

Metacognitive Skills Profiles of Students in Solving Higher-Order Differential Equation Problems: A Qualitative Case Study

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Abstract

Metacognitive skills is essential for solving complex mathematical problems, particularly in higher-order ordinary differential equations that require structured reasoning and reflection. This study aimed to describe university students' metacognitive skills profiles in solving higher-order differential equation problems based on their mathematical ability levels. A qualitative case study approach was employed. The population consisted of 43 students from Universitas Negeri Makassar who had enrolled in the Ordinary Differential Equations course. Three students were purposively selected to represent high, moderate, and low mathematical ability levels. Data were collected through problem-solving tests and semi-structured interviews. The data were analyzed qualitatively using the stages of data collection, data reduction, data display, and conclusion drawing, guided by three metacognitive indicators: planning, monitoring, and evaluation. The results showed that students with high mathematical ability demonstrated strong metacognitive awareness by effectively planning, monitoring, and evaluating their problem-solving processes. Students with moderate mathematical ability were able to plan and monitoring their solutions but experienced difficulties in evaluating their work. In contrast, Students with low mathematical ability can maximally fulfill one metacognitive indicator; Planning indicators. Students make a calculation error in the strategy that has been designed so it results in the final result of the answer. These findings highlight the need for instructional strategies that explicitly foster metacognitive awareness to support students in solving advanced differential equation problems.

Keywords: Metacognitive Skills; Higher-Order Differential Equations; Mathematical Problem Solving; Mathematical Ability; Qualitative Study.

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INTRODUCTION

Mathematics plays a fundamental role in school education, with its primary objective being to equip students with the ability to understand and solve problems (Asmaun & Baharuddin, 2024). In the fields of science and technology, mathematics occupies a vital position in developing a person's critical, logical, and systematic mindset, which consequently improves their problem-solving abilities (Setyaningsih & Rahmawati, 2022). As students develop metacognitive awareness skills, they simultaneously cultivate reflective thinking, which is a high-level cognitive skill (Ayazgök & Aslan, 2014). For that reason, appropriate and feasible strategies are needed to help students solve the mathematical problems they face. Strategies that utilize metacognitive skills are considered essential for students to navigate modern challenges and become successful 21st-century learners (Arsyad, 2016; Blakey & Spence, 1990). Similarly, in higher education, prospective teachers must be equipped with metacognitive skills to develop effective mathematical problem-solving strategies (Fatmawati et al., 2025; Putera et al., 2021). A teacher must strive to "reduce" the abstract nature of mathematical objects (facts, concepts, operations, or principles) to make mathematical problems taught in schools easier for students to understand (Ahmad et al., 2018). Therefore, prospective teachers must possess strong metacognitive skills to effectively teach appropriate strategies for solving various types of mathematical problems, ranging from the simple to the complex.

Some researchers explain that the metacognitive component is divided into two categories according to Tarricone, namely cognitive knowledge and regulation (Flavell, 1979; Kassimi, 2025; Oz, 2016). Cognitive knowledge is the general understanding and awareness regarding cognition (Oz, 2016). It is divided into three types (Schraw & Dennison, 1994; Young & Fry, 2008): (1) declarative, (2) procedural, and (3) conditional. Declarative knowledge involves having an adequate understanding of oneself, including the effective strategies and information needed to fulfill a task. Procedural knowledge is the awareness of the sequences and steps required to assemble and carry out a job. Conditional knowledge is a combination of declarative and procedural information about a person. Meanwhile, metacognitive regulation is the ability to control one's cognitive skills. It consists of three components—awareness, regulation, and evaluation—which are directly related to students' activities in solving mathematical problems (Jaleel & P, 2016; Magiera & Zawojewski, 2011; Wilson & Clarke, 2004). Awareness activities involve rethinking: 1) what was asked, 2) the information in the problem, and 3) the next steps needed to solve the problem. Regulation activities involve rethinking: 1) ways to solve problems, 2) different alternatives for solutions, and 3) what to do next. Evaluation activities involve



rethinking: 1) every step that has been taken, 2) whether other considerations are needed, and 3) whether the answer to the problem is correct (Jaleel & P, 2016; Magiera & Zawojewski, 2011; Wilson & Clarke, 2004).

Metacognitive awareness is one of the key influential factors in successful mathematical problem-solving. Metacognition is a person's awareness of their own thought processes to build appropriate strategies for solving problems (Pramono, 2017). Metacognitive skills significantly influence a student's success in problem-solving (Güner & Erbay, 2021). Metacognitive awareness refers to an individual's ability to be aware of, control, and reflect on their own thinking processes, which generally covers three main indicators: planning, monitoring, and evaluation (Blakey & Spence, 1990; Dirkes, 1985; Pramono, 2017; Schraw & Moshman, 1995). Students with high metacognitive awareness tend to be capable of determining appropriate settlement strategies, monitoring the suitability of the steps taken, and critically evaluating the accuracy of the results. Furthermore, students with high metacognitive skills tend to use the correct strategies, precise mathematical notation, and logical reasoning to provide correct answers (Fatmawati et al., 2025; Güner & Erbay, 2021). Students with moderate learning independence demonstrate proficiency in planning and monitoring but may encounter difficulties with evaluation, as they often overlook details in final calculations (Setyaningsih & Rahmawati, 2022). Conversely, students with low metacognitive awareness often commit procedural errors without realizing it and struggle to correct them. Such students experience difficulty in understanding problems, choosing strategies, and finding correct answers (Güner & Erbay, 2021).

