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Solving numerical method problems with mathematical software: Identifying computational thinking

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ABSTRACT

This research examines the application of students' computational thinking (CT) in solving numerical method problems through computer software. Data collection involved observing their learning process and conducting tests to evaluate their CT skills within the context of the root approach material using Newton-Raphson method. The results indicate that the use of Microsoft Excel facilitates problem-solving for students and educators when employing Newton-Raphson method. Furthermore, it helps identify aspects or indicators of CT in students' problem-solving processes. The research findings demonstrate that students with strong mathematical abilities should document their conclusions in the algorithmic aspect. Students with moderate mathematical abilities exhibit all indicators in every aspect of CT when solving problems using Newton-Raphson method. On the other hand, students with weak mathematical skills fail to articulate questions, formulas, or conclusions in the algorithm design aspect, but they do show all indicators in the pattern recognition and abstraction aspects.

Keywords: computational thinking, numerical method, software mathematics

INTRODUCTION

In mathematics, problem-solving is a crucial indicator of students' understanding of learning material (Siagian et al., 2019; Sumartini, 2016). Concept understanding involves not only knowledge acquisition but also the ability to re-express concepts in a more understandable form and apply them to problem-solving (Agustina, 2018; Fajar et al., 2019). The focus of learning mathematics should be on helping students develop their problem-solving skills. One of the reasons for students' failure in problem-solving is their thinking process, which needs to be corrected.

There are various ways of thinking when it comes to solving mathematical problems, one of which is computational thinking (CT). CT is a way of thinking and acting that can be demonstrated through specific skills and serves as a basis for assessing those skills (Saidin et al., 2021). It leverages computer science concepts, tools, and techniques in science, technology, engineering, and mathematics (Lee et al., 2020; Swaid, 2015). CT refers to the development of students' knowledge in designing computational solutions and coding (Angeli & Giannakos, 2020). It is also used in education (Saidin et al., 2021). The process involves problem definition, problem-solving, and analysis of the solutions used. Specific aspects or indicators can be used to assess students' CT skills.

CT indicators, as described by Huang et al. (2021) and Labusch et al. (2019), include decomposition, pattern recognition, abstraction, and algorithm thinking. These ways of thinking in problem-solving using CT enable students to think abstractly, algorithmically, and logically, preparing them to solve complex and open-ended problems (Angeli et al., 2016; Voogt et al., 2015).

There are several ways that students can utilize CT when solving mathematics problems. One effective method is to provide learning materials that assist in the problem-solving process. This enables students to think and comprehend mathematical concepts more effectively, resulting in accurate problem-solving. Learning media serves as a valuable tool for educators in facilitating the learning process (Puspitarini & Hanif, 2019; Tafonao, 2018). By utilizing learning media, educators can deliver lesson materials efficiently, while also helping students concentrate and engage with the material. Learning media is considered a type of learning tool (Nurrita, 2018).

The COVID-19 pandemic has necessitated the use of specific learning tools for online learning activities (Berrocoso et al., 2021). Educators have capitalized on existing technology, such as LCDs/projectors, computers/laptops, computer software for explaining learning materials, and even the internet and smartphones to facilitate the learning process. The students' response has been positive as well (Syaifuddin et al., 2020), as many students were dissatisfied with traditional lecture-based learning that relied solely on books for knowledge. In the case of mathematics, which involves complex formulas, many students tend to rely on rote

Table 1. Student mathematics ability category

No	Score	Category
1	75≤x≤100	High
2	50≤x<75	Medium
3	0≤x<50	Low

Table 2. Value & gender of research subjects

No	Score TKM	Category	Gender
1	82	High	Female
2	61	Medium	Female
3	40	Low	Female

methods and direct formulas for problem-solving (Baiduri, 2018). By utilizing software, students can grasp mathematical concepts more easily and solve problems accurately (Yeh et al., 2019), including the numerical methods material in this instance. Numerical methods encompass problem-solving techniques formulated arithmetically. Therefore, when addressing numerical methods problems, it is crucial to employ an efficient strategy or method. Additionally, the assistance of software is invaluable in facilitating the problem-solving process. Examples of software commonly utilized in numerical methods include GeoGebra, Java, Maple, Mathematica, MATLAB, Microsoft Excel, and Python among others.

