Math Didactic: Jurnal Pendidikan Matematika

Volume 10 Nomor 2, Mei – Agustus 2024, halaman 250 – 266

Tersedia Daring pada https://jurnal.upk.ac.id/index.php/math

ANALYSIS OF STUDENT ERRORS FUTURE MATHEMATICS TEACHERS IN SOLVING COMPLEX ANALYSIS PROBLEMS

ANALISIS KESALAHAN MAHASISWA CALON GURU MATEMATIKA DALAM MENYELESAIKAN SOAL ANALISIS KOMPLEKS

Arif Muchyidin*[1], Rasilah Rasilah[2], Zussette Candelario-Aplaon[3], Moh Hayat[4]

[1]IAIN Syekh Nurjati Cirebon, Jl. Perjuangan, Sunyaragi, Kec. Kesambi, Kota Cirebon, Indonesia

[2]STKIP NU Indramayu, Jl. Raya Kaplongan No.28, Kaplongan, Kec. Karangampel, Kabupaten Indramayu, Indonesia

[3]Mindoro State University, Victoria, Oriental Mindoro, Philippines

[4]Politeknik AKA Bogor, Jl. Pangeran Sogiri, Tanah Baru, Bogor Utara, Kota Bogor, Jawa Barat 16154, Indonesia

[1]arif.muchyidin@gmail.com, [2]rasilah.pramuka@gmail.com, [3]zcaplaon11@gmail.com, [4]moh_hayat@aka.ac.id

**Corresponding Author*

Abstract: This study aims to analyze the mistakes that are often made by future mathematics teachers when working on essay questions in complex analysis courses, using Watson criteria. This qualitative research was conducted in the odd semester of the 2023-2024 academic year, with the research subject being 5th-semester class C students at IAIN Syekh Nurjati Cirebon. From the data obtained, only 38.89% of students answered the questions correctly, while 61.61% of the errors made by students were categorized according to Watson's criteria. These criteria include inappropriate data (12.9%), inappropriate procedures (45.16%), omitted data (0%), omitted conclusions (9.68%), response level conflicts (8.68%), undirected manipulation (3.23%), skill hierarchy problems (20.97%), and other categories (0%). The most common error made by the majority of students was inappropriate procedures. This type of error often arises due to a lack of deep understanding of the material, confusion in applying certain concepts, or negligence in carefully reading instructions. Analysis of student errors based on Watson's criteria provides significant insight into the patterns of errors made by students.

Keywords: complex analysis, inappropriate procedure, skill hierarchy problems, Watson criteria

Abstrak*: Penelitian ini bertujuan untuk menganalisis kesalahan yang sering dilakukan mahasiswa calon guru matematika saat mengerjakan soal esai pada mata kuliah analisis kompleks dengan menggunakan kriteria Watson. Penelitian ini merupakan penelitian kualitatif dan dilakukan pada semester ganjil tahun akademik 2023-2024, dengan subjek penelitian berupa mahasiswa semester 5 kelas C di IAIN Syekh Nurjati Cirebon. Dari data yang diperoleh, hanya 38,89% mahasiswa yang menjawab soal dengan benar, sedangkan 61,61% menjawab salah. Kesalahan yang dilakukan mahasiswa kemudian dianalisa dan dikategorikan menurut kriteria Watson. Kriteria tersebut meliputi data tidak tepat (12,9%), prosedur tidak tepat (45,16%), data yang dihilangkan (0%), kesimpulan yang dihilangkan (9,68%), konflik tingkat respons (8,68%), manipulasi tidak terarah (3,23%), masalah hierarki keterampilan (20,97%), dan kategori lainnya (0%). Kesalahan yang paling umum dilakukan oleh sebagian besar mahasiswa adalah prosedur tidak tepat. Jenis kesalahan ini sering muncul akibat kurangnya pemahaman materi yang mendalam, kebingungan dalam menerapkan konsep tertentu, atau kelalaian dalam membaca instruksi dengan cermat. Analisis kesalahan siswa berdasarkan kriteria Watson memberikan wawasan yang signifikan terhadap pola kesalahan yang dilakukan siswa.*

Kata Kunci*: analisis kompleks, inappropriate procedure, kriteria Watson, skill hierarchy problems*

Cara Sitasi: Muchyidin, A., Rasilah, R., Candelario-Aplaon, Z., & Hayat, M. (2024). Analysis of Student Errors Future Mathematics Teacher in Solving Complex Analysis Problems. *Math Didactic: Jurnal Pendidikan Matematika*, 10(2), 250-266. https://doi.org/10.33654/d8dxsm75

Submitted: May 2, 2024
Revised: August 28, 2024
Published: August 30, 2024
Available Online Since: February 7, 2025

https://doi.org/10.33654/d8dxsm75

Mistakes often made by students in math essay problems can vary, including a lack of understanding of basic concepts (Afniandari et al., 2021; Lima et al., 2019; Sari et al., 2019), such as failing to execute the calculation operation correctly (Rulika et al., 2024), less skilled in performing calculations and do not carry out the completion process correctly (Wahyuni et al., 2023), or lack of student understanding of the symbols in math problems (Beba et al., 2022). Some students may rush to solve problems without fully understanding the underlying concepts. This can result in mistakes during problem-solving and harm the final result. Therefore, students need to spend enough time understanding the basic concepts before stepping into the stage of working on math essay problems.

Another common mistake is a lack of attention to the resolution steps. Some college students may be in a hurry and ignore the proper steps to solve the problem. A good understanding of the procedures and steps for completion is essential, as errors in the early stages can creep into the next stage and result in incorrect answers (Haryanti et al., 2019; Liew et al., 2022; Natalia et al., 2021; Rohmah & Sutiarso, 2018). For example, in a complex problem involving complex numbers, if a student makes an initial mistake in determining the polar form of a complex number, then this can lead to a series of errors in the following steps. A concrete example of this is when students are asked to find the root of a complex number. If, in the initial step, the student miscalculates or converts a complex number from a Cartesian form to a polar form, this error will affect all subsequent calculations. For example, if an actual complex number should be written as $r(\cos\theta + i\sin\theta)$ Furthermore, if students miscalculate the value r or θ, then any mathematical operation involving this polar form, such as calculating roots, exponents, or other operations, will be false. As a result, students may get mismatched results and become increasingly confused with related advanced concepts, such as complex number transformations or the application of de Moivre's theorem, which require a correct understanding of polar forms. These early mistakes create a large understanding gap, making it difficult for students to understand more complex concepts at a later stage. Therefore, students must practice following the steps systematically and thoroughly when doing math essay problems to increase their accuracy and understanding of the material, for example, by repeating steps with different problems to reinforce previous understanding.