The ability to solve complex mathematical problems is a crucial competence for students, especially in advanced subjects like High-Order Ordinary Differential Equations. This material demands not only procedural mastery but also the ability to consciously manage thought processes, including planning resolution strategies, monitoring steps, and evaluating results. However, in practice, many students still experience difficulty in solving high-order differential equations despite having learned the relevant concepts and formulas. Although metacognition supports success, prospective teachers still often face mental barriers (such as blindness, vandalism, and mirages) that hinder their effectiveness in mathematical problem-solving (Kaya & Kepceoglu, 2022). When individuals fail in metacognition, their primary weakness lies in the inability to evaluate whether their strategies are appropriate or whether their thinking has limitations in solving the problem (Hamda et al., 2024; Huda et al., 2018). This suboptimal ability is due to limited material coverage and cognitive teaching strategies that are still dominated by verbal presentation (Ahmad et al., 2018).



Most previous studies on metacognition in learning mathematics still focus on the secondary school level and basic topics such as algebra, geometry, and systems of linear equations. For example, the study by Setyaningsih & Rahmawati (2022) focuses on students' metacognitive abilities in solving systems of linear equations with two variables. Research by Ahmad et al. (2018) and Hamda et al. (2024) focuses on algebra, Sukiyanto (2020) on geometry, and Aulia & Murtiyasa (2023) on trigonometry. Regarding metacognitive awareness at the higher education level, studies by Cihanoglu (2012) and Putera et al. (2021) focus on general profiles of metacognitive awareness rather than specific problem-solving contexts. Additionally, Fatmawati et al. (2025) researched how different cognitive styles influence the effectiveness of metacognition and critical thinking in prospective teachers. Therefore, research that specifically describes the metacognitive awareness profiles of students in solving high-order differential equations, especially using a qualitative approach based on thought processes, is still very limited. Furthermore, there is not yet much research that deeply examines how students plan strategies, monitor their steps, and evaluate solutions for differential equations of a complex and procedural nature.

The novelty of this study lies in its effort to reveal the deep metacognitive awareness profiles of students in solving high-order differential equations, which demand simultaneous conceptual, procedural, and reflective abilities. Unlike previous studies that tended to evaluate metacognition based on final results or test scores, this research emphasizes the analysis of students' thought processes at every stage of metacognition—planning, monitoring, and evaluation—through qualitative case studies. Moreover, this research contributes by mapping the metacognitive awareness patterns of mathematics education students or prospective teachers in the context of advanced mathematics, enriching the currently minimal study of metacognition at the higher education level. This is considered important because teachers with good metacognitive awareness will be capable of transferring these skills to their students (Cihanoglu, 2012).

The results of this research are expected to provide recommendations for mathematics lecturers to design differential equation learning that is oriented not only towards procedural mastery but also towards strengthening students' metacognitive awareness. Findings regarding the variation in students' metacognitive profiles can serve as a basis for developing learning strategies that encourage students to be more aware in planning, monitoring their work, and independently evaluating their results. Thus, learning differential equations is expected to increase students' learning independence, accuracy in problem-solving, and reflective thinking



skills in a sustainable manner.

METHOD

This research employed a descriptive qualitative method to reveal the metacognitive skill profiles of students in solving high-order linear differential equations. The study was conducted within the Mathematics Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, during the odd semester of the 2025-2026 academic year.

The subjects of this research were third-semester students of the Mathematics Education study program. Subject selection was carried out using a purposive sampling technique, specifically targeting students who were currently enrolled in the Ordinary Differential Equations course. Additionally, the selection process considered students who were deemed capable of providing comprehensive data regarding their metacognitive skills during the problem-solving process.

Data collection techniques in this study included written tests to reveal data on students' metacognitive skill profiles, followed by interviews conducted to validate the written answers. The research instruments consisted of a primary instrument—the researcher—and supporting instruments. The supporting instruments included a test consisting of high-order linear differential equation problems, derived from the final semester examination questions previously administered to the research class. Furthermore, interview guidelines were utilized as an additional instrument. These interview guidelines were developed based on metacognitive skill indicators adapted from (Fatmawati et al., 2025), as presented in the following table.

Table 1. Indicators Skills Metacognition

Components	Indicators
Planning	1. Students are able to understand the information presented in the problem to be solved. 2. Students are able to make predictions before proceeding to a deeper reading of the problem. 3. Students are able to identify the given data and relevant information within the problem.



	- Students are able to select appropriate strategies to solve the problem. - Students are able to think through and plan the steps required for problem solving.
Monitoring	- Students are able to write mathematical formulas accurately. - Students are able to apply appropriate and correct problem-solving steps. - Students pay close attention to each step of the problem-solving process. - Students are able to monitor and evaluate the problem-solving steps based on the given information.
Evaluation	- Students are able to determine and accurately conclude the final solution. - Students are able to review and verify the steps of their solution to ensure consistency with the information provided in the problem. - Students are able to use the given information to plan and solve the problem using alternative approaches. - Students are able to identify the relevance of the strategies or methods used and apply them to other problem situations.

The research procedure began by categorizing the students into three levels of mathematical ability: high, medium, and low. This classification was based on the students' Cumulative Grade Point Average (GPA). Subsequently, the Final Semester Examination (UAS) questions were administered to the students in the selected class. The specific problems related to high-order linear differential equations are presented as follows:



Gunakan metode koefisien tak tentu untuk menentukan solusi umum dari persamaan berikut:

$$y^{iv} - 2y'' + y = e^x + \sin x$$

The tests were checked and the results were analyzed to determine the students' metacognitive skill profiles based on the established indicators. From the assessment results, at least three subjects were selected from each mathematical ability category. Subsequently, interviews were conducted with the selected subjects to confirm the consistency between their conceptual understanding and their written responses on the test. Furthermore, the interviews were used to reveal a deeper profile of the students' metacognitive skills in solving high-order linear differential equations.