Considering the aforementioned description, several fundamental aspects contribute to the effective resolution of mathematical problems. One such aspect involves students' ability to employ the appropriate mode of thinking. To aid students in tackling these problems, the use of learning media is highly recommended, as it can assist in problem-solving. This research aims to explore how students apply CT in utilizing mathematics software to solve numerical methods problems.

METHOD

This research employs descriptive research with a qualitative approach. The participants in this study were students enrolled in the mathematics education study program at a private university in Indonesia. Initially, the participants were administered a mathematics ability test (TKM). TKM consisted of five essay questions focusing on algebra. Algebra was chosen for the test as the participants had previously covered algebra and possessed the necessary foundational knowledge to tackle the practice questions in this study. Based on the results of this test, participants were selected using purposive sampling, with three students chosen, representing low, medium, and high mathematical abilities. The categorization of mathematical ability was determined according to Samawati and Kurniasari (2021), and the results are presented in **Table 1**.

From the categories presented in **Table 1**, the researchers then took subjects based on the median value of each category. Apart from being based on these mathematical abilities, the subject selection also considers the gender of the same subject. Research conducted by Zhu (2007) states that gender affects a person's thinking in the problem-solving process. Therefore, the subjects that became the focus of this study are presented in **Table 2**.

The research procedures began with research planning, which involved activities such as studying the library, preparing research tools, and conditioning students. The next step was the implementation of actions, which included providing teaching materials and explanations about Newton-Raphson method, giving example questions and facilitating discussions, and finally, providing practice questions, which served as the research instruments. The third procedure involved analyzing the research data obtained from the students' work on Newton-Raphson method material.

To collect research data, observation and tests were used as data collection techniques. Observations were conducted during the learning process and when students solved questions to understand how software was used in learning numerical method material on Newton-Raphson method topic. The instrument used for observation was the student response observation sheet. On the other hand, tests were conducted after students participated in learning and were used to assess the results of the students' work. The test results were then analyzed based on CT indicators, using a description test sheet as the instrument. The following is the instrument used in the test activity: Determine one of the roots of $x^5 + 2x^2 - 4 = 0$ using Newton Raphson method, if the starting point $x_0 = 1$ and error tolerance are known $x = 0.001$?

Data was analyzed using Miles and Huberman (2018) method, the analysis started with reducing the data by selecting answers based on CT category. The data was then presented in tables and conclusions were drawn for all CT indicators. This study used data from student work results, which were adjusted to CT indicators. The results were described and supported by the findings from the observation. CT indicators in **Table 3** were used as a reference in the data analysis chart, based on the indicators used by Huang et al. (2021).

RESULTS

This study involved 40 students enrolled in the mathematics education study program, specifically those taking numerical methods course. From this group, three students were selected as subjects based on their mathematics ability test scores (high, medium, and low), while also considering their gender. The research data was collected by administering essay questions that required students to solve problems using one of the chosen mathematics software. During the learning activities, the researcher

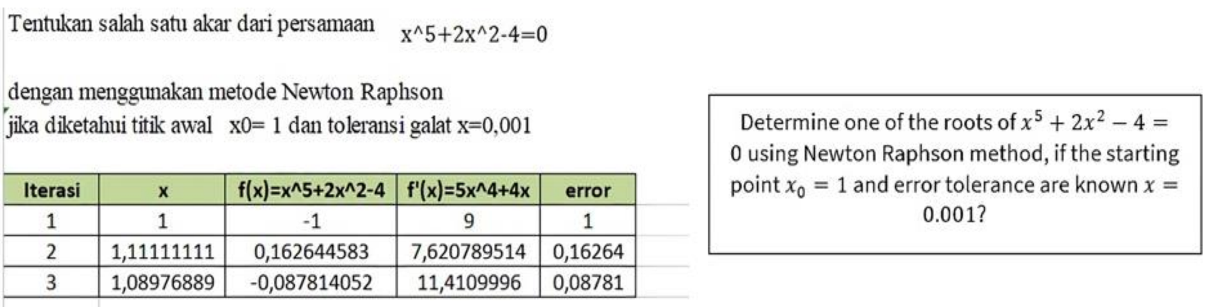
Table 3. Aspect computational thinking

No	Aspect	Indicator
1	Decomposition	Read information and problems that arise
		Break down the problem into sub-problems
		Changing from words to symbols or example
2	Pattern recognition	Determine what problems arise
		Determine the pattern/possibility of a solution
3	Abstraction	Focus on important information
		Develop a problem-solving plan
4	Algorithm design	Resolving problem following steps that have been made/arranged
		Making conclusions

