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Developing a Grounded Theory of Computational Thinking Patterns in Pre-service Primary Teachers' Mathematical Problem Solving

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ABSTRACT

This research project will define and trace the features of computational thinking (CT) of pre-service primary school educators in solving contextual mathematics problems. The qualitative paradigm with grounded theory design was adopted, which allowed the development of the theory with the use of empirical data. The problem-solving test according to Polya steps and semi-structured interview aiming at four CT indicators decomposition, pattern recognition, algorithmic thinking, and debugging were used to collect the data. The analysis of data was conducted according to the model suggested by Gioia as it included open coding, first-order concepts, second-order themes, and aggregate dimensions. The findings showed that there are three different patterns of CT characteristics namely systematic-conceptual, pragmatic-exploratory, and procedural-linear, and the results demonstrate the difference in CT application between university students and the need to improve reflective thinking and strategic approaches in teacher education. The study will assist in designing computational thinking-based mathematics programmes and instruction methods in the primary school level.

Keywords: Computational thinking, grounded theory, mathematics problem solving, pre-service primary school teachers

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INTRODUCTION

Higher-order thinking skills (HOTS) in primary mathematics education are also on the rise in reaction to the rapid technological changes across the globe, and the increasing demands of the 21st century competences.

In this stage, mathematics is no longer taught with a focus on basic numeracy, but it is being taught in the direction of problem-solving skills, logical thinking, and specifically, computational thinking (CT). Similarly to the modern educational systems, which emphasise the importance of CT in equipping students with digital literacy, teacher education programmes are also bound to change (Garner et al., 2017; Nahdi, 2019). Consequently, pre-service teachers working at the primary school level are now obliged to acquire two essential skills, namely, having a strong proficiency in mathematical concepts and being able to use the CT strategies effectively in solving complex, real-life problems.

An emerging body of evidence indicates the significance of the incorporation of HOTS into the mathematics curriculum. The HOTS based assessment system and problem-based learning (PBL) methods have been revealed to effectively assist the process of developing student critical and creative thinking (Melawati et al., 2022; Memnun & Çoban, 2015; Rahmawati, 2023; Septriani et al, 2018; Vlasenko et al., 2020). These strategies are especially useful in case of structured problems-solving activities which need cognitive profundity and strategic thinking. Furthermore, they have a great potential of developing CT at a young age (Apriani et al., 2024; Putriani et al., 2022).

Moreover, the strategies of mentoring teacher professional development, including mathematics teacher's circles, instructional modules integrated with CT, have also helped enrich the teaching knowledge of teachers on mathematical problem-solving strategies and innovative teaching practices (Gioia et al., 2012; Gurat, 2018; Jusmawati et al, 2021). The fact that pre-service teachers can work with mathematical literacy problems is strongly correlated with their willingness to develop the same in their learners (Febrianti et al., 2023; Lloyd, 2018; Novita et al., 2022; Suseelan et al., 2022). This indicates the necessity to equip pre-service teachers to not just have a good base of mathematical knowledge, but also to have instructional methods that would go beyond conceptual and procedural fluency.

The concept of computational thinking (CT) has also been recognised as one of the core competencies of the 21st century, which is kept by the rise of the increasingly digitalised world. Nordby et al. (2022) state that CT entails the mental activities that exist to put the problems and formulate solutions that can be implemented effectively both by machines and humans. In its most basic form, CT has several interconnected elements, such as decomposition, pattern recognition, abstraction, and algorithm construction (Holland, 2012, Nordby et al., 2022; Resnick, 1996; Supiarmo et al., 2022). These elements are directly related to the nature of mathematical reasoning, which is why the inclusion of CT in mathematics instruction is not merely a rational move, but one that would provide value to students in their learning processes (Nordby et al., 2022).

It is against this background that exploratory research was carried out in the study aimed at exploring the manifestations of CT in the mathematical reasoning of pre-service primary school's teachers. The researchers used a contextual problem as a food delivery task whereby the participants were requested to calculate the quickest delivery path using a scaled map. The given assignment demanded that the participants should separate the problem into smaller segments including the identification of location points, obligatory stops and potential routes, the identification of spatial patterns and the creation of an effective delivery route. As shown in Figure 1, the participants were tasked with converting scaled distances to actual distances in order to calculate the best route. These exercises represent major aspects of CT implemented in a real-world scenario (Ninnuan & Wongsaphan, 2022; Pradana, 2024; Salsabila et al., 2024; Sumartini, 2018).

The research results showed that there were several different problem-solving strategies and that there are procedural strategies that rely on linear calculations, but as well as conceptual ones that are based on the contextual understanding and estimation. This difference shows that there are varying inclinations in the use of CT, and it is imperative to comprehend the way pre-service teachers internalise CT.

Such results also attract a gap in the current literature. Despite the extensive research on the topic of student learning and higher education based on CT, there are only a few studies that specifically investigate the manifestations of CT in the problem-solving process of pre-service teachers, especially in the field of mathematics education (Yadav et al., 2014; Yadav et al., 2016; Yadav & Chakraborty, 2023; Zhang et al., 2024). Such a loophole is alarming since considering the strategic role that pre-service teachers can assume when introducing CT to learners.