The research data were analyzed using the theory proposed by Creswell (2016), which includes the following steps: (1) managing raw data (transcripts, field notes, images, etc.); (2) organizing and preparing data for analysis; (3) reading through all the data; (4) coding the data (manually or via computer); (5) interrelating themes and descriptions; and (6) interpreting the meaning of the themes and descriptions.

RESULT

The subjects in this study were selected based on their Grade Point Average (GPA). After collecting the GPA data from all students in class A12, they were classified into three categories: a GPA range of 3.45 to 3.65 represented students with low academic performance, 3.66 to 3.85 represented moderate academic performance, and 3.86 to 4.00 represented high academic performance. To facilitate data presentation and the reporting of research results, each subject was assigned a specific code: students with high ability were coded as **SKT**, students with moderate ability as **SKS**, and students with low ability as **SKR**.

Furthermore, the written test responses from these subjects, specifically regarding the solution of high-order differential equation problems, were reviewed and analyzed. This analysis was conducted based on the metacognitive skill indicators that had been previously established.

Skills Metacognition of SKT Subject

In the research regarding the Metacognitive skills on Solving Problem, the research subject selected one student with high mathematical ability. Based on results research in the field, the subject of SKT in general show all over indicator ability metacognition with okay, just just subject do a little error on wrong One steps that cause answer the final result wrong. However on interview, SKT subject with fast know mistakes and understanding How should the right solution. Following is explanation about every indicator metacognition on solution problem the.



Planning Indicators

Indicator planning considered fulfilled if student capable understand elements of the given question, understanding the purpose of the question said, determines strategy or draft beginning, and capable develop concepts mentioned. The following This served the result of interview with SKT subject.

P : Ketika pertama kali membaca soal persamaan diferensial orde tinggi ini, hal apa yang langsung Anda pahami dari soal tersebut?

SKT : Saya perhatikan karena ini pangkat 4, maka dia masuk persamaan diferensial orde tinggi dengan konstanta e^x dan $\sin x$. dari situ saya bisa tau harus menggunakan metode apa untuk menyelesaikannya

P : Informasi apa saja yang menurut Anda penting dari soal sebelum mulai menyelesaikannya?

SKT : Saya perhatikan dari kemungkinan solusi homogen berdasarkan persamaan karakteristiknya, untuk akar sama, akar berbeda, dan akar imajiner. Kemudian konstanta e^x dan $\sin x$ memberikan kemungkinan untuk solusi khususnya.

P : Strategi atau metode apa yang Anda rencanakan untuk menyelesaikan soal ini? Mengapa memilih strategi tersebut?

SKT : Untuk solusi homogennya saya menggunakan metode pemfaktoran karena saya lihat lamdanya pangkat 4, sehingga bisa dimisalkan $x = \text{lamda}^2$ sehingga bisa difaktorkan dengan mudah.

P : Apakah Anda mempertimbangkan lebih dari satu cara penyelesaian sebelum mulai mengerjakan? Jelaskan.

SKT : Menurut saya bisa menggunakan cara horner pak dan akan menghasilkan jawaban yang sama cuma terlalu panjang.

Based on the interview results with the **SKT** subject, it was shown that the planning indicators were successfully fulfilled. The subject understood the elements of the problem by identifying what was known and what was asked in the question. The subject recognized that the problem given was a high-order linear differential equation, as evidenced by identifying the highest rank of the y-derivative. Furthermore, the subject understood that to solve the given problem, it was necessary to first find the homogeneous solution of the equation, followed by finding the specific (particular) solution to obtain the final result. The subject was also able to determine the appropriate method for solving the problem and developed an initial draft for the solution. Additionally, the subject could provide several alternative methods for the



homogeneous solution, such as the Horner method, and expressed confidence that these alternatives would yield the same answer, albeit through a longer process.

Monitoring Indicators

The fulfillment of monitoring indicators was demonstrated by the student's ability to organize solution steps, analyze critical information, execute the subsequent steps, and employ appropriate strategies. The performance results of the **SKT** subject are presented in Figure 1. To support these findings, the researchers have included excerpts from the interview with the **SKT** subject.

$y'' - 2y' + y = 0$
 $\Rightarrow$ Solusi homogen
 $F_k \Rightarrow \lambda^2 - 2\lambda + 1 = 0$
 Mis. $x = \lambda^*$ maka,
 $\lambda^2 - 2\lambda + 1 = 0$
 $(\lambda - 1)(\lambda - 1) = 0$
 $(\lambda^2 - 1)(\lambda^2 - 1) = 0$
 $\lambda_{1,2} = \pm \sqrt{1} \quad \lambda_{3,4} = \pm \sqrt{1}$
 $\lambda_1 = 1, \lambda_2 = -1, \lambda_3 = 1, \lambda_4 = -1$
 $\lambda_1 = \lambda_3 = 1, \lambda_2 = \lambda_4 = -1$
 Maka solusi homogenya:
 $y_h = C_1 e^x + C_2 x e^x + C_3 e^{-x} + C_4 x e^{-x}$

Figure 1. Homogeneous Solution

- P** : Saat mengerjakan soal, bagaimana cara Anda memastikan bahwa setiap langkah yang dilakukan sudah benar?
- SKT** : Baik pak, pada solusi homogen, ketika saya telah mendapatkan solusi persamaan karakteristiknya saya substitusi kembali jika mendapatkan 0 maka saya yakin bahwa jawaban atau langkah pengerjaan saya sudah benar.
- P** : Apakah Anda pernah merasa ragu atau menyadari adanya kesalahan di tengah proses penyelesaian? Apa yang Anda lakukan saat itu?
- SKT** : Biasa pak, apalagi jika melibatkan tanda +/-, biasanya saya cek kembali dari awal setiap langkahnya apakah sudah sesuai atau tidak.