Future mathematics teachers need to reduce errors in solving essay problems because they will play an essential role in guiding and teaching students in the future. As future mathematics teachers, their ability to demonstrate a deep understanding of mathematical concepts through solving essay problems can be a role model for students. Reducing errors in the process will make it easier for students to understand the methods and steps of completion correctly.

In addition, mistakes in doing essay questions can also affect students' confidence in mathematics (Kartikasari & Widjajanti, 2017; Kaur & Prendergast, 2022; Mazana et al., 2019). As future mathematics teachers, they are responsible for guiding students in building confidence in their math skills. By reducing errors in essay problems, future math teachers can create a positive and supportive learning environment where students feel more confident and motivated to take on math challenges.

One effort to improve the understanding of future mathematics teacher students is to analyze the answers to essay questions given based on Watson's criteria. Watson's criteria are used in this study to make it easier to categorize students' errors from each step of students' answers (Buhaerah et al., 2022). Watson is an expert in stimulus-response (S-R) psychology who coined the eight criteria

for identifying errors (Hassan & Madhum, 2007). Analysis of essay errors based on Watson criteria is essential to improve the quality and effectiveness of learning (de Vries et al., 2022; Mafruhah & Muchyidin, 2020; Munna & Kalam, 2021). The criteria for errors experienced in solving the problems referred to by Watson include inappropriate data, inappropriate procedures, omitted data, Omitted conclusions, response level conflicts, undirect manipulation, and skill hierarchy problems. These errors indicate a gap in the basic skills needed, and in addition to the seven categories (Errors that do not fall into the above categories but are still relevant to the analysis of student errors. These may include errors due to negligence, inattention, or spelling errors)" (Mafruhah & Muchyidin, 2020; Surya & Syahputra, 2017). By utilizing Watson's criteria, educators can identify patterns of error that often occur at a given cognitive level. For example, do students have difficulty detailing the completion steps or experience barriers to understanding basic concepts? With this analysis, educators can design more targeted instructional interventions to help students overcome those mistakes.

The application of Watson's criteria in the analysis of essay errors can also provide deep insights related to cognitive and conceptual aspects that may be missed in learning. For example, teachers give questions and challenges to arouse curiosity (Buhaerah et al., 2022). Apperception that is less will adversely affect the success of students in the following material (Maharani et al., 2020), conceptual understanding and procedural knowledge are essential for students to master (Nahdi & Jatisunda, 2020). By understanding the root cause, educators can develop learning strategies that are more adaptive and responsive to students' individual needs. In addition, Watson-based error analysis can be an effective self-evaluation tool for students, helping them realize their weaknesses and formulate improvement plans. Thus, using Watson's criteria to analyze essay errors contributes to improving learning and developing a more personalized and effective learning approach.

One of the courses taught to future math teachers is complex analysis. Students need to study complex analysis, including the concepts of complex numbers, modulus of complex numbers, limits, derivatives, and integrals of complex numbers. A deep understanding of complex analysis provides invaluable provisions in teaching mathematics to students. As aspiring teachers, a good understanding of complex numbers allows them to provide students with more contextual and applicable explanations, helping them relate mathematical concepts to real-world situations. One example that is close to daily life is in electrical circuits and so on.

In addition, understanding complex analysis can also improve the quality of teaching and motivate students to develop higher analytical skills. By understanding these concepts, future mathematics teachers can deliver mathematics lessons more dynamically, show the connection between topics, and build a solid mathematical foundation for students. The ability to teach complex analysis also prepares future mathematics teachers to design innovative learning, utilize more contextual approaches, and provide challenges appropriate to the student's level of understanding. Thus, studying complex analysis gives aspiring mathematics teachers an edge, enriches their teaching quality, and indirectly motivates students to develop their interest and expertise in mathematics.

A review of various studies shows that students often experience difficulties and make mistakes in understanding and solving problems involving complex numbers. For example, Meifiani (2018) found that students at STKIP PGRI Pacitan often made misunderstandings, such as equating symbols that should be different, as well as errors in calculating roots and determining coordinates. A similar error was found by Afianti et al. (2024), who noted that errors in concepts and calculations

often occur in students of Tadris Mathematics. Yolanda & Sthephani (2021) at the Islamic University of Riau also show that students often make mistakes in facts, concepts, and principles, such as confusion in determining polarity and integral formulas, as well as operational errors caused by rushing to solve problems.

Other research, such as those conducted by Emily et al. (2015), emphasized the difficulty of students in switching between complex number forms and choosing the correct form to simplify calculations. Utami (2022) examines student errors based on the level of learning independence and finds that students with low independence are more prone to errors in process skills and answer writing. Meanwhile, EL-Khateeb (2016) at King Saud University identified a variety of common errors, including conceptual errors in complex number operations and simplification of numerical expressions.

Based on the above facts, assessing and analyzing future mathematics teacher mistakes in complex analysis course essay questions is crucial. The importance of analyzing the mistakes of future teacher students in working on complex analysis problems lies in their ability to identify and understand the difficulties students face in designing a more effective teaching approach. By understanding common patterns of errors, future mathematics teachers can provide more targeted and relevant guidance to students, helping them overcome barriers to understanding complex analytical concepts. Error analysis can also be a window into students' cognitive barriers (obstacles or difficulties faced by individuals in the process of thinking, understanding, learning, or processing information) to understanding the material so future mathematics teachers can develop more adaptive and responsive learning strategies (an approach to education that adapts teaching and learning methods based on student's individual needs and their responses during the learning process). In addition, error analysis skills help future mathematics teachers develop empathy for the learning journey.

Research Methods

This qualitative research was conducted during the odd semester of the 2023-2024 academic year at the Department of Tadris Mathematics, State Islamic Institute (IAIN) Syekh Nurjati Cirebon. The study focused on fifth-semester students in class C, who are future mathematics teachers, totaling 25 participants. The primary aim was to understand the types of mistakes these students make when solving complex analysis problems. Data were collected using a set of four essay questions and semi-structured interviews, which ensured the collection of information relevant to the research objectives. The essay questions covered topics such as finding the roots of complex numbers, the modulus of complex numbers, limits of complex functions, and harmonic functions. The students' answers were analyzed to identify the types of errors according to Watson's criteria. Based on the analysis of the 25 student responses, six students who demonstrated significant mistakes were selected for in-depth interviews.

Watson's criteria include various types of errors: inappropriate data (using irrelevant or incorrect information due to misinterpretation of the problem), inappropriate procedures (selecting unsuitable methods because of a lack of understanding), omitted data (failing to use all necessary information, indicating a lack of awareness of the importance of specific data), omitted conclusions

(not providing final answers due to uncertainty about the steps taken), response level conflicts (inconsistencies in understanding different stages of a problem), undirected manipulation (random calculations without a clear solution path), and skill hierarchy problems (lacking basic skills needed to tackle complex problems). Additionally, other errors that may not fit these categories but are still relevant, such as negligence, inattention, or simple mistakes, are also considered. These criteria help thoroughly analyze student errors to improve teaching and learning processes.