It has also been found out that to successfully incorporate CT into math curriculum, the pre-service teachers must not only be familiar with the elements of CT, but also how the elements relate to mathematics pedagogy (Albayrak, 2021; Angraini et al., 2024; Kang et al., 2022; Maharani et al., 2023). Without this knowledge, any attempts to implement

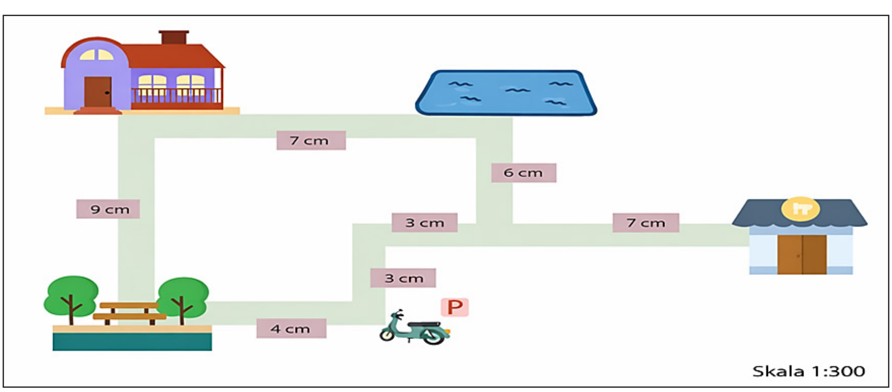


Figure 1. Test item: Online driver and Scaled Distance Conversion

CT in the classroom activity run the risk of losing its unity and efficiency.

To address this requirement, the current research will map and investigate the computational thinking patterns of pre-service primary school teachers using a qualitative method. Using the grounded theory methodology, the study does not have an established theoretical framework; rather, it permits categories and concepts to emerge throughout the problem-solving process by participants. This method is especially appropriate to the development of new theoretical proposals based on the empirical experience, and this is particularly relevant to such unexplored areas as CT in teacher education.

The paper aims at developing a preliminary conceptual framework that will describe the way of pre-service primary school teachers exhibit CT in solving mathematical problems. It is hoped that the results will be used in shaping teacher education curricula and the instructional design by providing deeper understanding of how the CT skills can be effectively fostered in mathematics learning and how the CT patterns of the pre-service primary teachers are manifested in their contextualised mathematics problem solving process.

This study offers a novel contribution by systematically mapping computational thinking (CT) patterns of pre-service primary school teachers during contextual mathematical problem-solving using a grounded theory approach. Unlike prior studies that predominantly employ quantitative measurements of CT skills or focus on student populations, this research develops an empirically grounded typology of CT thinking patterns systematic conceptual, pragmatic exploratory, and procedural linear based on authentic problem-solving processes. This typology extends existing CT frameworks by elucidating how CT indicators interact dynamically during problem solving in teacher education contexts.

LITERATURE REVIEW

21st Century Mathematics Education and the Role of Computational Thinking

The 21st century mathematics requires more than simple numeracy. It has been directed to the creation of Higher-Order Thinking Skills (HOTS), which comprise problem-solving, logical reasoning, and creativity (Bachman & Liu, 2015; Nahdi, 2019). Computational thinking (CT) can be discussed as one of the methods which best endorse this educational change the possibility to think in a systematic and algorithmic way in solving complex tasks (Grover & Pea, 2013). CT is commonly perceived to be very consistent with the aims of the modern curricula, because it makes the learners see the patterns, filter the relevant information, and create logical and step-by-step solutions (Angraini et al., 2024; Nordby et al., 2022).

According to the pedagogical content knowledge model (Shulman, 1986), the teacher should not just master mathematical concepts, but he or she should also know how to teach the mathematical concepts in a meaningful way. Thus, it is necessary to integrate the idea of CT in teacher teaching. Grover and Pea (2013) and Yadav et al. (2014) stress that CT should be a definite part of teacher education programmes to ensure that pre-service teachers can instil this mode of thinking in learning throughout the curriculum in a contextualised way.

Computational Thinking in the Mathematical Problem-solving Process

The Polya problem-solving model is particularly well suited to support the development of Computational Thinking (CT) because its sequential stages closely align with the core CT components of decomposition, pattern recognition, algorithmic thinking, and debugging. In the problem comprehension stage, learners decompose complex problems into smaller, manageable components, which reflects the decomposition process in CT. During the planning phase, students engage in pattern recognition by identifying relationships, similarities, and constraints within the problem structure. The execution stage corresponds to algorithmic thinking, as learners design and implement step-by-step solution procedures. Finally, the evaluation stage explicitly supports debugging, where students review their solutions, identify errors, and refine their strategies.

Empirical studies have demonstrated that classroom implementations integrating Polya's model with CT principles enhance students' strategic and reflective thinking in mathematics. For example, Maharani et al. (2019) reported that students who solved contextual mathematical problems using Polya-based CT activities showed improved ability in algorithm design and solution optimisation. Similarly, Gunadi et al. (2023) found that inquiry-based mathematics instruction grounded in Polya's problem-solving stages facilitated students' use of decomposition and error-checking strategies, leading to more efficient and accurate problem-solving outcomes. These classroom-based findings support the suitability of the Polya model as a pedagogical framework for fostering computational thinking within mathematics education, particularly in teacher preparation contexts.

Pre-service Teachers Readiness in Implementing CT

One of the aspects, that would make the process of implementing the approach in mathematics teaching effective, is the readiness of pre-service primary school teachers to implement CT. This training will include the comprehension of the concept of CT, the experience in the pedagogical process, and the self-efficacy of its application in the classroom (Butler and Leahy, 2020; Yadav et al., 2016). Research shows that the incorporation of CT in teacher education curriculum will raise cognitive and affective readiness of pre-service teachers (Caskurlu et al., 2021; Kang et al., 2023).

School experiences of professional placement are also important in preparing this readiness. Pre-service teachers will have their preparedness to implement CT in the real classroom enhanced by being encouraged to use inquiry-based methods and be reflective by field mentors (Poulton & Golledge, 2024). Moreover, the simulation through technology enables the pre-service teachers to model CT in contextualised and complex problem-solving situations (Butler & Leahy, 2020).

