*(1). Doi: 10.5860/crl.83.1.91.

[26]. Salha, S. H., & Qatanani, N. (2021). Impact of mathematical modeling on conceptual understanding among student-teachers. *Journal of Southwest Jiaotong University, 56*(5), 538-551. Doi: 10.35741/issn.0258-2724.56.5.49.

[27]. Kules, B. (2016). Computational thinking is critical thinking: Connecting to university discourse, goals, and learning outcomes. *Proceedings of the Association for Information Science and Technology, 53*(1), 1-6. Doi: 10.1002/pra2.2016.14505301092.

[28]. Lamb, R., Hand, B., & Kavner, A. (2021). Computational modeling of the effects of the science writing heuristic on student critical thinking in science using machine learning. *Journal of Science Education and Technology, 30*(2), 283-297. Doi: 10.1007/s10956-020-09871-3.

[29]. Angeli, C. (2022). The effects of scaffolded programming scripts on pre-service teachers' computational thinking: Developing algorithmic thinking through programming robots. *International Journal of Child-Computer Interaction,* 31, 100329. Doi: 10.1016/j.ijcci.2021.100329.

[30]. Ung, L., Labadin, J., & Mohamad, F. S. (2021). Computational thinking for teachers: Development of a localised E-learning system. *Computers & Education*, 177, 104379. Doi: 10.1016/j.compedu.2021.104379.

[31]. An Le, D. T., & Hockey, J. (2022). Critical thinking in the higher education classroom: Knowledge, power, control, and identities. *British Journal of Sociology of Education, 43*(1), 140-158. Doi: 10.1080/01425692.2021.2003182.

[32]. Denning, P. J., & Tedre, M. (2021). Computational thinking: A disciplinary perspective. *Informatics in Education, 20*(3), 177-198. Doi: 10.15388/infedu.2021.21.

[33]. Mafarja, N., & Zulnaidi, H. (2022). Relationship between critical thinking and academic self-concept: An experimental study of reciprocal teaching strategy. *Thinking Skills and Creativity*, 45, 101113. Doi: 10.1016/j.tsc.2022.101113.

[34]. Hancock, D. R., Algozzine, B., & Lim, J. H. (2021). *Doing case study research: A practical guide for beginning researchers.* New York, NY: Teachers College Press.

[35]. Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Thousand Oaks, CA: Sage.

[36]. Cohen, L., Manion, L., Morrison, K., & Morrison, K. (2005). *Research methods in education.* New York, NY: Routledge.

[37]. Boeren, E. (2018). The methodological underdog: A review of quantitative research in the key adult education journals. *Adult Education Quarterly, 68*(1), 63-79. Doi: 10.1177/0741713617739347.

[38]. Hidayat, R., Qudratuddarsi, H., Mazlan, N. H., & Mohd Zeki, M. Z. (2021). Evaluation of a test measuring mathematical modelling competency for Indonesian college students. *Journal of Nusantara Studies (JONUS), 6*(2), 133-155. Doi: 10.24200/jonus.vol6iss2pp133-155.

[39]. Hidayat, R., Idris, W. I. W., Qudratuddarsi, H., & Rahman, M. N. A. (2021). Validation of the Mathematical modeling attitude scale for Malaysian mathematics teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 17*(12), em2047. Doi: 10.29333/ejmste/11375.

[40]. Miksza, P., & Elpus, K. (2018). *Correlational design and analysis.* Oxford Scholarship Online. Doi: 10.1093/oso/9780199391905.003.0006.

[41]. Ary, D., Jacobs, L. C., & Razavieh, A. (2002). *Introduction to research in education* (6th ed.). USA.

[42]. Mulenga, E. M., & Marbán, J. M. (2020). Prospective teachers' online learning mathematics activities in the age of COVID-19: A cluster analysis approach. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(9). Doi: 10.29333/ejmste/8345.

[43]. Sarkar, A., Chakraborty, P., & Valeri, M. (2021). People's perception on dark tourism: A quantitative exploration. *Current Issues in Tourism*, *25*(13), 2042-2047. Doi: 10.1080/13683500.2021.1889483.

[44]. Krejcie, R. V., & Morgan, D. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, *30*, 607-610.

[45]. Haines, C., & Crouch, R. (2001). Recognizing constructs within mathematical modelling. *Teaching Mathematics and its Applications, 20*(3), 129-138. Doi: 10.1093/teamat/20.3.129.

[46]. Hernandez, J. A., Hernandez, H. M., Hernandez, L. A., & Julio, Y. F. (2017). Modeling and simulation of a high-pressure polyethylene tubular reactor. In 2017 *Congreso Internacional de Innovacion y Tendencias en Ingenieria* (CONIITI). Doi: 10.1109/coniiti.2017.8273320.

[47]. Sosu, E. M. (2013). The development and psychometric validation of a critical thinking disposition scale. *Thinking Skills and Creativity,* 9, 107-119. Doi: 10.1016/j.tsc.2012.09.002.

[48]. Mirahmadizadeh, A., et al. (2021). The correlation between temperature and COVID-19 incidence: An ecologic study. *Teaching Mathematics and Its Applications, 20*(3), 129-138. Doi: 10.21203/rs.3.rs-948329/v1.

[49]. Korkmaz, Ö., & Bai, X. (2015). Adapting computational thinking scale (CTS) for Chinese high school students and their thinking scale skills level. *Participatory Educational Research*, *6*(1), 10-26. Doi: 10.17275/per.19.2.6.1.

[50]. Fraenkel, J., Hyun, H., & Wallen, N. (2009). *How to design and evaluate research in education* (7th ed.). McGraw-Hill Education.

[51]. Chongo, S., Osman, K., & Nayan, N. A. (2020). Level of computational thinking skills among secondary science students: Variation across gender and mathematics achievement skills. *Science Education International*, *31*(2), 159-163. Doi: 10.33828/sei.v31.i2.4.

[52]. Yadav, A., Ocak, C., & Oliver, A. (2022). Computational thinking and metacognition. *TechTrends*, *66*(3), 405-411. Doi: 10.1007/s11528-022-00695-z.

[53]. Abrami, P. C., et al. (2008). Instructional interventions affecting critical thinking skills and dispositions: A stage 1 meta-analysis. *Review of Educational Research, 78*(4), 1102-1134. Doi: 10.3102/0034654308326084.

[54]. Zakaria, N. I., & Iksan, Z. H. (2020). Computational thinking among high school students. *Universal Journal of Educational Research, 8*, 9-16. Doi: 10.13189/ujer.2020.082102.

[55]. Chao, A. (2016). Real-life modeling within a traditional curriculum: Lessons from a Singapore experience. In G. Stillman, G. Kaiser, W. Blum, & J. Brown (Eds.), *Teaching modeling mathematical: Connecting to research and practice*, 131-140. Dordrecht: Springer.