Table 4. Results of student work analysis according to computational thinking indicator

No	Aspect	Indicator	Student mathematical ability		
			Low	Moderate	High
1	Decomposition	Read information and problems that arise	–	√	√
		Break down the problem into sub-problems	√	√	√
		Changing from words to symbols or example	√	√	√
2	Pattern recognition	Determine what problems arise	√	√	√
		Determine the pattern/possibility of a solution	√	√	√
3	Abstraction	Focus on Important Information	√	√	√
		Develop a problem-solving plan	√	√	√
4	Algorithm design	Resolving problem following steps that have been made/arranged	√	√	√
		Making conclusions	–	√	–

Note. √: Do & –: Not doing


Tentukan salah satu akar dari persamaan x^5+2x^2-4=0

dengan menggunakan metode Newton Raphson
jika diketahui titik awal x0= 1 dan toleransi galat x=0,001

Iterasi	x	f(x)=x^5+2x^2-4	f'(x)=5x^4+4x	error
1	1	-1	9	1
2	1,11111111	0,162644583	7,620789514	0,16264
3	1,08976889	-0,087814052	11,4109996	0,08781

Determine one of the roots of $x^5 + 2x^2 - 4 = 0$ using Newton Raphson method, if the starting point $x_0 = 1$ and error tolerance are known $x = 0.001$?

Figure 1. Results of students with low mathematical abilities (Source: Authors' own elaboration)

allowed the subjects to freely choose the software they preferred, such as Maple, Mathematica, MATLAB, or Microsoft Excel to assist them in solving the numerical method problems. After analyzing the students' work, it was found that all three students successfully completed the numerical method problem-solving process using Microsoft Excel. The data was then analyzed and summarized based on the students' CT indicators. The results of this analysis are presented in **Table 4**.

The following discussion will provide details on how each student solves the mathematics problems presented in **Table 4**.

Students With Low Mathematics Abilities

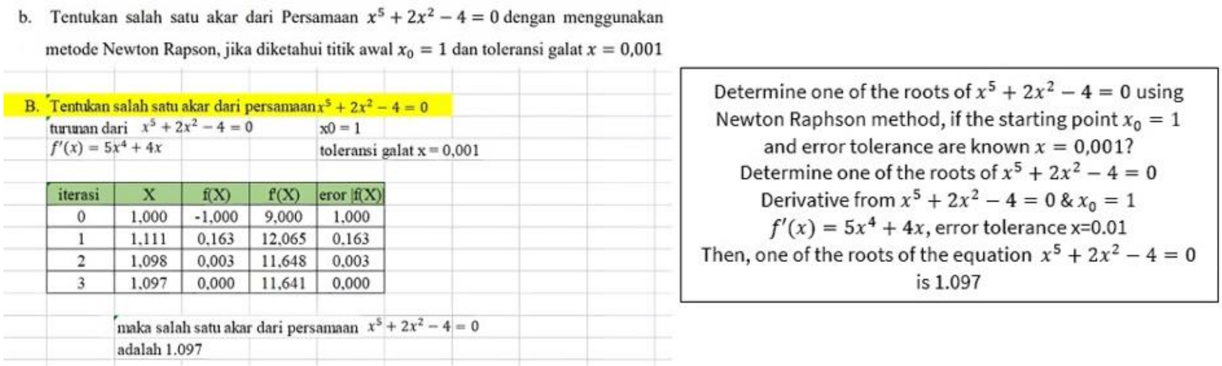
The results of students with low mathematical abilities are shown in **Figure 1**.

Decomposition

Figure 1 represents the work of students with lower writing abilities. It showcases their efforts in creating question tables and iterations. The indicator reveals the challenges faced by these students when writing questions in Microsoft Excel, as they do not provide detailed information about the known elements of the problem. Additionally, the indicator fails to include the formula x_{i+1}, which is crucial for solving the equation at hand.