Conceptual Relationship between CT, Problem-solving, and Professional Development

CT is the transition between conceptual learning of mathematics and its use in the teaching practice. With CT implemented as a part of teacher training, pre-service teachers not only get the opportunity to think mathematically but can also choose adaptive and transformative teaching strategies (Navarro & de Sousa, 2023). Angraini and Abdurrahman (2024) highlight that contextualised problem-solving tasks and curriculum development with the help of technologies can be rather effective in enhancing the CT readiness of pre-service teachers.

CT has demonstrated empirically to enhance student achievement in mathematics. Yadav et al. (2016) discovered that students that had been taught using a CT-based method had a higher comprehension of the concepts compared to the control group. This brings out the fact that the knowledge, and implementation of CT by teachers directly affect the quality of student learning outcomes.

Lastly, the incorporation of CT into mathematics instruction is supported in a constructive and stimulating manner through constructivist strategy and gamification (Angraini et al., 2024; Soboleva et al., 2021). Pre-service teachers who are trained under these frames will prove to be better placed to mentor the students to think in the 21st century skills.

METHODOLOGY

This study employed a qualitative research design using a grounded theory approach to explore and conceptualise patterns of computational thinking (CT) demonstrated by pre-service primary school teachers in solving contextual mathematics problems. Grounded theory was selected because the aim of this research was not to test or confirm an existing theoretical framework, but to generate an empirically grounded conceptual understanding of how CT manifests through participants' problem-solving processes.

Computational thinking represents a complex, process-oriented construct that is often embedded in cognitive actions such as problem decomposition, strategy selection, algorithmic sequencing, and reflective evaluation. These dimensions are not directly observable through outcome-based assessments alone. Grounded theory is therefore methodologically appropriate, as it enables theoretical categories to emerge inductively from participants' actions, explanations, and reflections during problem-solving activities through systematic coding and constant comparative analysis (Charmaz, 2014; Glaser & Strauss, 1967).

The analytic procedures of open coding, axial coding, and selective coding were used to identify recurring problem-solving actions and reasoning strategies, which were subsequently conceptualised into higher-order categories representing distinct computational thinking patterns. This approach ensures a strong alignment between the empirical data, the analytical process, and the theoretical constructs under investigation, allowing the resulting framework to remain closely grounded in participants' authentic cognitive experiences.

Location and Research Subject

The research was carried out in Primary School Teacher Education (PGSD) programme (Figure 2). The study participants were chosen using the purposive sampling technique depending on various factors: they had to be seventh-semester students having taken up courses in Fundamental Concepts of Mathematics and Models of Mathematics Instruction in primary schools, had been taught problem-solving and CT, and were willing to participate throughout the research process. The selection of participants with different academic backgrounds was to investigate a broad spectrum of CT features in the solving of mathematical problems with the Polya problem solving framework.

Two kinds of instruments were used in this study. The former was a CT-based problem-solving test, which was aimed at testing the skills of students in solving problems through a computational thinking model, which follows the stages of problem-solving, as proposed by Polya. All the items in the test were associated with four stages (understanding the problem, identifying the important information, and finding the focus of the problem; planning an answer, and designing strategies and procedures; carrying out the plan and implementing the selected procedures; and evaluating the outcome, checking the correctness, and completeness of the solution).

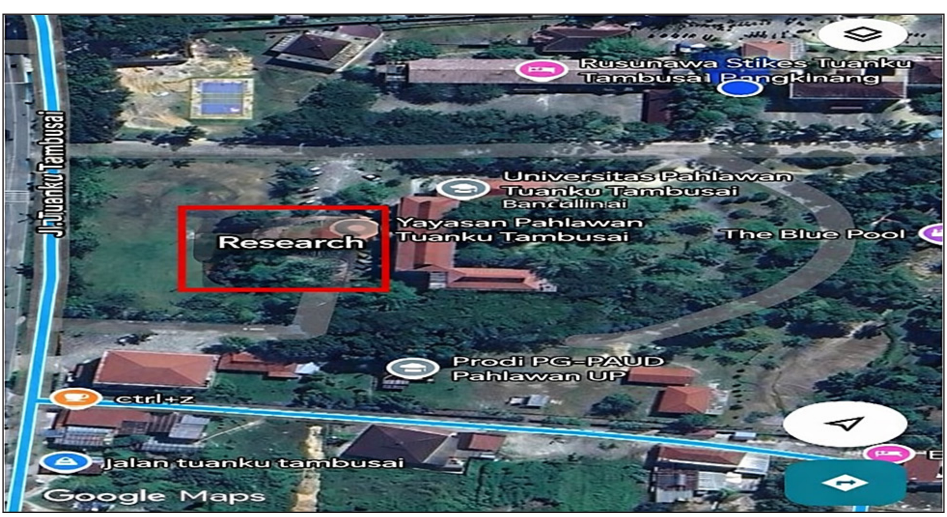


Figure 2. Map location research

The second tool was a semi-structured interview guide, which was to investigate the thought of reflection that students underwent when utilising CT steps in solving problems. The interviews also centred on the main aspects of CT including decomposition, pattern recognition, abstraction, and algorithm design, and in addition they centred on the methods used by the students in making their decisions and it is also about how they evaluated their solutions.

The research process started with the students who qualified the set criteria to take part in the study being chosen. Then the participants involved were requested to solve a problem on their own. During this, the researcher followed and made notes of the strategies employed by every student. The semi-structured interviews were held after the test, to investigate the thinking and strategies behind every step that they used to solve the problem. Lastly, data triangulation was enhanced by collecting and analysing the written responses and the transcripts of interviews made by the students.