Research Results and Discussion

Results

After the data was taken and processed from the research, it was found that most of the questions were not answered correctly by students. Consider the following diagram:

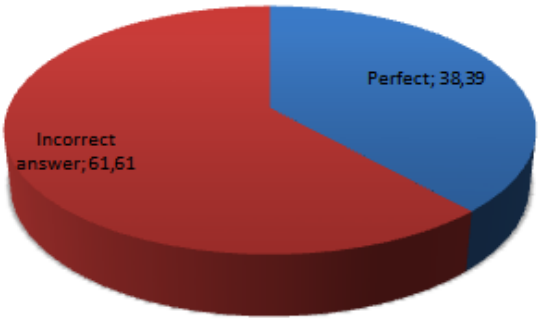
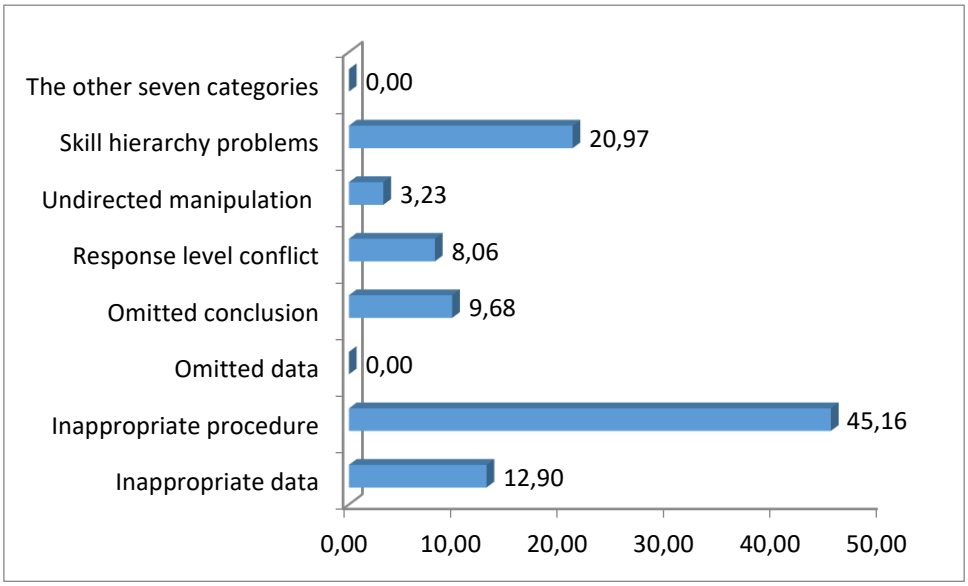


Figure 1. Percentage of answers

Based on Figure 1 above, it can be seen that the percentage of students answering each question correctly is 38.39%, and the rest are wrong. The number of students who answer questions incorrectly is a phenomenon that can invite serious consideration regarding the learning and evaluation process in the academic environment. The causes of these errors can vary, ranging from a lack of understanding of the material and lack of preparation before exams to psychological pressure that students may feel.

The 61.61% of answer errors made by students were mapped according to Watson's criteria. The criteria for errors experienced in solving the problems referred to by Watson include inappropriate data, inappropriate procedures, missing data, missing conclusions, response level conflicts, indirect manipulation, skill hierarchy problem, and in addition to the seven categories (above other) (Aswin & Juandi, 2022; Buhaerah et al., 2022; Evriyanti et al., 2020; Nursalam et al., 2020). From these eight criteria, the following results were obtained:

Table 1. Percentage of error type



Based on Table 1 above, of the eight Watson error criteria, the most common mistake made by students is in the criteria of inappropriate procedures. In this context, these errors can include using procedures or methods that are inappropriate for the specific situation or context. These errors can harm operational efficiency and lead to inaccurate or undesirable results. Therefore, understanding and identifying findings of inappropriate procedure type errors makes an essential contribution to improved procedures, increased efficiency, and improved results quality in various application contexts. By correcting detected procedure nonconformities, we can optimize a system's or procedure's performance, minimize the risk of errors, and improve the reliability of the entire process.

In addition to reading a recapitulation of the types of errors in answering the questions, the following will discuss examples of mistakes made by students in solving complex analysis problems carried out by future teacher students. For details, please see below:

Inappropriate data

Inappropriate data type error is when the data does not match or values are incorrectly entered into variables (Nursalam et al., 2020). The impact of inappropriate data errors can be significant, undermining data integrity and resulting in inaccurate analysis. Therefore, careful attention to data validity during collection and processing is crucial to ensure that the information produced is relevant, consistent, and reliable. Identifying and correcting this type of error is a crucial step to improve data quality so that the results of the analysis taken from the data become more valid and can support proper decision-making.

Based on Table 1 above, this type of error is made by students as much as 12.90%. Students rarely make this error because the tested questions are more proof questions. However, some students still make mistakes that should not be done. For example, below is an Inappropriate data type error made by one of the students as follows:

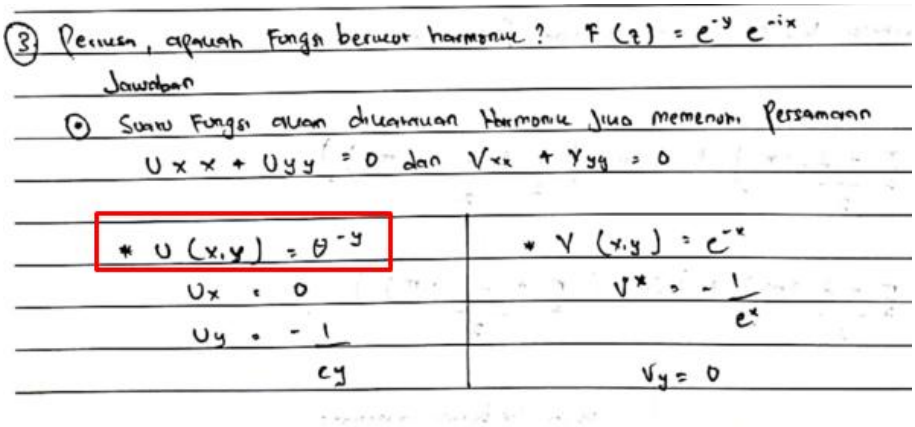


Figure 2. Example 1 Inappropriate data type error

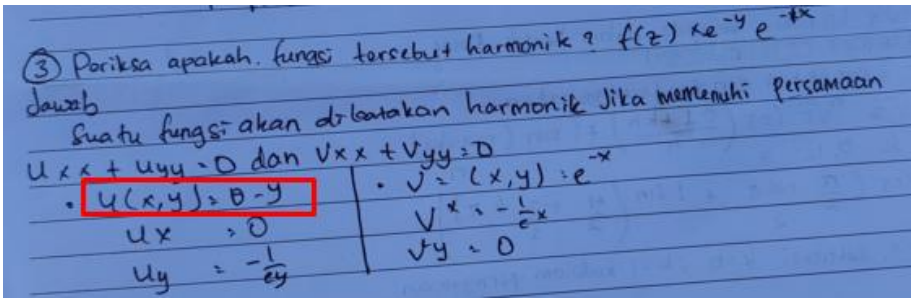


Figure 3. The second example is an Inappropriate data type error

Based on Figure 2 and Figure 3 above, at first glance, the two answers are almost similar, but if you look carefully, there is a significant difference. In the section marked red, students miswrite known data. From the matter, it is known that $\boldsymbol{f(z) = e^{-y}e^{-ix}}$. However, one of the students wrote it down by taking one of the functions $\boldsymbol{u(x,y) = \theta^{-y}}$ And another student wrote $\boldsymbol{u(x,y) = \theta - y}$. Although there are differences in writing ranks, there is a similarity between the two examples, which is that they are both wrong in writing the exponent form ($\boldsymbol{e^{-y}}$) and replace it by writing as theta ($\boldsymbol{\theta}$).

Inappropriate procedure

Inappropriate procedure type error is a condition in which students try to solve problems with the right system, but the use is wrong. Such as incorrectly using formulas, number operations, and operation signs (Nursalam et al., 2020). This situation creates a gap between the student's intention to solve the problem and the implementation of the procedure that should be carried out.

Based on Table 1 above, this type of error is made by students as much as 45.90%. This type of mistake is the type of mistake that most students make. This error can arise due to a lack of deep understanding of the material, confusion in applying certain concepts, or negligence in reading instructions carefully. Identifying and understanding inappropriate procedure-type errors is essential in improving problem-solving skills and understanding mathematical concepts. Educators can help students improve their approach to solving math problems and strengthen their understanding of basic concepts by paying particular attention to correcting these errors.

For example, below is an inappropriate procedure type error made by one of the students as follows:

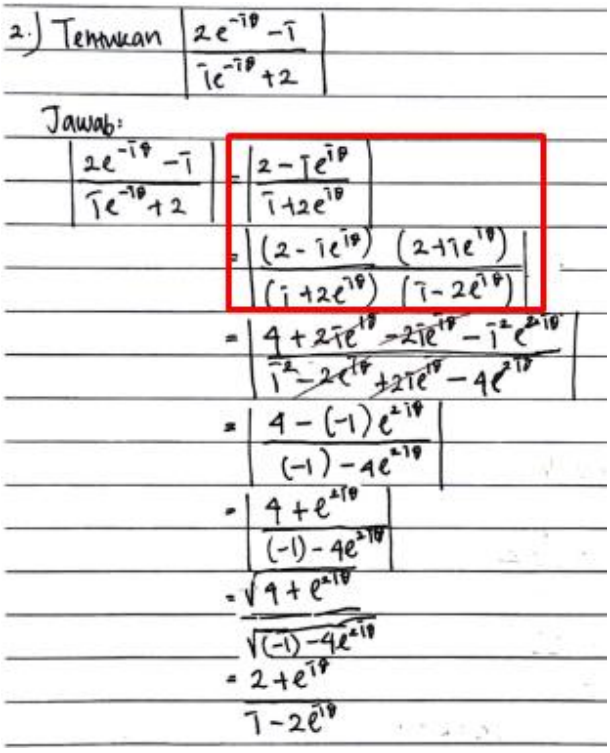


Figure 4. Examples of Inappropriate procedure-type errors

Based on Figure 4 above, students intend to solve the form of the modulus of complex numbers using the properties of the modulus of division. Nevertheless, in the red-marked part, the student mis deciphered the imaginary part of the known problem. If only the form $\boldsymbol{e^{i\theta}}$ outlined in form $\boldsymbol{cos\,\theta + i\,sin\,\theta}$, the form of the problem will become simpler to do.

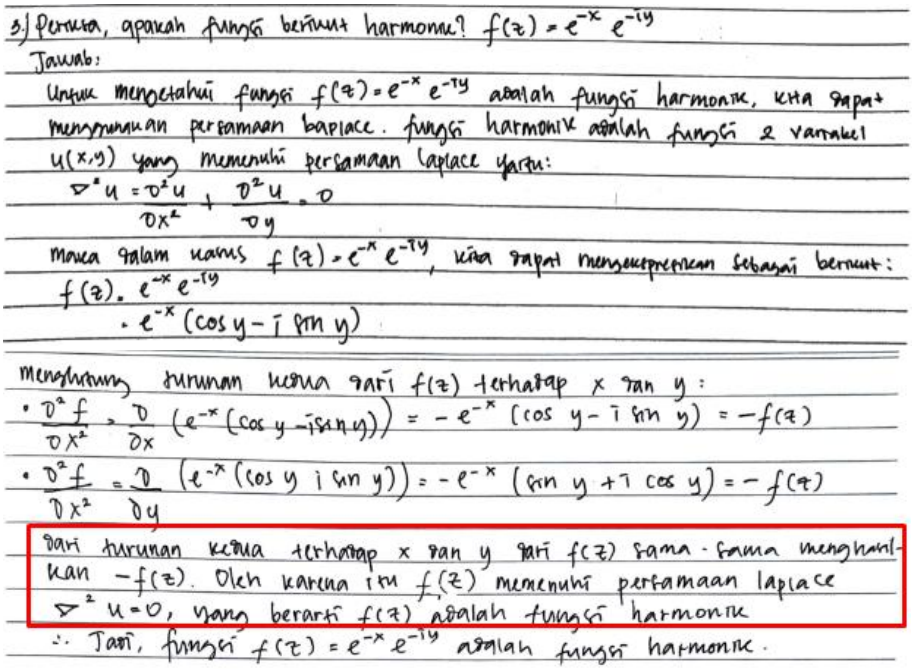
Omitted data

Omitted data type errors occur when data that should have been recorded or incorporated into an analysis or report is intentionally or unintentionally ignored or omitted (Nursalam et al., 2020). This condition can lead to incompleteness of the dataset, resulting in significant errors in the interpretation and analysis of the results. These errors can stem from negligence in data collection, inadvertence in data processing, or even specific intentions to hide information that may be critical. Based on Table 1 above, students do not make this error because the questions do not display much data.

