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Assessing Student Skills: Research on Algebraic Complex Number Mastery Through Learning Experience

Nuraina[1], Muliana[2], Rohantizani[3], Rahmy Zulmaulida[4] and Novianti[5]

Abstract

The problem faced in this study is the mistake that students often make in solving complex number algebra problems, which is caused by a lack of basic understanding of the mathematical operations involved. This study aims to analyze the types of errors that occur and the factors that affect these errors. The method used is descriptive qualitative analysis, with data collection through giving questions to students and interviews to explore the reasons behind the mistakes made. The results show that the main errors stem from inaccuracy in the operations of addition, subtraction, and multiplication of complex numbers, as well as mistakes in simplifying algebraic expressions. The interviews revealed that his lack of practice, confusion in understanding basic concepts, and limited time to work on questions also contributed to the error. In conclusion, to reduce these errors, students need to be given a deeper understanding of the basic concepts of complex number algebra and given more varied practice problems. Therefore, it is important to develop teaching methods that focus more on strengthening basic concepts and familiarizing students with more diverse questions.

Keywords: *Student Errors, Complex Number Algebra, Basic Understanding, Practice Problems, Mathematics Teaching*

INTRODUCTION

As one of the main topics in complex analysis, algebraic complex numbers have a unique mathematical structure because they involve the concept of imaginary numbers, which often poses its own challenges for students. The concept of complex numbers is not only important in mathematics, but is also widely used in engineering, physics, and computer science, so a good understanding of them is crucial for aspiring mathematics educators (Cross Francis et al., 2022; Hernandez-Martinez et al., 2023; Suppa et al., 2020). However, a number of studies show that students often have difficulty understanding complex number representations, complex algebraic operations, and connections with other mathematical concepts, such as trigonometry and exponentials, which are important components in advanced mathematics learning (Enu & Ngcobo, 2022; Martignone et al., 2022).

This research focuses on students' ability to master complex algebraic numbers, which is a fundamental concept in complex analysis courses in the mathematics education study program. Algebraic complex numbers play an important role in the advanced understanding of mathematics and engineering applications, especially in the field of complex analysis that is often used in modeling and solving technical problems (I. EZE et al., 2020; Sandiyani et al., 2023). Based on various studies, students often have difficulty in understanding and applying the concept of complex algebraic numbers. These factors include difficulties in algebraic operations, lack of visualization of complex number concepts, and limitations in solving problems that relate complex numbers to real situations (Acharya et al., 2021; Amador, 2022; Enu & Ngcobo, 2022). Previous research has shown that a deep understanding of complex numbers can be improved through experiential learning methods, which strengthen students' conceptual understanding through a direct and contextual approach (Amador, 2022). However, the main challenge that lecturers often face is to integrate these methods effectively in large and

[1] Department of Mathematic Education, Faculty of Teacher Training and Education, Malikussaleh Universty, Indonesia. E-mail: nuraina@unimal.ac.id

[2] Department of Mathematic Education, Faculty of Teacher Training and Education, Malikussaleh Universty, Indonesia. Email*: muliana.mpd@unimal.ac.id

[3] Department of Mathematic Education, Faculty of Teacher Training and Education, Malikussaleh Universty, Indonesia. E-mail: rohantizani@unimal.ac.id

[4] Department of Mathematic Education, Faculty of Teacher Training and Education, IAIN Lhokseumawe, Indonesia. E-mail: rahmyzulmaulida@gmail.com

[5] Department of Mathematic Education, Faculty of Teacher Training and Education, Al Muslim Universty, Indonesia. E-mail: novianti@umuslim.ac.id

heterogeneous classes, so it requires adaptations that are able to overcome the diversity of understandings among students (Acharya et al., 2021; Beswick & Goos, 2018; John et al., 2016).

This limitation in mastering complex numbers is also influenced by learning methods that are less contextual or experience-based. Most teaching methods are still theoretical, with an emphasis on algebraic formulas and calculations without any connection to real situations or practical applications, which makes it difficult for students to understand the essence of the concept (Ismail et al., 2019; Macanas & Rogayan, 2019). Experiential learning models can provide a more effective alternative, where students not only learn from theory but also through practical activities, simulations, or contextual problem-solving that require a deep understanding of complex numbers (Ismail et al., 2019; Soltura, 2021).