Based on the results of the work process and subsequent interviews with the **SKT** subject, it was evident that the monitoring indicators were successfully fulfilled. The problem-solving steps taken by the **SKT** subject were appropriate and demonstrated the ability to analyze critical information. It could be observed that the subject effectively executed the plans previously established. Furthermore, the **SKT** subject was able to determine the necessary subsequent steps,

and the designed strategies were implemented efficiently. The subject successfully identified the characteristic roots of the equation, leading to the correct homogeneous solution. The process for determining the specific (particular) solution is further detailed in Figure 2 and supported by the interview data.

Handwritten notes showing the initial assumption for a particular solution for e^x . The notes include: "Solusi Homogen", "karena $r(x) = e^x + \sin x$ maka pilih:", $y_{k1} = Ax^2 e^x$, $y_{k2} = A \cos x + B \sin x$, and the differential equation $y'' - 2y' + y = e^x$.

Should be
 $y_{k1} = Ax^2 e^x$

Handwritten notes showing the calculation of the particular solution for e^x . The notes include: "Subst. y_{k1} , y_{k2} , dan y_{k3} ke PD", $y'' - 2y' + y = e^x$, $Ax^2 - 2(Ax^2)' + A(x^2)'' = e^x$, $Ax^2 - 2Ax^2 + 2Ax = e^x$, $A = 1/2$, $y_{k1} = 1/2 e^x$, and $y_{k2} = 0$.

Figure 2. Initial Assumption of a Particular Solution for e^x

Handwritten notes showing the calculation of the particular solution for $\sin x$. The notes include: "Subst. y_{k1} , y_{k2} , dan y_{k3} ke PD", $y'' - 2y' + y = \sin x$, $A \cos x + B \sin x - 2(A \cos x + B \sin x)' + (A \cos x + B \sin x)'' = \sin x$, $A \cos x + B \sin x - 2A \cos x - 2B \sin x + A \cos x + B \sin x = \sin x$, $A = 0$, $B = 1/2$, and $y_{k2} = 1/2 \sin x$.

Figure 3. Particular Solution for $\sin x$

- P : Kemudian untuk solusi partikularnya, bagaimana memastikan bahwa setiap langkahnya sudah benar?*
- SKT : Untuk pemisalan yang pertama sepertinya salah pak, harusnya disitu Ax^2e^x karena yang xe^x adami disolusi homogenya, kemudian pada bagian turunan saya yakin bahwa turunan dari $\sin x$ adalah $-\cos x$ serta $\cos x$ adalah $\sin x$ kemudian bisa juga menggunakan integral yang merupakan anti turunan.*
- P : Bagaimana Anda mengecek kesesuaian antara langkah yang sedang Anda kerjakan dengan rencana awal yang telah dibuat?*
- SKT : Pertama saya perhatikan kembali langkah pengerjaan saya, kemudian melihat apakah tidak ada kesalahan pada setiap langkahnya.*
- P : Apakah Anda mengubah strategi atau metode di tengah pengerjaan? Jika iya, apa alasan perubahan tersebut?*
- SKT : Tidak ada pak, saya kerjakan sesuai dengan rencana awal yang saya tentukan.*
- P : Bagaimana Anda memantau penggunaan rumus atau prosedur agar tetap sesuai dengan jenis persamaan diferensial yang dihadapi?*
- SKT : Misal pada solusi khususnya pak, Saya perhatikan kembali dari konstantanya, misalnya karena konstantanya $\sin x$ maka pemisalannya adalah $A \cos x + B \sin x$, karena $\sin x$ tidak ada pada solusi homogen maka tidak perlu lagi dikalikan x , atas dasar itu saya yakin bahwa jawaban saya benar.*

Regarding the particular solution, the subject made a minor error in the trial solution for e^x , where the subject initially wrote Axe^x . During the interview, the subject realized the mistake, noting that it resulted from a lack of thoroughness in reviewing the homogeneous solution. Specifically, the subject acknowledged that the trial solution should have been Ax^2e^x , as the previous simplification showed that a similar term already existed in the homogeneous solution. For the $\sin x$ component, the subject understood that the particular solution did not need to be multiplied by x again, as there was no corresponding term in the homogeneous solution. Consequently, the subject was able to complete the particular solution for this part without further errors.

Indicators of Evaluation

The evaluation indicators are considered fulfilled if the student is capable of writing the final answer, expresses confidence in their response, and can demonstrate the accuracy of the



final results obtained. Figure 4 presents the work of the **SKT** subject, which is further supported by the accompanying interview results.

Handwritten work showing a differential equation solution. The final line is $y = C_1e^x + C_2xe^x + C_3e^{-x} + C_4xe^{-x} - xe^x + \frac{1}{4} \sin x$. A red arrow points from a box on the right to the $-xe^x$ term.