Data analysis was done according to the method suggested by Gioia et al. (2012), which involves several steps. The initial concepts were discovered by first analysing interview transcripts and problem-solving responses using open coding. These ideas were further classified into first-order categories with similar meaning. In the second step, second-order themes were formulated that are more abstract to interrelate the first-order categories. Lastly, such themes were condensed into aggregate dimensions that formed the basis of formulating grounded theory. This procedure enabled the researcher to develop a holistic picture of the nature of CT among the students in the context of solving mathematical problems.

To make the data credible, both methodological and source triangulation was used in this study. The triangulation was done through the combination of problem-solving tests, the reflective interviews, and observations. Besides this, the accuracy of data interpretation was checked with the help of member checking and peer discussions. Such measures contributed to the reduction of researcher bias and the fact that the developed theory like the realities of the field.

RESULTS

This section will present the research results of the nature of CT exhibited by the pre-service primary school teachers (PGSD students) to resolve mathematical problems in the Polya problem-solving framework. The problem-solving test which was used to collect data was aimed at investigating four primary CT indicators decomposition, pattern recognition, algorithm design, and error checking (debugging).

The sample comprised 150 final year students who had gone through course work that concerned mathematics education and computational thinking. The analysis of the data was based upon three-stage coding including open coding, axial coding, and selective coding. This was done to determine the degree to which the participants were interacting with the CT indicators when solving mathematical problems.

The qualitative analysis revealed differences in the degree of participants' engagement across each CT indicator. In the first stage, all participants were coded. Subsequently, an in-depth analysis was conducted on the first ten participants, who were selected to represent the broader population, in order to provide a more detailed description of the identified CT patterns, as presented in Table 2. The overall distribution of engagement across the four CT indicators is presented in Table 1. As shown in Table 1, decomposition had the highest number of engagements (142), followed by pattern recognition (130), algorithm design (125), and debugging (113). Furthermore, the total number of participants who demonstrated characteristics associated with each CT indicator is displayed in Table 3. As indicated in Table 3, decomposition was demonstrated by 136 participants, algorithm design by 128 participants, pattern recognition by 120 participants, and debugging by 97 participants.

Table 1
Coding distribution of 150 pre-service teachers displaying CT indicator for all participants

CT Indicator	Number of Engagements
Decomposition	142
Pattern Recognition	130
Algorithm Design	125
Debugging	113

Table 3
Total number of participants who demonstrated characteristics of each CT indicator

CT Indicator	Number of Participants
Decomposition	136
Pattern Recognition	120
Algorithm Design	128
Debugging	97

In the decomposition sub-aspect, most of the pre-service primary school teachers displayed much strength in the aspect of decomposing problems that are complex to complex structure of solutions. This was reflected in the way they indicated all the checkpoints (nodes) of the problem,

Table 2
Distribution of the first 10 pre-service teachers

No.	Decomposition Pattern	Recognition	Algorithm Design	Debugging
1	3	2	3	1
2	2	2	3	2
3	4	3	4	2
4	3	2	3	1
5	3	2	2	2
6	2	1	2	1
7	3	2	3	2
8	4	3	4	2
9	2	1	2	1
10	3	2	3	2

beginning with the starting point (A) to the endpoint (G). Considering the case of one student, he said: *"First, I marked all the points from A to G, then I looked at which routes could be taken. I also checked which ones couldn't be used because they had a no-entry sign"* (Participant 07).

In addition, students were able to classify existing information, such as the distances between nodes, which were expressed using indirect mathematical forms, for instance, square root notation like $\sqrt{27}$, basic operations such as $4 \times (16 \div 2)$, or percentages like $20\% \times 60$. One participant described this process by stating: *"I noticed some of the distances were written with roots or percentages, so I calculated each one first to find out the actual lengths"* (Participant 12).

Furthermore, the students were also able to break down longer routes into manageable combinations of smaller segments. Among the routes they proposed were A–B–C–E–F–G, A–G, and A–D–E–F–G. This indicates an understanding of how to construct solutions from smaller and discrete components. One of the participants said: "*I started by listing several possible paths from A to G, for example, going through B or directly to G, and then I calculated which one was the shortest"* (Participant 21).

Some students even identified critical elements on the task map, such as restricted paths and letter markers on stones at each node, which they used to systematically organise information. One of them noted: *"At each point, I made small notes like the distance and whether it could be passed or not, so I wouldn't get confused when adding them up"* (Participant 03).

This decomposition strategy proved to be effective in helping students narrow down alternative solution and simplify total distance calculations. One student described their approach to streamlining the route selection process: *"Instead of trying every route, I picked the one that seemed to have the fewest points first, because it was more likely to be shorter"* (Participant 16).

Overall, the decomposition skills demonstrated by the pre-service primary school teachers in solving contextual mathematical problems reflected a strong conceptual understanding, both in recognising problem structures and in deriving more efficient solution strategies.

Pattern recognition is a critical aspect of computational thinking as it enables pre-service teachers to identify hidden structures or recurring elements within a problem. In this study, many students showed the ability to recognise patterns in distance labels, particularly those presented in indirect mathematical forms such as square roots, percentages, or mixed operations. One of the participants reflected: *"I first looked at all the numbers some used roots, some used percentages, then I converted them into ordinary numbers. For example, $\sqrt{27}$ is about 5 point something, and 20 percent of 60 is 12"* (Participant 14).

This excerpt illustrates the students' ability to simplify mathematical expressions into more concrete numerical values. This skill is crucial as it facilitates the comparison between possible routes and serves as a foundation for identifying patterns of efficiency.