To simplify the process, students manually calculate the derivative of $f(x)$ and input it into Microsoft Excel calculation column. The indicators then transition from using words to symbols or examples, helping students understand what needs to be entered in Microsoft Excel for problem-solving purposes. This includes loading iterations, $x, f(x)$ or derivatives of $f'(x)$ in their entirety, as well as denoting the error.

During interviews, students adjusted their Microsoft Excel entries to match the requirements of the problem, as it was easier to operate and understand what needed to be substituted. They faced difficulties in determining derivatives using Microsoft Excel, which led them to manually calculate derivatives. The understood error is the absolute value of f $f'(x)$ or the difference between the actual value and the calculated value of $f'(x)$.



b. Tentukan salah satu akar dari Persamaan $x^5 + 2x^2 - 4 = 0$ dengan menggunakan metode Newton Rapson, jika diketahui titik awal $x_0 = 1$ dan toleransi galat $x = 0{,}001$

B. Tentukan salah satu akar dari persamaan $x^5 + 2x^2 - 4 = 0$

turunan dari $x^5 + 2x^2 - 4 = 0$ x0 = 1

$f'(x) = 5x^4 + 4x$ toleransi galat x = 0,001

iterasi	X	f(X)	f'(X)	eror |f(X)|
0	1,000	-1,000	9,000	1,000
1	1,111	0,163	12,065	0,163
2	1,098	0,003	11,648	0,003
3	1,097	0,000	11,641	0,000

maka salah satu akar dari persamaan $x^5 + 2x^2 - 4 = 0$ adalah 1.097

Determine one of the roots of $x^5 + 2x^2 - 4 = 0$ using Newton Raphson method, if the starting point $x_0 = 1$ and error tolerance are known $x = 0{,}001$?
Determine one of the roots of $x^5 + 2x^2 - 4 = 0$
Derivative from $x^5 + 2x^2 - 4 = 0$ & $x_0 = 1$
$f'(x) = 5x^4 + 4x$, error tolerance x=0.01
Then, one of the roots of the equation $x^5 + 2x^2 - 4 = 0$ is 1.097

Figure 2. Results of students with moderate mathematical abilities (Source: Authors' own elaboration)

Pattern recognition

Indicators identify problems by examining the values of $x, f(x), f'(x)$ and error in the solution table. In order to determine patterns or possibilities, the subject performs a second iteration by using the value of x obtained from the operation $x - \frac{f(x)}{f'(x)}$. The interview with the subject reveals that the x used in the second iteration is derived from the value $x - \frac{f(x)}{f'(x)}, f$ while the x for the third iteration is obtained from the second iteration of $x - \frac{f(x)}{f'(x)}$ and he Gelat is the absolute value of $f(x)$ and does not provide any explanation.

Abstraction

The primary indicator to prioritize crucial information relied upon by the subject for problem-solving is the value of x and the error. This indicator assists the subject in formulating a problem-solving strategy by substituting each x value into the formulas $f(x), f'(x)$ and subsequently determining the error value using the absolute formula. The findings from interviews with the subject regarding the understanding of the iteration process indicate that the iteration will be concluded once the error value reaches 0. In order to gain a more comprehensive understanding of the error value, it is advisable to utilize a greater number of decimal places.

Algorithm design

To solve the problem using the given steps, three iterations are performed, starting from iteration 1 and ending at iteration 3. The indicator determines that the subject fails to record the conclusion, the number of roots, and the error value. The subject deems a root to be $x = 1.08976889$, with an error value of 0.08, as the error value is either 0.08 or close to it. The subject asserts that there is no need to continue to the next iteration since 0.08 sufficiently indicates the presence of a root. The subject does not provide a written conclusion, stating that if it is done in the final iteration, it adequately demonstrates that the sought root has been found, and the subject claims it will remain constant henceforth.

Students With Moderate Mathematical Abilities

The results of students with moderate mathematical abilities are shown in **Figure 2**.