Should be
 $-1/4 xe^x$

Gambar 4. Final Answer

P : Setelah mendapatkan jawaban akhir, apa yang Anda lakukan untuk memastikan bahwa jawaban tersebut benar?

SKT : Saya tidak sempat mengecek kebenaran jawaban saya pak karena kehabisan waktu. Jika masih ada waktu saya biasanya cek kembali langkah-langkah setiap pengerjaan saya untuk memastikan jawaban saya sudah benar.

P : Apakah Anda meninjau kembali langkah-langkah penyelesaian yang telah dilakukan? Bagian mana yang biasanya Anda periksa?

SKT : Iya pak, saya cek pertama pada bagian solusi homogen karena itu akan menentukan kebenaran jawaban untuk selanjutnya pada solusi khusus dan jawaban akhir. Jika salah disolusi homogen maka akan berpengaruh ke solusi akhirnya juga pak.

P : Jika jawaban Anda ternyata salah, menurut Anda di bagian mana kemungkinan kesalahan terjadi?

SKT : Menurut saya pada bagian pemisalan untuk solusi khususnya pak, seharusnya disitu Ax^2e^x karena Axe^x sudah ada pada solusi homogenya, disitu kesalahan saya pak.

Based on the final written answers and the interviews conducted with the **SKT** subject, it was observed that the subject was unable to provide the correct final answer. This was due to an error the subject made while simplifying the particular solution for e^x . However, during the interview, the subject was able to identify and realize the location of the error and subsequently understood what the correct solution should have been. This indicates that while the **SKT** subject has not yet fully reached the evaluation indicator effectively—given the inability to write the correct final answer—the subject demonstrated the ability to critically correct their mistakes and identify the necessary improvements to obtain the appropriate solution.

Skills Metacognition of SKS Subject

In this study on metacognitive skills in problem-solving, one student with moderate mathematical ability was selected as a research subject. The results indicated that subject **SKS** was able to fulfill two metacognitive indicators, namely planning and monitoring, although the subject did not fully succeed in obtaining the correct answer. The following is a detailed explanation of each metacognitive indicator in the problem-solving process for the subject with moderate mathematical ability:

Planning indicators

The interview results with the SKS subject are presented below.

- P : Ketika pertama kali membaca soal persamaan diferensial orde tinggi ini, hal apa yang langsung Anda pahami dari soal tersebut?*
- SKS : Pertama kali saya tahu bahwa persamaan ini merupakan persamaan diferensial linear orde tinggi nonhomogen*
- P : Informasi apa saja yang menurut Anda penting dari soal sebelum mulai menyelesaikannya?*
- SKS : Yang pertama dari soalnya, karena disitu y pangkat 4 – 2 y pangkat 2 + $y = e^x + \sin x$ berarti merupakan nonhomogen karena tidak sama dengan 0*
- P : Strategi atau metode apa yang Anda rencanakan untuk menyelesaikan soal ini? Mengapa memilih strategi tersebut?*
- SKS : Untuk Solusi homogennya bisa menggunakan beberapa cara, pertama metode horner, pefaktoran dan rumus ABC, tapi saya menggunakan metode horner karena menurut saya itu yang paling mudah. Untuk Solusi partikularnya menggunakan metode koefisien tak tentu sesuai dengan soalnya pak.*
- P : Apakah Anda mempertimbangkan lebih dari satu cara penyelesaian sebelum mulai mengerjakan? Jelaskan.*
- SKS : Bisa menggunakan metode ABC, misalnya koefisien lamda pangka 4nya kita ambil sebagai a, -2 sebagai b dan 1 sebagai c kemudian dimasukkan kedalam rumus ABC*
- P : Tapi kan ini pangkat 4 sedangkan rumus ABC untuk persamaan kuadrat?*
- SKS : Oh iya ya pak, saya tidak begitu memahami caranya*

Based on the interview results with the **SKS** subject, it was evident that the subject was capable of developing proper planning to solve the given problems. The subject demonstrated a clear understanding of the essential information required for the solution. Specifically, the subject identified that the problem was a non-homogeneous high-order linear differential equation, as



indicated by the fact that the function was not equal to zero 0. Furthermore, the subject understood the necessary steps: first determining the homogeneous solution and then finding the particular (specific) solution to obtain the final result. The subject was also able to select an appropriate method for the problem and developed an initial draft for the solution.

Monitoring Indicators

Figure 5 displays the subject's answer, followed by the results of the interview with the subject.

The roots of the solution should be 1, 1, -1, and -1

Should use (+)

Figure 5. Homogeneous Solution

- P : Saat mengerjakan soal, bagaimana cara Anda memastikan bahwa setiap langkah yang dilakukan sudah benar?
- SKS : Baik pak, pada Solusi homogen saya memperhatikan koefisien dari persamaan karakteristiknya untuk dimasukkan kedalam metode horner kemudian saya melakukan uji angka untuk dimasukkan dan mencari akar penyelesaiannya.
- P : Kenapa pada Langkah ini kamu kurangkan padahal sebelumnya dan setelahnya ditambah?
- SKS : Supaya mendapatkan angka 0 pak.

Based on the written answers and interviews, it was observed that the subject attempted to execute the homogeneous solution in accordance with the previously established plan. The subject employed the **Horner method** to determine the roots of the characteristic equation. However, an error occurred during the implementation of the Horner method; the subject incorrectly used a minus (-) sign in the second step, reasoning that it was necessary to make the result equal to zero, whereas a plus (+) sign should have been maintained. This lack of precision in calculation resulted in inaccurate roots, which ultimately led to an incorrect homogeneous

solution. The subject's process for determining the particular solution is illustrated in Figure 6, followed by the corresponding interview results.