Challenges in the implementation of experiential learning in complex analysis classes include time constraints, large class management, and lecturers' readiness in designing relevant and interesting learning activities. In addition, students' cognitive obstacles, such as the inability to describe complex numbers in geometric forms or visualize abstract concepts, are also obstacles in the learning process (Bingen et al., 2020; Dessie et al., 2023; Zhang, 2022). Through this research, it is hoped that more structured and appropriate experiential learning strategies can be identified, as well as able to overcome various obstacles faced in teaching complex numbers in higher education (Dewi et al., 2023; Gamanik et al., 2019).

This study aims to further investigate the extent to which an experiential approach can improve the mastery of complex algebraic numbers among fifth-semester students at Malikussaleh University, as well as identify the obstacles that may be faced. The results of this study are expected to make a significant contribution to the development of more effective mathematics learning methods at the higher education level, especially on the concept of algebraic complex numbers which are essential in the discipline of mathematics (Abu Bakar & Ismail, 2020; Ashipala et al., 2023).

By involving students in learning activities that emphasize conceptual understanding through hands-on experience, this research also seeks to add insight into how mathematics learning can be designed to be more effective and adaptive. The findings of this study are expected not only to provide input for the development of the curriculum in the Mathematics Education Study Program of Malikussaleh University, but also to contribute to improving the quality of mathematics education in general, especially in the topic of algebraic complex numbers which are fundamental for students' progress in mathematics and science disciplines (Svellingen et al., 2021; Y. chu Yeh et al., 2023).

The increase in research interest in learning complex numbers indicates an impulse to find more effective methods to help students master these abstract concepts. Recent research underscores the importance of learning approaches that focus on students' active participation, such as problem-based learning and technology-based simulations, which have been shown to improve understanding and application of complex number concepts (Aksel Stenberdt & Makransky, 2023). For example, Rahim and colleagues found that students who engaged in digital simulations showed significant improvements in understanding complex number representations in Cartesian and polar forms, which are often a challenge in traditional learning (Kikomelo et al., 2023; Zaim et al., 2022).

In addition, recent research also highlights the development of visual aids and interactive applications to help visualize complex numbers, which have been proven to reduce barriers in understanding this concept at an advanced level (Simpson, 2008; Y. C. Yeh et al., 2019). The application of tools such as GeoGebra and other math mobile apps gives students the opportunity to visualize complex number transformations in real time, allowing them to develop a more intuitive and in-depth understanding. The effective use of this technology has been shown to be helpful in reducing cognitive difficulties, particularly in understanding complex number operations and their applications in real-life contexts.

Previous research has mostly focused on theoretical approaches to teaching complex numbers, but these recent studies provide a strong foundation for moving to a more dynamic and experience-based approach, which emphasizes not only conceptual understanding but also practical applications (Borisov, 2018; Richter, 2022; Simpson, 2008). This research is expected to broaden the insight into the effectiveness of experiential learning methods in higher mathematics education, make a valuable contribution to the development of a more relevant and effective curriculum in the Mathematics Education Study Program, Malikussaleh University, and overcome the obstacles that have been faced for a long time in teaching complex numbers.

METHODS

The research method used in this study is a qualitative approach with a phenomenological method, which aims to explore the learning experience of students in understanding and mastering the concept of complex number algebra. The subjects of this study are 60 students of the fifth semester mathematics education study program at Malikussaleh University who have taken the Complex Analysis course. This research not only explores students' subjective experiences, but also measures their mastery of concepts through complex number algebra question tests designed to test basic to advanced understanding and skills on this material.

Data was collected through two main methods: in-depth interviews and written tests. Interviews are conducted to explore students' views on the difficulties they experience, the learning strategies they apply, and their perceptions of the learning process. The written test, which consists of complex number algebra problems, aims to objectively measure the level of mastery of students. The results of this test provide quantitative data that complement the results of the interviews, thus allowing for a more comprehensive analysis of the mastery of the concept of complex numbers in algebra.