Decomposition

Figure 2 represents the work of students with moderate abilities. It showcases the students' efforts in writing questions, determining the first derivative in the given problem, and establishing the values of x_0 and the error tolerance ($x = 0.001$). The students' approach involves noting down the questions and all the necessary elements for problem-solving, focusing on simplifying the information. Notably, the students directly calculate the derivative of $f(x)$ manually and input it into Microsoft Excel using Microsoft Excel equations. They transform the information from words to symbols or examples, accurately recording the contents of Microsoft Excel column based on their understanding of the problem and its solution, including $x, f(x), f'(x)$, and the $error$ of $f(x)$.

During the interviews, the students confirmed that what they wrote in Microsoft Excel aligned with their understanding of the variables x, $f(x)$, $f'(x)$, and $error\ f(x)$ without any other factors influencing their choices. Additionally, they manually determined the derivatives due to the challenges faced when using Microsoft Excel for derivative calculations. The errors were also recorded as $error(x)$ because, according to the subject matter, there are two types of errors: those related to intervals and those related to $f(x)$. Using $error(x)$ was deemed the most appropriate choice.

Pattern recognition

To determine the problems that arose, the subject calculates the values for $x, f(x), f'(x)$, and $error\ f(x)$ by substituting the x values. In the second iteration, the subject determines the pattern/possibility by directly using the operation $x - \frac{f(x)}{f'(x)}$ and examining the value of $error(x)$ from absolute $f(x)$.

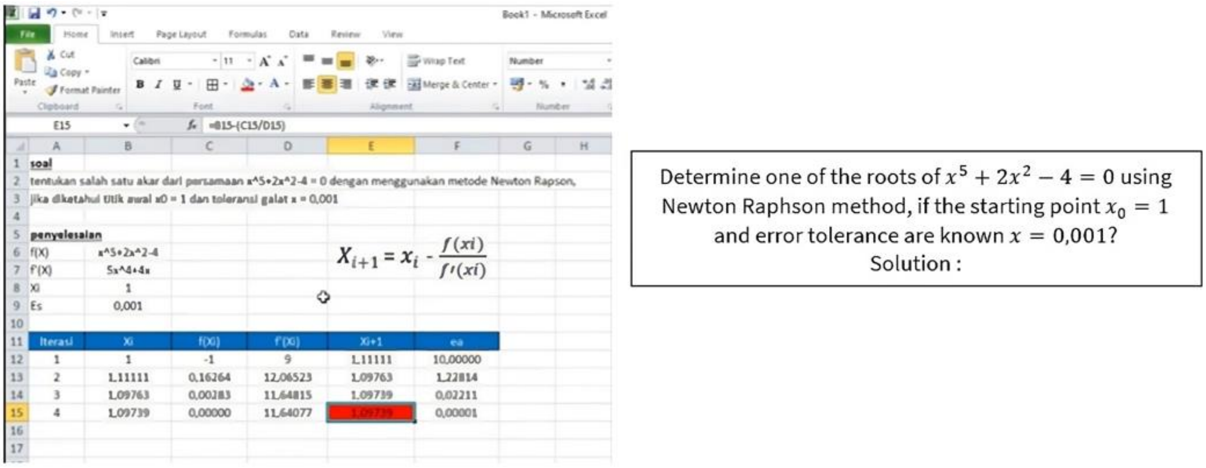


Figure 3. Results of student work with high mathematical ability (Source: Authors' own elaboration)

Based on interviews with the subject, it was found that for the second iteration, the value of x is obtained from $x - \frac{f(x)}{f'(x)}$. For the third iteration, the value of x is the second value obtained from $2 - \frac{f(x)}{f'(x)}$ and the error is the absolute value of $f(x)$ since it represents the substitution of x into $f(x)$. If the error value is close to 0, then x represents the root.

Abstraction

The key indicator for the subject to prioritize important information in problem-solving is the x error value (x). To determine the problem-solving plan, the subject replaces each x value into the formulas $f(x)$, $f'(x)$, and $error(x)$ until the smallest error value is achieved.

Interviews with the subject indicated that the iteration process is considered complete when the error value approaches 0, as this indicates the determination of the root. If the error value is already zero or very close to zero, a constant x value will be identified later.

Algorithm design

The indicator solves the problem by following a series of steps. Specifically, the subject goes through four iterations, starting from the 0th iteration and ending at the 3rd iteration. The completion steps for the 0th and 1st iterations are the same. In conclusion, the subject writes the conclusion at the end of the table, stating that one of the roots is 1.097. During the interview, the subject explains that since the error value is found to be 0.000, they immediately conclude that the 3rd iteration is the last one. This is because a minor error value has been obtained and the subject considers it sufficient, so they do not proceed to the next iteration.