Handwritten mathematical work showing the derivation of a particular solution for a differential equation. The work is divided into two parts. The top part shows the derivation of a particular solution for a differential equation with a sine/cosine forcing function, resulting in $y_p = \frac{1}{4} \sin x$. The bottom part shows the start of finding a particular solution for a differential equation with an exponential forcing function, where $y_p = Ax^2e^x$ is written. A red arrow points from a text box to this expression.

Should be Ax^2e^x

Figure 6. Particular Solution

- P : Kemudian untuk Solusi partikularnya, bagaimana memastikan bahwa setiap langkahnya sudah benar?
- SKS : misal pada bagian turunan $A \sin x + B \cos x$, untuk mengecek kebenarannya bisa menggunakan cara integral, jadi dibalik kemudian ketika yakin sudah benar saya lanjutkan ke turunan berikutnya.
- P : Apakah Anda pernah merasa ragu atau menyadari adanya kesalahan di tengah proses penyelesaian? Apa yang Anda lakukan saat itu?
- SKS : Sebenarnya sering pak, jika terjadi saya kerja ulang soalnya selagi masih ada waktu pak untuk memastikan apakah benar atau tidak.
- P : Apakah kamu yakin bahwa pemisalan untuk solusi partikularnya sudah tepat?
- SKS : Saya kurang yakin pak, karena saya lupa pemisalan untuk e pangkat x . Kalau untuk pemisalan $\sin x$ saya ingat dari tabel yang bapak berikan.
- P : Bagaimana Anda memantau penggunaan rumus atau prosedur agar tetap sesuai dengan jenis persamaan diferensial yang dihadapi?
- SKS : Saya perhatikan Kembali bentuk soalnya pak, jika sudah yakin dengan rumus yang saya gunakan maka saya menggunakan rumus tersebut.

Regarding the particular solution, specifically the trial solution for e^x , the subject made a minor error by writing Ax^3e^x as the initial assumption. During the interview, when asked about this step, the subject admitted to forgetting the correct analogy (rule of substitution) for such cases. In contrast, for the $\sin x$ component, the subject understood that the particular solution did not need to be multiplied by x , as there was no corresponding term in the homogeneous solution. Consequently, the subject was able to complete the particular solution for this part without further errors.

Indicators of Evaluation

The SKS subject did not have sufficient time to write the final answer due to time constraints during the examination. The following are the interview results with the SKS subject regarding the evaluation indicators.

P : Setelah mendapatkan jawaban akhir, apa yang Anda lakukan untuk memastikan bahwa jawaban tersebut benar?

SKS : Saya belum sempat menuliskan jawaban akhir karena terkendala waktu kemudian saya mengalami kendala lupa dengan rumus-rumus yang harusnya digunakan. Tapi untuk memastikan apakah jawaban saya benar biasanya saya kerja ulang jika waktu memungkinkan.

P : Apakah Anda meninjau kembali langkah-langkah penyelesaian yang telah dilakukan? Bagian mana yang biasanya Anda periksa?

SKS : Iya pak, bagian pertengahan, apakah langkah-langkahnya sesuai atau tidak, misal pada bagian turunan, saya cek ulang kembali karena waktu mengerjakan banyak saya ganti karena kesalahan yang saya lakukan.

P : Jika jawaban Anda ternyata salah, menurut Anda di bagian mana kemungkinan kesalahan terjadi?

SKS : Menurut saya pada bagian turunannya $\sin x$ dan $\cos x$ pak, saya kebingungan dengan tanda negatifnya, kemudian juga pada turunan Ax^3e^x dan Ax^3e^x , harusnya menggunakan u.v

Based on the interview results, it was evident that the SKS subject had not yet achieved the evaluation indicators. This was because the subject was completely unable to provide the final answer to the given problems. When asked to identify the location of their errors, the subject assumed that the mistake occurred during the differentiation process of the trial solution (particular solution). However, this perception was incorrect; the actual error originated from the



initial trial solution, which was fundamentally inappropriate from the beginning. The subject failed to realize this fundamental mistake, leading to the subsequent errors in the solution.

Skills Metacognitive SKR Subject

In this study concerning the profile of metacognitive abilities in problem-solving, one student with low mathematical ability was selected as a research subject. Based on the field study involving the **SKR** subject, it was found that only one metacognitive indicator was nearly fulfilled, namely the planning indicator. The following is a detailed explanation of each metacognitive indicator related to the problem-solving process of the low-ability subject.

Planning Indicators

The interview results with the SKR subject are presented below.

P : Ketika pertama kali membaca soal persamaan diferensial orde tinggi ini, hal apa yang langsung Anda pahami dari soal tersebut?

SKR : Yang pertama menurut saya ini adalah persamaan diferensial linear orde 4 pak, saya perhatikan pangkat tertinggi dari y nya.

P : Informasi apa saja yang menurut Anda penting dari soal sebelum mulai menyelesaikannya?

SKR : Pertama Pak kita harus mencari solusi homogen dari persamaan tersebut. Kemudian menurut saya persamaan ini merupakan persamaan homogen. Tapi saya lupa alasannya pak.

P : Strategi atau metode apa yang Anda rencanakan untuk menyelesaikan soal ini? Mengapa memilih strategi tersebut?

SKR : Untuk solusi homogennya saya menggunakan metode horner pak. Untuk solusi khususnya menggunakan metode koefisien tak tentu sesuai dengan soalnya pak.