The data was analyzed with a thematic analysis approach, where the results of interviews and tests were grouped into relevant themes. The test results were analyzed descriptively to see the distribution of scores and identify patterns of student understanding, while the interview data was interpreted to gain a deeper understanding of the student learning experience. With a combination of interviews and tests, this study is expected to provide a comprehensive picture of students' mastery of complex number algebra through their learning experiences (Dovgodilin, 2022; Richter, 2021; Suppa et al., 2020).

RESULTS

Students' understanding of the concept of complex number algebra is obtained through their written answers on the complex number algebra material test consisting of four questions. Furthermore, some of these answers were confirmed through semi-structured in-depth interviews conducted with students. In addition, the researcher also explored other knowledge related to the concept of complex number algebra and their experience in studying algebra and following the learning process of Complex Analysis face-to-face in the fifth semester of lectures. The following is a presentation of the results of the analysis of student answers to the problem of determining the results of operations on complex numbers:

Given and. Define or write down complex numbers and in the form a + bi; a and b real. Explain!$z_1 = 2 - 3i z_2 = -5 + i z_1 + z_2, z_1 - z_2, z_1 z_2, \frac{z_1}{z_2}$

The answer to this first question, most of the subjects only focus on the value/result of number operations, namely a real and imaginer number. They don't think to enumerate some of the possibilities that can occur for real value and imaginers that arise. The subject gives a variety of explanations for the same final answer, namely the value of the real part and the imaginer part.

Table 1. Incorrect Determination of Complex Numbers

Question Item	Types of mistakes made
Given z1 = 2 − 3i and z2 = −5 + i. Define or write down the complex numbers z1 + z2, z1 − z2, z1z2, and z1 z2 in the form a + bi; a and b are real. Explain!	Error using subtraction operations Error using the add operation Incomplete in simplifying the answer The problem is not solved to its simplest form Error when using the add operation Errors when calculating the final result Errors when using multiplication operations

Table 1 shows the different types of errors that respondents experience in navigating the complexity of complex number algebra. The pattern of repeated errors is obvious, generally due to a lack of understanding of the basic algebraic concepts needed to complete these tasks. In particular, respondents had difficulty performing certain mathematical operations, especially in subtraction and addition. In addition, there were also cases where participants faced challenges in simplifying algebraic expressions, obtaining the correct final result, and performing multiplication operations with sufficient accuracy.

From the results of their answers, various errors have been identified, especially related to the operation of complex numbers, such as errors in entering values, errors in basic operations such as addition and subtraction, and inaccuracy in solving problems to the end. To further clarify and strengthen the analysis, interviews with students were conducted to dig deeper into the reasons behind the mistakes they made. The results of this interview provide further insight into the challenges faced by each student in solving these problems. Here is a summary of the interview results that support the analysis of errors that have been carried out:

Table 2. Summary of Interview Results

Subject	Mistakes Occurred	Interview Results
M2	Errors in reduction operations	Admittedly confused by the rules of negative number subtraction, especially when it comes to minus signs.
M3	Not solving the problem until the end	Stating that they do not understand the last step because they are in a hurry to solve the problem.
M4	Errors in reduction operations and not simplifying results	He admitted that he had difficulty understanding the concept of complex reduction and was not thorough when simplifying answers.
M5	Incorrect entry of the initial value and error in the operation	Explain that mistakes occur because they do not read the questions carefully and forget the rules of complex operations.
M6	Entered the wrong initial value.	He admitted that he lacked concentration when working on problems and often mistakenly entered known data.