In addition, students demonstrated the ability to recognise structural features of the routes presented in the visual map. Most participants were able to identify point G as the end destination and understood that certain symbols (such as prohibition signs) indicated impassable routes. *"I first marked the final point, which is G. Then I crossed out all the paths with prohibition signs. So, I only looked for the ones I could still use"* (Participant 06).

This statement shows that the participant was able to categorise visual information based on certain characteristics such as recognising valid and invalid patterns in the route selection process. Such ability shortens the exploration process and eliminates irrelevant options.

However, not all students were able to recognise patterns of efficiency. Some attempted to calculate the distance of every possible route without filtering them based on indicators such as relatively large or small numerical values, which led them to choose longer routes without considering efficiency from the beginning. *"I just tried all the routes first. The numbers were confusing, some were big, some were small, but I couldn't immediately tell which was shorter"* (Participant 17).

This response suggests that some students still faced challenges with pattern abstraction, which is drawing general rules or trends from the available numerical data. This limitation affected the efficiency of their problem-solving strategies.

In contrast, students with stronger skills were able to quickly simplify the given values and construct a comparison scale between possible routes. This allowed them to identify shorter paths with greater ease. *"If I see that the distances are small, it probably means that route is shorter. So, when I see large numbers, like 106, I avoid them straight away"* (Participant 10).

This planning represents an ability to make decision on a pattern-oriented elimination whereby the respondents judged route values by mathematical patterns and number logics instead of by visual sequence only.

Overall, the aspect of pattern recognition in the given study suggests that most of the students could have read and interpreted the numerical as well as the visual form of the problem. Despite the different degree of analysis and effectiveness of the applied strategies, the skill to identify the symbolic and spatial patterns proved to be one of the major strengths in resolving contextual mathematical problems in a successful manner.

In this area of algorithm design, pre-service primary school teachers were found to be different in their capability to create methodical steps in determining the shortest and longest paths of point A to G. It is a practice of a systematic use of computational thinking, especially in the field of algorithm design, which focuses on the rational and effective order of solution steps.

One of the strategies employed by students was to outline route options in the form of tables or lists of combinations. This served as the foundation for calculating distances and selecting the optimal solution. Participant 9 said *"I created a table of all routes from A to G, then calculated the distances one by one. If any route already looked too long, I immediately eliminated it from my options"* (Participant 09).

Such a reaction suggests that the participant noted the necessity to organise tracks and create a rational process, not only to visit all tracks but also to use preliminary methods of elimination. This kind of mentality is efficient in thinking and value-based decision making.

But elimination was not the main strategy used by all students. Some took a brute force approach and tried all the possible paths between the starting point and the end point to come up with what they thought was the most correct solution. Participant 4 said *"I explored every possible route from A to G and calculated each total distance. It was a bit exhausting, but I wanted to be sure I found both the shortest and longest paths"* (Participant 04).

This strategy represents the exhaustivity of the search of the entire solution space of the students, although it is not yet the most efficient. Early mastery of algorithm design, but not optimised in strategy, is usually signalled using brute-force methods.

The other major move taken by students was to expression mathematical formulas like a root, percentage, or compound operations to simplified numerical values and then continue with calculations. *"I converted the distances with roots and percentages into ordinary numbers first, so it would be easier to add them later"* (Participant 18).

This quote indicates the realisation that, in terms of designing algorithms, pre-processing is crucial to make information simple to provide a reliable assessment. This is one of the major aspects of good problem representation. In addition, reflective thinking was also reflected by students in choosing the strategies of problem-solving considering the extreme values of some routes. *"If the route goes through F, it seems longer because the value from E to F is already high. So, I tried looking at the ones that go through B or D first"* (Participant 13).

This is a demonstration of the application of heuristic judgement where the students determined the probable events by relying on initial indications and then did a complete calculation. It implies that the focus is on a transition between the purely exploratory processes to the more selective and strategic thinking. Lastly, there were students who could develop a full algorithm to completion by using a logical step by logical step sequence. *"First, I identified the points, then I calculated all the distances. After that, I worked out all the combinations from A to G. I put everything in order"* (Participant 20).

This quote is an example of how a student can develop an algorithm as an integrated process, therefore demonstrating the skills in sequencing in computational thinking. A characteristic feature of good algorithm design is the systematic organisation of steps. In general, the results concerning the design of the algorithm suggest that most of the students were able to arrange the logical steps to complete mathematical tasks. Although there was variation as far as efficiency and strategy was concerned, the overall trend is students could think procedurally and systematically handle information to arrive at a solution.

The process of determining and rectifying mistakes during or after problem solving, the debugging stage, showed that the pre-service primary school teachers had significant differences in their capability. It is the level of metacognitive awareness of the students, especially their ability to notice logical inconsistencies in their work.

Several students showed high levels of detection and correction of errors. They recalculated their calculations particularly when the final outcomes seemed unrealistic or contrasted with their previous estimates. *"At first, I got 140, but it seemed too long, so I went back to check the root and percentage calculations. It turned out that I miscalculated 20% × 60"* (Participant 08).

This reaction shows the capacity of the student to think critically about an irrational outcome and a desire to go back. The reflection of this type is also one of the most important components of debugging within the framework of computational thinking.

Alternatively, a few students were more proactive, and they would check the values of symbolic mathematical components like square roots and percentages before going to the next step. This implies making sure that errors do not occur in the first place. *"Before I added everything up, I made sure I knew the exact value of √27. If I wasn't sure, I used a calculator just to be certain"* (Participant 11).

Nonetheless, all students did not exhibit the competence of this step. Others did the job without reviewing their work and thus ended up making mistakes that went unnoticed and most of the time were those involving simple conversions or omission. *"I thought the result was correct because I followed all the steps. But when the lecturer checked it, the distance was too much because I forgot to count one of the paths"* (Participant 19).