P : Apakah Anda mempertimbangkan lebih dari satu cara penyelesaian sebelum mulai mengerjakan? Jelaskan.

SKR : Kalau dari persamaannya pak, Menurut saya bisa juga mungkin menggunakan pemfaktoran dan rumus ABC. Tapi saya ragu karena disitu lamdanya pangkat 4.jadi menurut saya tidak bisa karena akan sulit diselesaikan.

Based on the written answers and interviews conducted with the **SKR** subject, it was evident that the subject was capable of basic planning to solve the given problems, although they did not yet fully understand the accurate information regarding the questions. The subject actually



understood the essential information required for the solution. However, while they recognized the problem as a high-order linear differential equation, their classification of the equation type was inaccurate because the subject considered the given problem to be homogeneous. Despite this, the subject understood that solving the problem required determining both the homogeneous and particular solutions. Furthermore, the subject was able to identify a method for solving the problem, namely using the Horner method followed by the method of undetermined coefficients, as suggested by the information provided in the question.

Monitoring Indicators

Figure 7 displays the subject's answer, followed by the results of the interview with the subject.

The characteristic equation is incorrect

Figure 7. Homogeneous Solution

- P :** Saat mengerjakan soal, bagaimana cara Anda memastikan bahwa setiap langkah yang dilakukan sudah benar?
- SKR :** Kalau untuk solusi homogen saya perhatikan lagi persamaan karakteristiknya pak, tapi saya ragu dengan jawaban yang saya berikan, nampaknya salah pak.
- P :** Apakah Anda mengubah strategi atau metode di tengah pengerjaan? Jika iya, apa alasan perubahan tersebut?
- SKR :** Tidak ada pak, saya kerjakan sesuai dengan rencana awal yang saya tentukan.
- P :** Bagaimana Anda memantau penggunaan rumus atau prosedur agar tetap sesuai dengan jenis persamaan diferensial yang dihadapi?
- SKR :** Saya lihat dari hasil akhirnya pak. Saya juga kurang memahami apakah langkah yang saya lakukan sudah benar.

Based on the written answers and interviews conducted with the **SKR** subject regarding the homogeneous solution, it was evident that the subject made errors in determining the characteristic equation of the given differential equation. Furthermore, the subject committed errors while applying the Horner method, as they were unable to identify the correct coefficients.



Consequently, the obtained eigenvalues λ were incorrect, leading to an erroneous homogeneous solution. These findings indicate that the subject was unable to meet the monitoring indicators effectively. The subsequent process for the particular solution is illustrated in Figure 8, followed by the interview results with the subject.

Handwritten mathematical work for finding a particular solution. The top part shows an incorrect assumption $y = e^x$ and its derivatives, with a red arrow pointing to a box stating "Should be Ax^2e^x ". The bottom part shows the correct assumption $y = A \cos x + B \sin x$ and its derivatives, with a red arrow pointing to a box stating "Sholud be $A \cos x + B \sin x$ ".

Figure 8. Particular Solution

- P : Kemudian untuk Solusi partikularnya, bagaimana memastikan bahwa setiap langkahnya sudah benar?
- SKR : Kalau saya sesuai dengan apa yang sudah dipelajari saat perkuliahan pak, seperti turunan e^x adalah dirinya sendiri jadi saya yakin jawaban saya benar. untuk turunan $\sin x$ dan $\cos x$ saya tidak begitu yakin pak karena saya lupa caranya.
- P : Apakah Anda pernah merasa ragu atau menyadari adanya kesalahan di tengah proses penyelesaian? Apa yang Anda lakukan saat itu?
- SKR : Sering pak, Kucoba terus pak sampai saya tidak bisa lagi mengerjakannya pak.
- P : Ketika mengalami kesulitan pada tahap tertentu, apa yang biasanya Anda lakukan untuk mengatasinya?
- SKR : Memeriksa kembali setiap langkah yang saya gunakan dari awal pak.

Regarding the particular solution, specifically the trial solution for e^x , the subject committed an error by simply writing e^x as the assumption. During the interview, it became evident that the subject did not know the correct analogy (rule of substitution) required for this step. For the $\sin x$ component, the subject multiplied the trial solution by x , even though $\sin x$ did not appear in the homogeneous solution, meaning such a multiplication was unnecessary. In the interview, the subject admitted to not knowing the appropriate distinctions and having an inadequate understanding of the process. This indicates that the **SKR** subject was unable to meet

the monitoring indicators effectively when solving the given problems.

Indicators of Evaluation

The **SKR** subject did not have sufficient time to write the final answer due to time constraints while working on the given problems. The following are the results of the interview with the subject regarding the evaluation indicators:

P : Setelah mendapatkan jawaban akhir, apa yang Anda lakukan untuk memastikan bahwa jawaban tersebut benar?

SKR : Saya tidak mengerjakan sampai selesai pak, karena ada yang salah dari metode yang saya gunakan pak. Untuk memastikan jawaban saya benar atau tidak saya kurang tau juga pak.

P : Apakah Anda meninjau kembali langkah-langkah penyelesaian yang telah dilakukan? Bagian mana yang biasanya Anda periksa?

SKR : Untuk soal ini tidak sempat pak, karena saya kehabisan waktu tapi saya lihat pada jawaban solusi homogen yang kurang tepat, karena disitu ada lamda yang sama harusnya tidak begitu jawabannya.

P : Jika jawaban Anda ternyata salah, menurut Anda di bagian mana kemungkinan kesalahan terjadi?