Omitted conclusion

An omitted conclusion type error is when students show the proper procedure but fail to conclude (Nursalam et al., 2020). Based on Table 1, a small percentage of students commit this type of error or about 9.68%. Omitted conclusion-type errors occur when a student successfully

demonstrates the proper procedure or steps in solving a problem or task but fails to draw the appropriate conclusion. This situation can be caused by the student's inability to relate the results of the steps he or she takes to an adequate final answer. Such errors often result from a lack of analytical skills or a deep understanding of concepts. For example, below is an Omitted conclusion-type error made by one of the students as follows:


3) Periksa, apakah fungsi berikut harmonik? $f(z) = e^{-x} e^{-iy}$

Jawab:

Untuk mengetahui fungsi $f(z) = e^{-x} e^{-iy}$ adalah fungsi harmonik, kita dapat menggunakan persamaan laplace. fungsi harmonik adalah fungsi 2 variabel $u(x,y)$ yang memenuhi persamaan laplace yaitu:

$$\nabla^2 u = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y} = 0$$

Maka dalam kamus $f(z) = e^{-x} e^{-iy}$, kita dapat mengekspresikan sebagai berikut:

$f(z) = e^{-x} e^{-iy}$

$= e^{-x} (\cos y - i \sin y)$

Menghitung turunan kedua dari $f(z)$ terhadap x dan y:

- $\frac{\partial^2 f}{\partial x^2} = \frac{\partial}{\partial x} (e^{-x}(\cos y - i \sin y)) = -e^{-x}(\cos y - i \sin y) = -f(z)$
- $\frac{\partial^2 f}{\partial x^2} = \frac{\partial}{\partial y} (e^{-x}(\cos y \; i \sin y)) = -e^{-x}(\sin y + i \cos y) = -f(z)$

dari turunan kedua terhadap x dan y dari $f(z)$ sama-sama menghasilkan $-f(z)$. Oleh karena itu $f(z)$ memenuhi persamaan laplace $\nabla^2 u = 0$, yang berarti $f(z)$ adalah fungsi harmonik

∴ Jadi, fungsi $f(z) = e^{-x} e^{-iy}$ adalah fungsi harmonik.

Figure 5. Example of Omitted conclusion type Error

Based on Figure 5, the first nine steps carried out by students follow the procedure, but at the end of the work (the last seven steps), students cannot make differentials according to the proper concept, so the conclusions drawn are wrong.

Response level conflict

Response level conflict type error is when students work on a problem without using concepts or directly reaching it logically (Nursalam et al., 2020). Table 1 shows that this type of upset is carried out by 8.06% of students or is rarely done by students. Students in this condition may rely on personal memory or intuition without understanding the principles or strategies that should be applied. This can result in less accurate answers or inconsistency with the method that should be used. For example, below is a Response level conflict type error made by one of the students as follows:

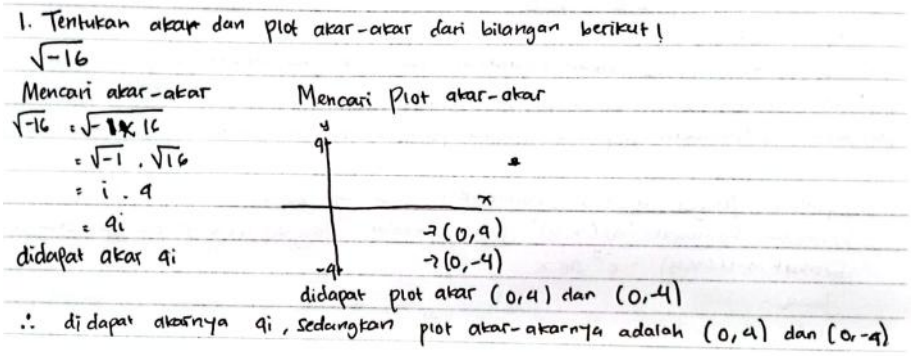


Figure 6. Example of Response level conflict type Error

The question on question number 1 is very tricky. As seen in Figure 6, students immediately pull the root to say negative. Determining the root of a negative number and describing its root has its way and concept.

Undirected manipulation

Undirected manipulation type error is when students get the final answer without giving the right reason (Nursalam et al., 2020). Based on Table 1, this error was made by students as much as 3.03%, which means that only a small percentage of students answered the question without using the proper method or concept. Undirected manipulation occurs when a student manages to get the final answer to a problem but fails to provide a proper reason or explanation related to the steps or processes used to reach that answer. Students may show the correct results but cannot clearly and systematically communicate how they arrived at those answers. For example, below is an Undirected manipulation type error committed by one of the students as follows:

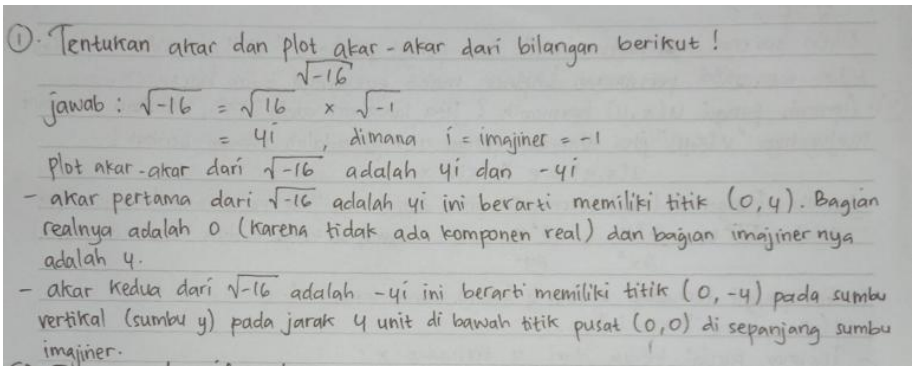


Figure 7**.** Examples of Error type Undirected manipulation

Based on Figure 7, students answer questions without using concepts appropriate to the problem's context. Determining negative numbers' roots and describing their roots has its own concept.