It seemed that students in this group were following a procedure and a mechanical method without reflecting and evaluating finally. This implies that there is a weakness in metacognitive awareness that is essential in the learning process using CT. According to the open and axial coding done in the process of data analysis based on the grounded theory, three primary categories of the characteristics of the computational thinking were observed among the pre-service teachers and they were seen as:

Students in this category demonstrated a high level of proficiency across all CT indicators: decomposition, pattern recognition, algorithm design, and debugging. They were able to construct strategies based on the structure of the problem, filter options early in the process, and systematically verify their results. *"I started by analysing all the possible routes, then ordered them based on their lengths. If any of the calculations seemed off, I checked them again until, I was sure"* (Participant 02) as shown in Figure 3.

From the analysis of one of the research participants, it appears that pre-service

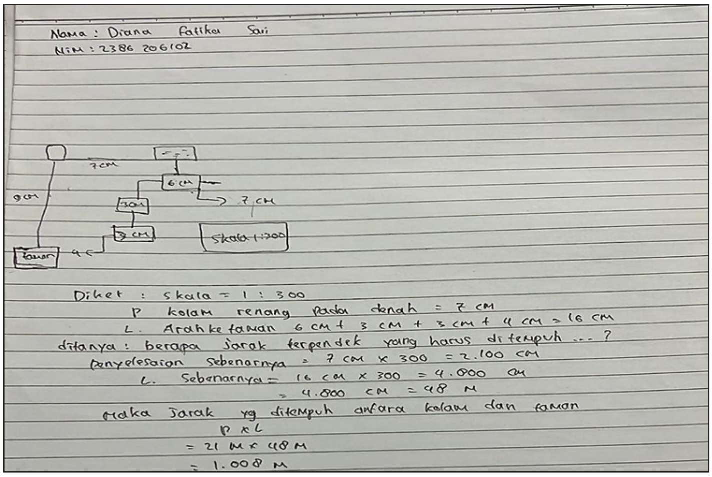


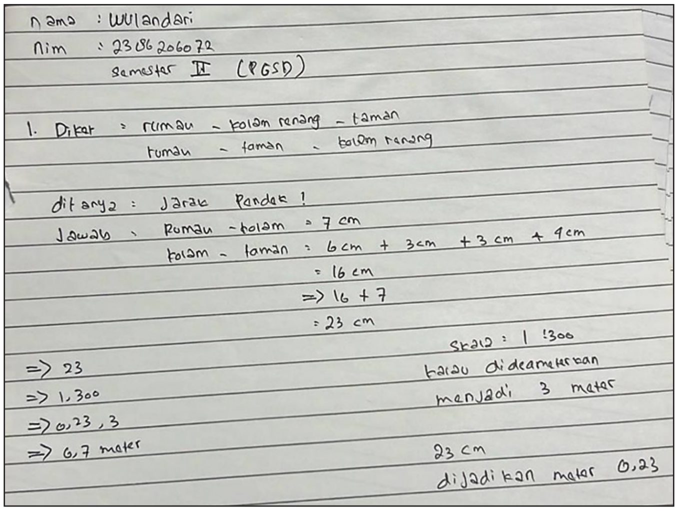
Figure 3. Work sample from participant 2

teachers showed a systematic–conceptual pattern of thinking, characterised by reflective, efficient, and comprehensive problem-solving, supported by a strong understanding of the task structure. The participant employed map visualisation, logically compared alternative routes, and applied CT principles effectively, making them a representative example of a pre-service teacher well-prepared to integrate CT into classroom practice.

This group showed reasonably strong abilities in decomposition and algorithm design but demonstrated inconsistencies in pattern recognition and debugging. They explored various alternative solutions, though their approach was not always effective in filtering options or correcting errors. *"I created a few different routes and tried them one by one. If one seemed too long, I moved on to another. But sometimes I forgot to double-check the results"* (Participant 13) as shown in Figure 4.

The pragmatic-exploratory thinking pattern was observed in one of the participants through his problem-solving approach. Although the pre-service teacher could develop systematic steps, the process was mostly a trial-and-error one. The participant has not screened route choices effectively at the beginning and was not very reflective or evaluative of the result. This implies that there should be increased metacognitive awareness and problem-solving strategies.

Pre-service teachers in this category tended to follow procedural steps without developing exploratory strategies. Their focus was on completing the task using methods previously taught, with minimal reflection or evaluation of the process. *"I just followed the steps like we were taught. From A to G, I just calculated directly, I didn't think about other ways"* (Participant 20) as shown in Figure 5.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semester II (PGSD)
1. Diket = rumah – kolam renang – taman
rumah – taman – kolam renang
ditanya : Jarak Pendek !
Jawab : Rumah – kolam = 7 cm
kolam – taman = 6 cm + 3 cm + 3 cm + 4 cm
= 16 cm
=> 16 + 7
= 23 cm
Skala : 1 : 300
kalau dideameterkan
menjadi 3 meter
=> 23
=> 1.300
=> 0,23 , 3
=> 0,7 meter
23 cm
dijadikan meter 0,23