Students With High Mathematics Ability

The results of students with high mathematical abilities are shown in **Figure 3**.

Decomposition

Figure 3 depicts the outcomes achieved by highly skilled students. It reveals that these students were able to articulate questions and identify the necessary information and formulas to solve the given problem. This indicator demonstrates that students possess the ability to comprehend and write questions, as well as the elements crucial for problem-solving. Specifically, the indicator indicates that students can write the formula x_{i+1}, which represents the root of the equation in question.

Regarding the indicators aimed at simplifying information, students exhibited the capability to determine the derivative of $f(x)$ through manual calculations and input it into Microsoft Excel. Furthermore, they were able to convert verbal instructions into symbolic or exemplar form, enabling them to enter the required values in Microsoft Excel for problem-solving purposes, including loading iteration, x_i, $f(x_i)$, $f'(x_i)$, x_{i+1}, and ea (error).

Additionally, during interview activities, it was observed that students adjusted the data entered in Microsoft Excel to align with the formula, making it more convenient to operate and carry out calculations while ensuring adherence to the required format. Moreover, due to the challenges associated with determining derivatives using Microsoft Excel, students resorted to manual calculations, with only the final derivative results being written directly in Microsoft Excel.

Pattern recognition

Figure 3 illustrates the results achieved by students who performed the iteration by substituting the value of x_i to determine the values of $f(x_i)$, $f'(x_i)$, and x_{i+1}. To identify the arising problems, the subject searches for the values of $f(x_i)$, $f'(x_i)$, and x_{i+1} along with ea, where x_{i+1} represents one of the roots of the given equation, and ea denotes the error value. In order to gauge the pattern/possibility, the second iteration can directly utilize x_i from x_{i+1} and assess the value of ea, which should not be less than es, thereby enabling the iteration to proceed.

Based on the interview findings, it was revealed that for the second iteration, the subject utilizes x_i aquivalent to x_{1+1}, while for the third iteration, x_i correspond to x_{2+1}due to its sequential nature as a result of the calculation. Consequently, the error value can be calculated using the formula $ea = \frac{x_{i+1}-x_i}{x_{i+1}} \times 100$.

Abstraction

The subject in the completion uses the value of x_i and x_{i+1} along with the value of ea, as a critical information focus indicator. When developing a problem-solving plan, the subject substitutes each x_i value into the formula $f(x_i)$, $f'(x_i)$, and x_{i+1} , and checks for a value of ea that is smaller than the specified error value. This process is repeated until the error value matches the desired value. During the interview with the subject, it is noted that if the value of ea is smaller than es, the error is smaller than the specified value, and x_{i+1} represents the root..

Algorithm design

The first indicator addresses the problem through a step-by-step process. Specifically, the subject utilizes four iterations involving references x_i and x_{i+1} in order to determine the error value that meets the requirements. The indicator for drawing conclusions is not recorded in Microsoft Excel. The subject claims to have obtained one of the root values by following the steps described in the fourth iteration, with a value of 1.097 and an error of 0.00001. This information was conveyed during the interview. Additionally, the subject asserts that since the value of x_{i+1} remains constant and the error is small and less than ea, then, x_{i+1} is the root.

DISCUSSION

Based on the research results provided, it can be concluded that low ability students have completed most of the indicators for CT. However, they struggle with decomposition indicator, specifically in understanding the problem information and writing formulas. Additionally, in algorithm design, these students do not provide final conclusions. They tend to solve problems based on their understanding of the problem, rather than following steps from existing theory, resulting in suboptimal solutions and deficiencies.

Moderate ability students also struggle with decomposition aspect and the indicator of writing formulas. However, they complete other aspects and indicators by following the steps and conditions for using Newton Raphson method. On the other hand, high ability students demonstrate proficiency in all aspects and indicators of CT and successfully use Newton Raphson method to determine roots. The only area for improvement is that these students do not provide detailed conclusions at the end, only marking completion with red in Microsoft Excel.