SKR : Pertama di solusi homogennya pak seperti yang saya jelaskan sebelumnya. Kemudian pada solusi partikularnya juga pak tapi saya tidak begitu mengetahui letak kesalahannya pak.

P : Seperti pemisalan pada solusi partikularnya, untuk e^x kenapa tidak menambahkan variabel dan untuk $\sin x$ kenapa bisa dikalikan lagi dengan x ?

SKR : Oh iya pak saya keliru saat mengerjakannya. Karena saya lupa pemisalan yang benar seperti apa pak.

Based on the interview results with the **SKR** subject, it was evident that the subject had not yet reached the evaluation indicators. This was because the subject was completely unable to write the final answer to the given problems. When asked to identify the location of their errors, the subject only stated that an error occurred in both the homogeneous and specific solutions without being able to explain the specific nature of the mistake.

Based on the presentation of research results for each subject across the metacognitive skill indicators, it was found that students with high mathematical ability demonstrated good metacognitive skills in solving the given problems. These students were able to read and



understand the problems thoroughly before attempting them. This finding is positively correlated with previous research by (Pramono, 2017), which found that students with high mathematical ability think about methods to understand the problem, verify their understanding, and consider other aspects that might be inherent in the problem. Furthermore, students with high mathematical ability were also able to implement and monitor the methods they had established. This is in line with a previous study suggesting that students with high metacognitive skills tend to use appropriate strategies, correct mathematical notation, and logical reasoning, enabling them to provide correct answers (Fatmawati et al., 2025). Regarding the evaluation indicators, these students were capable of writing the final results, even though minor errors occasionally occurred due to a lack of precision in their settlement steps. However, in general, students with high mathematical ability possess strong metacognitive skills. This aligns with previous research stating that students with good metacognitive awareness tend to be capable of determining appropriate settlement strategies, monitoring the suitability of the steps taken, and critically evaluating the accuracy of the results (Güner & Erbay, 2021).

Students with moderate mathematical ability were generally able to reach the planning and monitoring indicators, although not perfectly. These students understood the important information and methods required to solve the problem and were able to plan an appropriate strategy. However, they made errors in implementing the determined methods for both the homogeneous and specific solutions. These errors occurred because the students forgot the concepts required to solve the given questions. Huda et al. (2025) previously found that students may experience a decrease in metacognitive levels because they fail at certain information-processing stages (for example, failing to store information in long-term memory or incorrectly retrieving data). Consequently, these students were completely unable to write the final answer, meaning the evaluation indicators could not be fulfilled. This is in line with a study by Setyaningsih & Rahmawati (2022), which found that students with moderate metacognitive ability are only capable of fulfilling the planning and monitoring indicators but fail to reach the evaluation stage due to procedural errors. The failure to reach the evaluation stage occurs because students do not realize that an error has occurred, thus they do not perform a re-check. This statement is consistent with previous research suggesting that students may be able to plan, but upon reaching the evaluation stage, they fail to realize that their strategy was ineffective or their calculations were incorrect (Huda et al., 2018).

Students with low mathematical ability were only able to reach the planning indicator. These students could explain the necessary information and identify the right method to solve the



problem, although further tracing revealed they did not fully understand the specific type of equation given. In the process of strategy implementation, they made errors in determining characteristic equations and specific solution examples, leading to a failure in obtaining the final result. This indicates that the monitoring indicator was not successfully achieved. This is consistent with a study by Huda et al. (2018) which noted that subjects experiencing metacognitive failures often fail in evaluation when considering the effectiveness and limitations of their own thinking, the chosen strategy, and the difficulty level of the problem. Finally, they were unable to write the final answer due to a lack of time and an inability to implement efficient strategies. Their understanding was limited to what was asked, consistent with a study by Adinda et al. (2023), which found that students with low ability often solve problems without a specific strategy, relying instead on trial and error.

These findings show that a student's success in solving high-order linear differential equations is highly dependent on the consistency of metacognitive regulation at every stage of information processing. The failure of medium and low-ability students to reach the evaluation indicator confirms that procedural mastery alone is insufficient without the awareness to monitor thinking limitations and strategy effectiveness. Therefore, it is recommended that educators focus not only on verbal material delivery and routine practice but also integrate learning models that explicitly practice metacognitive skills, such as scaffolding techniques or the use of reflective journals.

CONCLUSION

The findings of this study demonstrate that students' problem-solving skills are significantly influenced by their metacognitive abilities, which vary according to their mathematical proficiency. Students with high mathematical ability exhibited strong metacognitive skills across all indicators: planning, monitoring, and evaluating their problem-solving strategies effectively. Students with moderate mathematical ability showed metacognitive competence in planning and monitoring but faced difficulties in evaluation; they frequently overlooked details in their calculation steps, leading to a failure in producing the final answer. Conversely, students with low mathematical ability were only able to reach the planning indicators, struggling significantly with monitoring and evaluation, which resulted in errors during strategy implementation and a complete inability to provide the final results.

Nevertheless, this research has limitations, including a limited number of subjects and a focus on only one specific topic, namely high-order linear differential equations. Consequently,



these findings cannot be generalized to all mathematical topics. Furthermore, this study was limited to describing metacognitive profiles without providing specific interventions to address the identified metacognitive failures. Therefore, it is suggested that future research conduct experimental studies to test the effectiveness of metacognition-based learning models in increasing students' learning independence. The use of more objective instruments, such as eye-tracking software or digital think-aloud methods, is also recommended to uncover students' cognitive processes in a more in-depth and accurate manner.

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