Figure 4. Work sample from participant 13

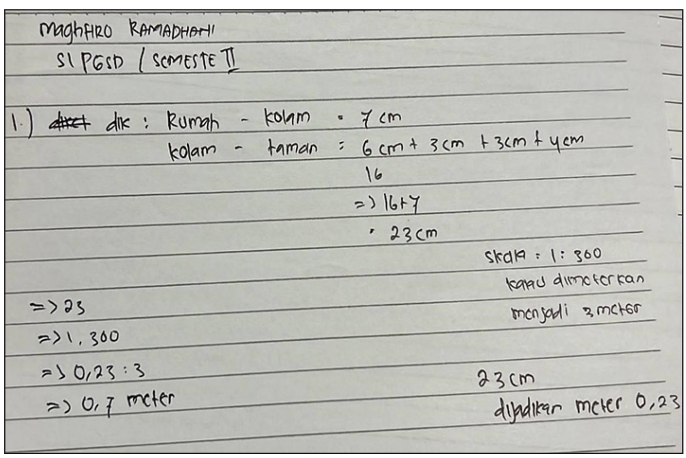
MAGHFIRO RAMADHANI
S1 PGSD / SEMESTE II
1.) dik : Rumah – kolam = 7 cm
kolam – taman = 6 cm + 3 cm + 3 cm + 4 cm
16
=> 16+7
= 23 cm
Skala : 1 : 300
kalau dimeterkan
menjadi 3 meter
=> 23
=> 1 , 300
=> 0,23 : 3
=> 0,7 meter
23 cm
dijadikan meter 0,23

Figure 5. Work sample from participant 20

All these three types represent a continuum of computational thinking styles with one end being conceptual and reflective to the other one being more procedural and mechanical. The results are important in informing the pedagogical interventions in teacher education. They emphasise the need to train more pre-service teachers into becoming strategic thinkers who approach mathematical problem-solving thinking adaptively and reflectively.

One of the interviewees demonstrated procedural linear type of thinking with an inclination towards finding mechanical solutions to problems without reflective and optimisation strategies. The participant used the simplest procedures and did not strive to assess the efficiency of the route or debug, which indicates that the participant did not apply the most sophisticated computational thinking to the problem-solving process.

DISCUSSION

Theoretically, this study contributes to the growing literature on computational thinking by advancing an empirically derived model that conceptualises CT as a continuum of thinking patterns rather than a set of isolated skills. While previous studies have operationalised CT primarily through discrete indicators, the present findings demonstrate how these indicators co-occur and interact within authentic mathematical problem-solving activities. This grounded typology provides a nuanced theoretical lens for understanding CT development in pre-service teachers.

The results of this research show that pre-service primary school teachers have different degrees of capability in implementing the concept of computational thinking (CT) to the contextual mathematical problems. The strategies used by the participants were found to have all four CT indicators, decomposition, pattern recognition, algorithm design, and debugging, with varying levels of proficiency (Kannadass et al., 2023; Yadav et al., 2016). These findings point to the multiplicity of methods used and emphasise the importance of enhancing every aspect of CT in teacher preparation programmes.

Among the four indicators that have been observed, decay stood out the most. Most students could reduce complex issues into smaller and manageable sections. This observation is consistent with the studies that have proposed decomposition to be a core component of computational thinking, which allows a person to build solutions based on simpler parts and justify statements in the existing literature (Nordby et al., 2022; Yadav et al., 2016). This skill not only benefits students in solving problems, but it also demonstrates the mastery of the Polya mathematical problem-solving model, especially the stage of cognising the problem (Angraini et al., 2024).

This skill in decomposition implies that students have learned constructivist-oriented learning processes, in which knowledge is gained and arranged based on tangible experiences (Angraini et al., 2024). This is most vital in primary education where the teachers need to have the capacity of presenting mathematical problems in a conceptual and visual manner that is comprehensible. Pre-service teachers with high levels of decomposition would also be in a better position to simplify and present mathematical problems of the complex nature in an easy way that would be comprehended by their students (Albayrak, 2021; Mohmad and Maat, 2024).

Pattern recognition indicator was observed to develop among some of the participants in this study. Such students were also able to determine recurring mathematical concepts like square roots, percentage operations, and prohibition symbols to the task map. Nevertheless, even with this development, some participants could not simplify mathematical expressions even at the beginning of the process, which led to inefficient strategies. This observation points to the deficiency in abstract and symbolical reasoning in the students (Andrian et al., 2021; Kang et al., 2022).

The literature has indicated that pattern recognition within the CT helps to solve problems more efficiently because it will allow the elimination of suboptimal solutions at the initial stage (Kang et al., 2022). Pattern-recognition skill enables the students to select shorter and more efficient methods in resolving problems. Regrettably, the students who are not used to simplifying the value will choose longer defining paths of solutions, which insinuates that the process of recognising the patterns is not an automatic process in the thinking yet (Yokuş & Kahramanoğlu, 2022).

This aligns with the studies that highlight the relevance of pattern recognition in mathematics learning and CT, wherein organised and efficient thinking is the main factor in solving problem-related issues (Y. Li et al., 2020). In this regard, learners who can successfully use pattern recognition have a higher probability to become faster and more accurate in solving mathematical problems contributing to the formation of the critical thinking skills (Diantary & Akbar, 2022).

In general, although one might see a certain level of achievement in the field of pattern recognition, such crucial skills as simplifying mathematical problems should be enhanced. This skill will not only help the students in their academic activities but will also equip them to be pre-service teachers (Fauzi et al., 2022).

The indicator of the algorithm design was strongly observed in students who systematised their solution. They showed abilities in planning routes sequentially, calculating values, and finding the best solutions. Such a strategy represents a logical sequencing and structured thinking, both of which are basic elements of computational thinking (Supiarmo et al., 2022).

Practically, the students that tried all possible paths and compared the distance were more likely to adopt a brute-force solution. There were however other students who showed that they could use the early elimination techniques, such as automatically shunning routes with greater weights. The skill signifies an increasing ability to optimise solution strategies that is needed in creating effective algorithms and finding solutions efficiently (Esteve-mon et al., 2020; Kumala et al., 2023).