Skill hierarchy problems

Skill hierarchy problems are conditions when students cannot solve problems because they are less skilled in formulas and less careful in counting (Nursalam et al., 2020). Based on Table 1,

this error occurs as much as 20.97%. Skill Hierarchy Problems occur when a student faces difficulties in solving a problem due to a lack of skills in using formulas or a lack of caution in calculations. Students may have difficulty applying concepts or formulas that should be used to solve a particular problem or may make simple calculation errors that may affect the final result. For example, below is a Skill hierarchy problem type error made by one of the students as follows:

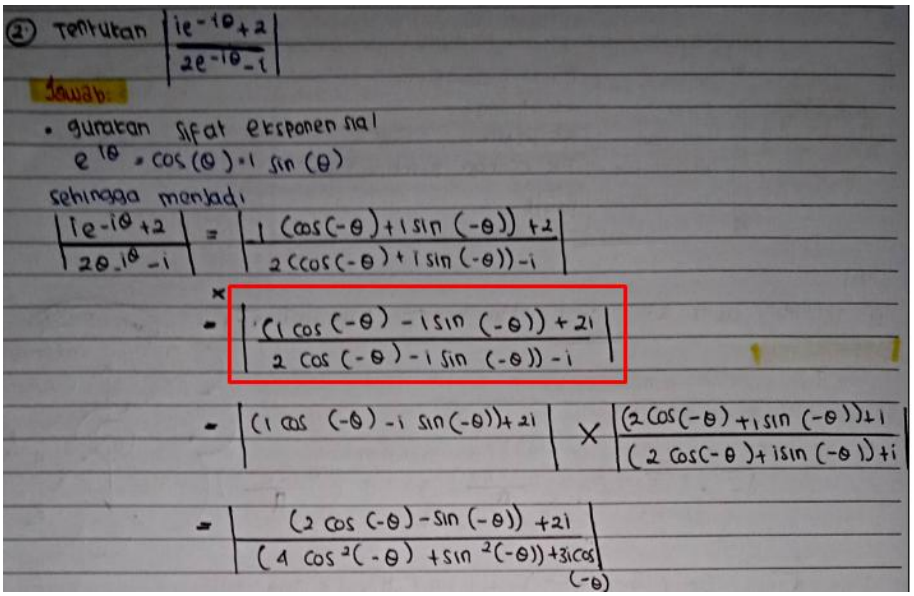


Figure 8. Examples of Skill hierarchy problems

From Figure 8 above, the student's goal in solving the problem is quite good. However, there is an error in the part marked red. In part marked red, the numerator is not 2i because i should only be applied to the form $\boldsymbol{cos(-\theta) + i\,sin(-\theta)}$. In addition, students are also mistaken for the concept of odd functions and even functions in trigonometry. So, form $\boldsymbol{cos(-\theta) + i\,sin(-\theta)}$ same as $\boldsymbol{cos(\theta) - i\,sin(\theta)}$ because it is known that cosine is an even function and sine is an odd function.

The other seven categories

The other seven categories are conditions where students do not mention questions or items (Nursalam et al., 2020). Based on Table 1, none of the students fall into this category.

Discussion

Based on the research results in Table 1, the type of student error in doing essay questions is more in the type of "Inappropriate Procedure" as much as 45.16%. The "Inappropriate Procedure" type error in the Watson criteria refers to a situation in which students use inappropriate approaches or methods of solving to deal with a mathematical problem (Nursalam et al., 2020). This can include using incorrect formulas, irrelevant resolution steps, or applying concepts that do not fit the context of the problem. Inappropriate procedure error analysis helps educators understand students' difficulty choosing the right strategies to solve specific math problems (Hunaifi & Darhim, 2020; Suciati &

Sartika, 2023). By identifying these error patterns, educators can guide students to help them understand when and how to use appropriate procedures in completing math tasks. Through this approach, solutions can be found to improve students' understanding and guide them toward applying more effective and contextual methods in solving mathematical problems.

To reduce the use of inappropriate procedures in working on complex analysis problems, which is the most common error with a percentage of 45.16%, it is essential to apply several effective teaching strategies. First, educators need to provide a more in-depth explanation of basic concepts and correct procedures through explicit teaching and structured steps. The use of concrete examples and analogies in explaining complex concepts can help students understand the correct steps in solving problems. Second, students should be given the opportunity to practice repeatedly with a variety of problems, accompanied by direct feedback explaining the mistakes made and how to fix them. In addition, implementing a collaborative learning approach, where students work in groups to solve problems, can encourage discussion and a deeper understanding of the correct procedures. With this combination of strategies, it is expected that students can improve their understanding and reduce the frequency of procedural errors in complex analysis.

The second most common type of error is skill hierarchy problems, which account for 20.97% of them. Skill hierarchy problems in Watson's criteria include situations where students have difficulty mastering mathematical concepts in stages and tiers (Aswin & Juandi, 2022; Evriyanti et al., 2020). This type of error indicates an obstacle to building a hierarchy of mathematical skills, where understanding basic concepts is critical to understanding more complex concepts (Fritz et al., 2013; Godino, 1996; Nahdi & Jatisunda, 2020). Analysis of these errors can provide educators with insight into skill areas that students may have missed or not fully mastered, thus enabling the development of a more structured curriculum and teaching approach. By identifying patterns of "skill hierarchy problems," educators can design more in-depth learning strategies and ensure that students have a strong foundation of math skills before stepping into more complex concepts (Maskur et al., 2020; Nahdi & Jatisunda, 2020; Warner & Kaur, 2017). This helps improve students' overall understanding and promotes the continuous and integrated building of mathematical skills.

To reduce the problem of skill hierarchy in solving complex analysis problems, which accounts for 20.97% of total errors, educators need to ensure that students have a solid understanding of basic concepts before moving on to more complex materials. One effective strategy is through a stepwise learning approach, where materials are taught sequentially from the most basic to the most advanced. Educators should conduct an initial diagnostic assessment to identify the essential skills that students have not mastered and provide remedial teaching as needed. In addition, using problem-based learning methods can help students apply their basic skills in more complex contexts, strengthening their understanding. Providing tasks that vary in difficulty can also help students gradually build their skills and understand the relationship between primary and advanced concepts. Thus, this approach can help reduce the problem of *skill hierarchy* and improve students' ability to solve complex analysis problems.

They conduct error analyses on future mathematics teacher students when answering essay questions, which are fundamental to improving the quality of teaching and understanding of mathematical concepts (Maskur et al., 2020; Rushton, 2018; Warner & Kaur, 2017). Error analysis provides deep insight into students' obstacles, helping future mathematics teachers design more

effective teaching approaches. By understanding error patterns, future mathematics teachers can identify areas of concept that require special attention and devise learning strategies that better suit students' needs.

Conclusions and Suggestions

Conclusion

From the data obtained, only 38.89% of students answered the questions correctly, while 61.61% of the errors made by students were categorized according to Watson's criteria. These criteria include inappropriate data (12.9%), inappropriate procedures (45.16%), omitted data (0%), omitted conclusions (9.68%), response level conflicts (8.68%), undirected manipulation (3.23%), skill hierarchy problems (20.97%), and other categories (0%). The most common error made by the majority of students was inappropriate procedures. This type of error often arises due to a lack of deep understanding of the material, confusion in applying certain concepts, or negligence in carefully reading instructions. The analysis of student errors based on Watson's criteria provides significant insights into the patterns of mistakes students make, offering a comprehensive view of the cognitive barriers encountered during the learning process. Watson's criteria enable researchers to classify and analyze student errors with a high degree of accuracy. Consequently, the findings of this study can offer valuable insights to educators and curriculum developers, helping to enhance learning design, develop more targeted remediation strategies, and create learning materials that are more responsive to students' needs.