Based on this information, it can be inferred that software can effectively assess students' CT skills in solving mathematical problems. This aligns with research conducted by Rodríguez-Martínez et al. (2020), which emphasizes the use of mathematical software for developing CT. Additionally, Yoh (2017) suggests that Microsoft Excel is sufficient for solving various problems without the need for programming. Furthermore, Bernard and Senjayawati (2019) state that VBA-based mathematical games for Microsoft Excel can enhance conceptual understanding in learning. Therefore, when used appropriately, Microsoft Excel can aid students in comprehending mathematical concepts.

In addition, the software also relates to CT, as described in Kwon and Kim (2018). CT enables students to learn to think abstractly, algorithmically, and logically. The software contains algorithmic and abstraction processes that may not be directly understood. Thus, integrating CT into mathematics learning using software is very suitable. Moreover, learning mathematics is closely connected to problem-solving processes, cognitive processes, and transposition. These three processes are important aspects of CT, as found in research by Kallia et al. (2021).

Newton Raphson method is a useful tool in the field of mathematics and computer science for finding the roots of non-linear equations. Microsoft Excel, a popular spreadsheet program, can be effectively used to solve problems using Newton Raphson method. Microsoft Excel can calculate the iterations required to find the roots of non-linear equations (Gaik et al., 2009). By utilizing the formulas and functions available in Microsoft Excel, Newton Raphson method can be easily implemented. The use of Microsoft Excel in solving Newton Raphson method problems offers advantages such as user-friendliness, powerful computational capabilities, and various features and tools for simplifying the problem-solving process (da Rocha et al., 2014). Newton-Raphson method is frequently applied in advanced mathematics learning, particularly in calculus and numerical analysis. Educators may find it challenging to understand and teach Newton-Raphson method. However, Microsoft Excel can enhance the learning process by making it more effective and efficient. For students, Microsoft Excel plays a crucial role in learning Newton-Raphson method. It allows students to perform calculations easily, visualize calculation results, and conduct sensitivity analysis of parameters. Consequently, Microsoft Excel can improve students' understanding of Newton-Raphson method and facilitate their learning in mathematics.

Microsoft Excel's ability to perform complex mathematical calculations is one of its uses in learning Newton-Raphson method. In this method, calculations involving derivatives are common. Microsoft Excel provides mathematical formulas and functions that enable educators to automatically calculate derivatives. This saves time and effort compared to manual calculations. Additionally, Microsoft Excel can be used to solve equations iteratively. The iteration process in Newton-Raphson method can be implemented easily by using Microsoft Excel's existing formulas and functions. Educators can change initial values, iteratively calculate function values and derivatives, and observe how these values converge to the root of the equation.

Furthermore, Microsoft Excel can serve as a tool for storing and organizing data related to Newton-Raphson method. Educators and students can create tables to store iteration values, function values, and function derivatives. This enables easy tracking and analysis of data to evaluate the success of Newton-Raphson method.

CONCLUSIONS

The research results indicate that regardless of students' mathematical abilities (whether moderate, high, or low), they all used Microsoft Excel as the medium to solve root determination problems using Newton-Raphson method. Each subject had their own approach and reasons for solving these mathematical problems. The subjects with low mathematical abilities lacked the skills to read the necessary information in the decomposition aspect and did not provide conclusions in the algorithm aspect. On the other hand, subjects with moderate abilities demonstrated proficiency in all aspects of CT. Subjects with high abilities, however, did not include conclusions in the algorithm aspect. Therefore, it can be concluded that subjects with moderate mathematical abilities successfully performed all indicators in CT aspect.

Microsoft Excel offers various features that are highly beneficial for educators teaching Newton-Raphson method. Its capability to handle complex mathematical calculations, visual aids for data visualization, and ability to iterate and store data make it an invaluable tool for educators. By leveraging these advantages, the learning process of Newton-Raphson method can become more effective and efficient.

The use of Microsoft Excel in learning can enhance students' thinking patterns, help them solve mathematical problems, and increase their interest in mathematics as a subject. Additionally, utilizing Microsoft Excel's functions aids in directing and optimizing the teaching and learning process for mathematics problem-solving. Microsoft Excel simplifies students' understanding of numerical methods during lectures. Therefore, technology plays a crucial role in numerical lectures as it facilitates lengthy calculations and improves accuracy compared to manual calculations.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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