Not every student, however, could use effective algorithmic techniques. Most of them were going by visually logical courses without making comparisons of the sum values of the available possibilities. This shows that there is a knowledge and practice gap in algorithmic concepts of students that is a worthwhile observation in the development of CT-based pedagogical curriculum in teacher education (Maharani et al., 2019; Kumala et al., 2023). This gap could be overcome by paying more attention to teaching algorithm design, including using optimisation methods.

As an illustration, past research found out that students critical and systematic thinking is improved when they are exposed to the use of CT in mathematics classes (Maharani et al., 2019). This is in line with requirement of training pre-service teachers to implement CT principles in the instructional practice (Kumala et al., 2023). In this way, a curriculum development that combines an algorithm design can provide a great advantage to pre-service teachers, not only prepare them to provide more effective problem-solving strategies (Andrian et al., 2021; Rosali & Suryadi, 2021).

The debugging indicator demonstrated extremely high diversities among the students. Students who possessed better metacognitive awareness demonstrated those skills as they had the ability to check the results again; they could name the errors in calculations and correct the mistakes. Otherwise, other people passed verification without undergoing it, and simple conversion errors were not noticed. These results highlight the significance of the facilitation of problem-solving with metacognition, reflective, and affective aspects of CT learning.

Q. Li et al. (2023) explain that acquisition of the skills in CT should not only be based on the technical knowledge, but also the reflective and affective support. Whereas technical skills are associated with the ability to comprehend procedures and algorithms, reflective components like the ability to realise mistakes and re-enter that step plays an important role in more profound and transformational learning. When students form a habit of checking their work, they are usually in a better position to teach the problem-solving because they have internalised the successful processes of problem-solving and can comfortably re-teach the processes effectively.

The significance of metacognitive facets of CT learning as they discovered that reflective practice should be incorporated in instruction to increase the willingness of students to use knowledge in practice. Learning the reasons why errors are made as well as the ways that it is possible to correct errors not only enhances the ability to solve problems but also creates the attitude of being critical of the way students thought.

The results of the current research found that there were three major thinking patterns that occur among students within the framework of computational thinking (CT), and they may be presented in the following way:

Systematic–Conceptual (Strategic Planner)

Students in this category showed extensive knowledge in the structure of mathematical problems. Their reflective and efficient approaches allowed them to develop solutions which means that they had high CT skills. All these features cause them to serve as the best illustrations of pre-service teachers who can apply CT in their instruction. It has been argued that students who think strategically are better placed to deal with complex problems and their instructional advice can contribute to the development of the critical and analytical approach to problems among the students (Y. Li et al., 2020). Moreover, their capacity to create problem-based learning can be critical in equipping the students to handle the current day challenges (Y. Li et al., 2020).

Pragmatic–Exploratory

This type had satisfactory skills in decomposition and algorithm design but mostly they used a trial-and-error approach. Their verification and pattern recognition were found to be weak, yet they could often reach solutions. The results are consistent with the researchers who claim that reflective strategies must be encouraged among pragmatic learners (Sercenia & Prudente, 2023). The lack of verification capability also reveals the necessity to empower the metacognitive power of such group that is identified as an indispensable part of successful problem-solving (Bellon and Fias, 2019; Manan et al., 2024).

Procedural–Linear (Linear Executor)

In this type of students were more inclined towards problems solving by strictly adhering to the set steps without paying attention to the efficiency or thinking about the consequences. Their orientation to logical yet strict procedures implies that they require better strategic knowledge and development of meta-cognition. Metacognitive skills are also important to know and practice to change the linear methods of students to more dynamic and efficient ways of solving problems (Zhang et al., 2024).

These results show that the effective implementation of CT in teacher education relies largely on the design of curriculum that facilitates the acquisition of critical thinking, reflection, and metacognition. In this regard, the teacher education programmes must include more problem-based learning chances that openly incorporate CT principles (Manan et al., 2024; Yurt, 2022). With the help of such a combination, pre-service teachers not only should be knowledgeable in theoretical frameworks but also should also implement them in practice and be able to help their future students develop CT skills (Smith and Mancy, 2018).

Metacognition according to Flavell (Manan et al., 2024) develops the awareness about how students think so that they can assess and re-assess their approaches to solving problems. This is especially significant with mathematics education, as an aptitude to reflect on problem-solving strategies may contribute greatly to the learning outcomes (Ajisuksmo & Saputri, 2017). As such, it is very important to establish the learning atmosphere which will help to develop metacognitive skills allowing learners to effectively solve mathematical problems and teach them in an encouraging manner.

To sum up, the current research confirms the necessity of the CT in the process of educating teachers as well as the necessity of the immediate development of the curriculum that will help to foster the development of the three thinking patterns identified during the research.

Decision-makers in educational institutions should consider the results of this analysis and improve the quality of pre-service teacher training by applying innovative and responsive learning methods to respond to the needs of modern education.

CONCLUSION

Practically, the identified CT patterns have direct implications for teacher education curriculum design. Teacher education programmes should move beyond procedural exposure to CT concepts and intentionally scaffold reflective and metacognitive practices, particularly for pre-service teachers exhibiting pragmatic-exploratory and procedural-linear patterns. Structured problem-based learning, explicit debugging activities, and reflective prompts aligned with Polya's problem-solving stages are recommended to foster more systematic-conceptual CT development.

This paper exhibits that the specific inclusion of the CT methodologies within the teacher training curriculum, especially mathematics problem solving units, is necessary. It is also necessary to strengthen metacognitive abilities with the help of training based on reflections, implementation of new teaching methods like problem-based learning. Besides, the criticise diagnostic tool to periodically measure the CT skills of the students and the enhancement of the symbolic and numerical literacy are a tactical move in ensuring that pre-service teachers learn to think systematically, efficiently and reflectively during the learning process.

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