Relevance to Educational Context:

The results of this study can contribute significantly to our understanding of the broader mathematics learning process by revealing common error patterns experienced by students when learning complex analysis. Given that procedural errors and skill hierarchy problems are the most common errors, we can assess that there is an urgent need to strengthen the basics of mathematical concepts before students are invited to learn more complex concepts. This study also suggests that providing more explicit instructions, using timely feedback, and a collaborative learning approach can improve students' understanding and minimize errors.

Furthermore, these findings highlight the importance of an adaptive and responsive learning approach to students' individual needs, which can be applied not only to complex analysis but also to other mathematical topics. By broadening the focus of this study, educators and curriculum developers can design more effective teaching strategies that focus not only on the mastery of the material but also on the development of critical thinking and problem-solving skills. Thus, this study can be a foundation for a more holistic approach to mathematics teaching, which supports students' overall intellectual and analytical development.

Suggestions

To help students reduce inappropriate procedures and skill hierarchy problems in solving complex analysis problems, educators should employ several vital strategies. First, they need to provide in-depth explanations of basic concepts and correct procedures, using explicit teaching, structured steps, concrete examples, and analogies to clarify complex ideas. Offering repeated practice with a variety of problems, along with direct feedback to explain mistakes and guide corrections, is also crucial. Implementing a collaborative learning approach can further enhance understanding, as group work encourages discussion and more profound comprehension of the correct procedures. Additionally, ensuring that students have mastered basic skills before advancing to more complex material is essential. This can be achieved through a stepwise learning approach and initial diagnostic assessments to identify gaps and provide necessary remedial support. Finally, incorporating problem-based learning and varying the difficulty of tasks can help students build their skills progressively and understand the relationship between foundational and advanced concepts. By implementing these strategies, teachers can improve students' understanding and reduce errors in complex analysis.

For further research, it is recommended that studies be conducted to test the effectiveness of the proposed learning strategies in reducing procedural errors and skill hierarchy problems in students in complex analysis. Experimental studies comparing learning outcomes between groups of students using these strategies and a control group can provide empirical data on the effectiveness of the approach. In addition, expanding the scope of student error analysis to include other mathematical topics, such as abstract algebra or calculus, can help understand broader and more specific error patterns in mathematics learning. This approach will provide deeper insight into how learning strategies can be tailored to different mathematical topics and help develop more effective curricula in the future.

References

Afianti, F. D., Azizah, W., & Mahmudah, U. (2024). Error Analysis of Mathematics Tadris Students on The Level of Understanding in Solving Complex Analysis Problems. *CONIE FTIK UIN K.H. Abdurrahman Wahid Pekalongan*, 2431–2442. https://proceeding.uingusdur.ac.id/index.php/iconie/article/view/1917/996

Afniandari, L. N., Supardi, K. I., & Asikin, M. (2021). Understanding Mathematical Concepts in the Missouri Mathematics Project Learning Model in terms of Student's Independent Attitude. *Journal of Primary Education*, *10*(2), 163–178. https://journal.unnes.ac.id/sju/jpe/article/view/47947

Aswin, A., & Juandi, D. (2022). Using Watson Criteria for Analyzing Student Errors: Systematic Literature Review (SLR). *Hipotenusa : Journal of Mathematical Society*, *4*(1), 13–23. https://doi.org/10.18326/hipotenusa.v4i1.7239

Beba, H., Sulistyaningsih, M., & Kaunang, D. F. (2022). Analisis Kesalahan Siswa dalam Menyelesaikan Soal Cerita Program Linear di SMA Negeri 1 Moronge. *MARISEKOLA: Jurnal*

Matematika Riset Edukasi Dan Kolaborasi, *3*(1), 29–36. https://doi.org/10.53682/marisekola.v3i1.1157

Buhaerah, B., Nasir, M., & Dangnga, M. S. (2022). Student's Mistakes in Solving Problem Based on Watson's Criteria and Learning Style. *Jurnal Pendidikan Matematika (JUPITEK)*, *5*(2), 95–104. https://doi.org/10.30598/jupitekvol5iss2pp95-104

de Vries, J. A., Dimosthenous, A., Schildkamp, K., & Visscher, A. J. (2022). The impact on student achievement of an assessment for learning teacher professional development program. *Studies in Educational Evaluation*, *74*, 101184. https://doi.org/10.1016/j.stueduc.2022.101184

EL-Khateeb, Dr. M. M. (2016). Errors Analysis of Complex Numbers among Students of preparatory year at the King Saud University. *Journal of Educational & Psychological Sciences*, *17*(3), 409–436. https://doi.org/10.12785/jeps/170315

Evriyanti, I., Yuniawatika, & Madyono, S. (2020). *Errors Analysis Resolving Problems Story Based on Watson's Error Category a Student in the 4 th Class of Elementary School* . *487*(Ecpe), 115–121. https://doi.org/10.2991/assehr.k.201112.022

Fritz, A., Ehlert, A., & Balzer, L. (2013). Development of mathematical concepts as basis for an elaborated mathematical understanding. *South African Journal of Childhood Education*, *3*(1), 38–67.

Godino, J. D. (1996). Mathematical Concepts, Their Meanings, and Understanding. In P. y A. Gutierrez (Ed.), *XX Conference of the International Group for the Psychology of Mathematics Education* (Vol. 2, pp. 1–7). Universidad de Valencia. https://www.ugr.es/~jgodino/articulos_ingles/meaning_understanding.pdf

Haryanti, M. D., Herman, T., & Prabawanto, S. (2019). Analysis of students' error in solving mathematical word problems in geometry. *Journal of Physics: Conference Series*, *1157*, 042084. https://doi.org/10.1088/1742-6596/1157/4/042084

Hassan, K. El, & Madhum, G. (2007). Validating the Watson Glaser Critical Thinking Appraisal. *Higher Education*, *54*(3), 361–383. https://doi.org/10.1007/s10734-006-9002-z

Hunaifi, & Darhim. (2020). Students error analysis in solving mathematical communication problems of square and triangle material for 7th grade based on watson criteria. *International Conference on Elementary Education*, *2*(1), 914–924.

Kartikasari, A., & Widjajanti, D. B. (2017). The Effectiveness of Problem-Based Learning Approach Based on Multiple Intelligences in Terms of Student's Achievement, Mathematical Connection Ability, and Self-Esteem. *Journal of Physics: Conference Series*, *812*, 012097. https://doi.org/10.1088/1742-6596/812/1/012097

Kaur, T., & Prendergast, M. (2022). Students' perceptions of mathematics writing and its impact on their enjoyment and self-confidence. *Teaching Mathematics and Its Applications: An International Journal of the IMA*, *41*(1), 1–21. https://doi.org/10.1093/teamat/hrab008

Liew, C. Y., Leong, S. H., Julaihi, N. H., Lai, T. W., Ting, S. U., Chen, C. K., & Hamdan, A. (2022). Children's Errors in Written Mathematics. *Mathematics Teaching-Research Journal*, *14*(5), 141–158.

Lima, P. da S. N., Silva, L. das A., Felix, I. M., & Brandao, L. de O. (2019). Difficulties in Basic Concepts of Mathematics in Higher Education: A Systematic Review. *2019 IEEE Frontiers in Education Conference (FIE)*, 1–7. https://doi.org/10.1109/FIE43999.2019.9028658

Mafruhah, L., & Muchyidin, A. (2020). Analisis Kesalahan Siswa dalam Menyelesaikan Soal Cerita Matematika Berdasarkan Kriteria Watson. *Pythagoras: Jurnal Pendidikan Matematika*, *15*(1), 24–35. https://doi.org/10.21831/pg.v15i1.26534

Maharani, A., Wahyuni, I., & Oktavianingsih, C. (2020). Watson's Categories Analysis of Sequences and Series Question. *Infinity Journal of Mathematics Education*, *9*(1), 31–40. https://doi.org/10.22460/infinity.v9i1.p31-40

Maskur, R., Sumarno, S., Rahmawati, Y., Pradana, K., Syazali, M., Septian, A., & Kinarya, E. (2020). The Effectiveness of Problem Based Learning and Aptitude Treatment Interaction in Improving Mathematical Creative Thinking Skills on Curriculum 2013. *European Journal of Educational Research*, *9*(1), 375–383. https://doi.org/10.12973/eu-jer.9.1.375

Mazana, M. Y., Montero, C. S., & Casmir, R. O. (2019). Investigating Students' Attitude towards Learning Mathematics. *International Electronic Journal of Mathematics Education*, *14*(1), 207–231. https://doi.org/10.29333/iejme/3997

Meifiani, N. I. (2018). Profil Kesalahan Mahasiswa Pada Mata Kuliah Analisis Kompleks. *Eksponen*, *7*(2), 80–86. https://doi.org/10.47637/eksponen.v7i2.152

Munna, A. S., & Kalam, M. A. (2021). Teaching and learning process to enhance teaching effectiveness: literature review. *International Journal of Humanities and Innovation (IJHI)*, *4*(1), 1–4. https://doi.org/10.33750/ijhi.v4i1.102

Nahdi, D. S., & Jatisunda, M. G. (2020). Conceptual Understanding and Procedural Knowledge: A Case Study on Learning Mathematics of Fractional Material in Elementary School. *Journal of Physics: Conference Series*, *1477*(4), 1–6. https://doi.org/10.1088/1742-6596/1477/4/042037

Natalia, F., Rahman, A., Minggi, I., & Fausia, N. (2021). Description of Students Creative Thinking Abilities with Split Attention in Solving Math Problems. *International Conference on Educational Studies in Mathematics (ICoESM 2021)*, *61*(ICoESM), 505–510.

Nursalam, N., Angriani, A. D., Kamariah, K., Kusumayanti, A., & Yuliany, N. (2020). Students' Errors in Resolving Set Item Test based on Watson's Criteria. *Proceedings of the International Conference on Mathematics and Islam (ICMIs 2018)*, 455–459. https://doi.org/10.5220/0008523604550459

Rohmah, M., & Sutiarso, S. (2018). Analysis problem solving in mathematical using theory Newman. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(2), 671–681. https://doi.org/10.12973/ejmste/80630

Rulika, G. T., Prihatiningtyas, N. C., & Sumarli, S. (2024). Analisis Kesalahan Siswa dalam Menyelesaikan Soal Cerita Matematika Berdasarkan Teori Newman Materi Pecahan. *Pedagogik Journal of Islamic Elementary School*, *7*, 1–18. https://doi.org/10.24256/pijies.v7i1.4923

Rushton, S. J. (2018). Teaching and Learning Mathematics through Error Analysis. *Fields Mathematics Education Journal*, *3*(4), 1. https://doi.org/10.1186/s40928-018-0009-y

Sari, D. N., Usodo, B., & Pramudya, I. (2019). Analysis of Concept Understanding Student in Class X Inequalities Material. *Journal of Physics: Conference Series*, *1306*(1), 012029. https://doi.org/10.1088/1742-6596/1306/1/012029

Smith, E. M., Zwolak, J. P., & Manogue, C. A. (2015). Student difficulties with complex numbers. *2015 Physics Education Research Conference Proceedings*, 311–314. https://doi.org/10.1119/perc.2015.pr.073

Suciati, I., & Sartika, N. (2023). Students' Errors Analysis in Solving Mathematics Problems Viewed from Various Perspectives. *12 Waiheru*, *9*(2), 149–158. https://doi.org/10.47655/12waiheru.v9i2.145

Surya, E., & Syahputra, E. (2017). Improving High-Level Thinking Skills by Development of Learning PBL Approach on the Learning Mathematics for Senior High School Students. *International Education Studies*, *10*(8), 12–20. https://doi.org/10.5539/ies.v10n8p12

Utami, N. S. (2022). Analisis Kesalahan Mahasiswa Pada Bentuk Kutub Bilangan Kompleks Ditinjau dari Kemandirian Belajar. *Jurnal Kiprah Pendidikan*, *1*(4), 237–246. https://doi.org/10.33578/kpd.v1i4.99

Wahyuni, S., Anggraini, V., & Melisa, M. (2023). Analisis Kesalahan Siswa Berdasarkan Kriteria Watson Materi Pola Bilangan di Kelas VIII.3 SMPN 3 Batang Anai. *Jurnal Pendidikan Tambusai*, *7*(3), 21375–21383. https://doi.org/10.31004/jptam.v7i3.9896

Warner, S., & Kaur, A. (2017). The Perceptions of Teachers and Students on a 21st Century Mathematics Instructional Model. *International Electronic Journal of Mathematics Education*, *12*(2), 193–215. https://doi.org/10.29333/iejme/609

Yolanda, F., & Sthephani, A. (2021). Analisis Kesalahan Mahasiswa Pendidikan Matematika UIR pada Penyelesaian Analisis Kompleks. *SJME (Supremum Journal of Mathematics Education)*, *5*(1), 32–42. https://doi.org/10.35706/sjme.v5i1.4393