DISCUSSION

The results of the test conducted to analyze students' mistakes in solving complex number algebra problems will be explained in more detail in the following discussion. This explanation includes an analysis of the types of errors found, as well as interviews that provide a deeper picture of the factors that affect these errors. Subject M2 made a mistake when using the reduction operation, this is evidenced by the results of subject M2's answers as follows:

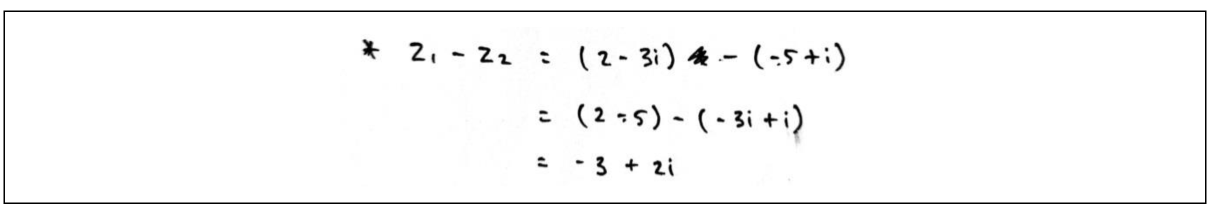

Figure 1. Error using subtraction operations

The image above shows that the subject M2 made a mistake in completing the reduction operation. It can be seen that the subject M2 immediately subtracts 2 by 5, when 2 should be subtracted by -5, and -3i should also be subtracted by i, so the correct form is 2 - (-5) - 3i - i. As a result, the final answer obtained by students becomes incorrect. Meanwhile, the M3 subject also made a mistake in using the addition operation on negative numbers, but the end result remained correct. This can be seen in the answers given by the following M3 subjects:

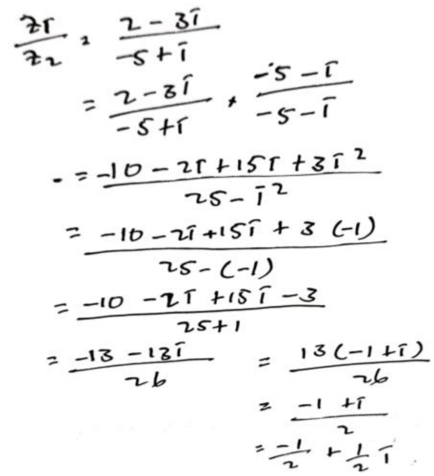

Figure 2. Error using summation operations

From the image above, it can be seen that students make mistakes in calculating the addition of negative numbers. Supposedly, -2i + 15i results in 13i, not -13i. However, this error only occurs at the summation operation stage and does not affect the final result. In addition, M3 subjects also make mistakes by only completing the answer halfway, without continuing until they get the right final result. This can be seen from the answers presented by the following M3 subjects:

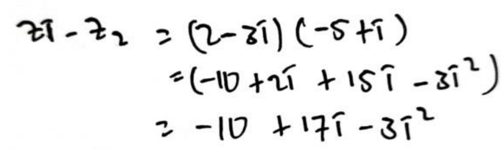

Figure 3. Error using summation operations

It can be seen that the M3 subject only completed the problem until the third step, even though there are still three more steps needed to reach the correct final answer. Meanwhile, subject M4 made an error in using the reduction operation, which is evident in the answer given by the following subject M4:

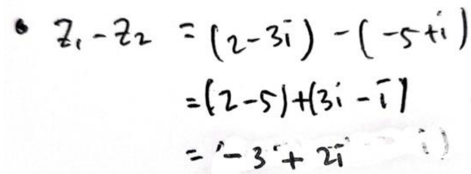

Figure 4. Error using subtraction operations

The image above shows that students do not fully understand how to complete the reduction surgery. It appears that the student immediately subtracts 2 by 5, when the 2 should be subtracted by -5, and -3i is subtracted by i, so the correct step is 2 - (-5) - 3i - i. As a result, the final answer obtained by M4 subjects became incorrect. In addition, the M4 subject also did not solve the problem until it reached the simplest correct form, as seen in the following M4 subject answer:

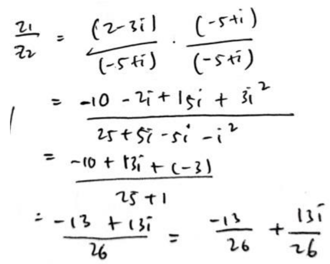

Figure 5. Incomplete in simplifying answers

It can be noted that to make $-\frac{13}{26}+\frac{13}{26}\,i$ simpler can be equally divided by 13 so as to obtain the result $-\frac{1}{2}+\frac{1}{2}\,i$. Subject M5 made a mistake when entering the known value into the solution, this is evidenced by the results of the answer of subject M5 as follows:

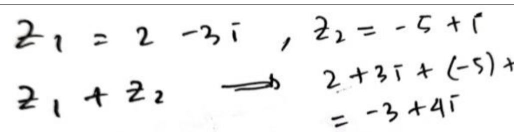

Figure 6. Error entering a value

The figure above shows that the subject M5 is less thorough in incorporating known values into the solution. The value for z1-z2 should be 2−3i2 - 3i2−3i, but subject M5 writes it as 2+3i2 + 3i2+3i, resulting in an incorrect final answer. In addition, subject M5 also made a mistake in using the reduction operation, which is evident from the following answer of subject M5:

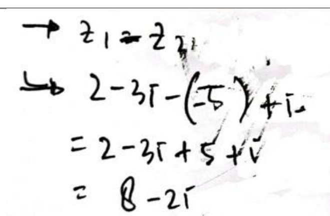

Figure 7. Error using summation operations

From the image above, it can be seen that the subject M5 is still making mistakes in the addition operation. Subject M5 writes 2 - 3i + 5 + i, when it should be 2 - (-5) and -3i - i, so the correct step is 2 - (-5) - 3i - i. After that, the results are only calculated to get the final answer. Therefore, the answer obtained by the M5 subject is not correct. In addition, the M5 subject also did not solve the problem until it reached the simplest correct form, as seen in the following M5 subject answer:

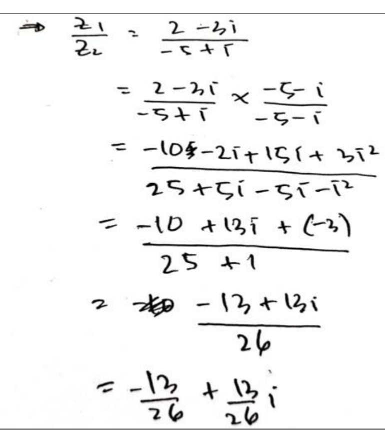

Figure 8. Not solving problems in the simplest form

It can be noted that to make $-\frac{13}{26}+\frac{13}{26}\,i$ simpler can be equally divided by 13 so as to obtain the result $-\frac{1}{2}+\frac{1}{2}\,i$. Subject M6 also made the same mistake as subject M5 did where subject M6 was also wrong when entering the known value into the equation, this is proven from the results of subject M6's answer as follows:

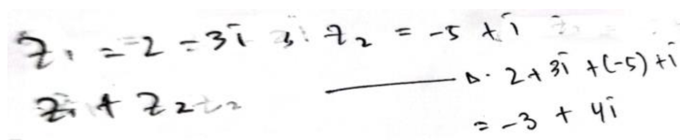

Figure 9. Not entering a known value

The figure above shows that subject M6 is less careful in incorporating known values into the solution, where the value of Z1 should be 2 - 3i, but subject M6 writes it as 2 + 3i. This error resulted in the final answer obtained being incorrect.

Based on table 2 above, the results of interviews with students provide deeper insight into the mistakes they make when solving complex number algebra problems. Here is a detailed explanation of the interview results of each subject:

M2 Subject

- Mistakes Occurred
  Subject M2 made a mistake in complex number reduction operations. They immediately subtract 2 by 5, when 2 should be reduced by -5, and -3i reduced by i.
- Interview Results
  Subject M2 admitted to feeling confused by the negative number subtraction rule, especially when it comes to minus signs. They do not fully understand how to properly handle negative signs in complex number algebra operations. This leads to errors in the calculation process, as the reduction of complex numbers requires a careful understanding of the signs and sequence of operations.

M3 Subject

- Mistakes Occurred
  Subject M3 does not complete the problem until the last step. They stopped at the third step, even though there were still three more steps to be done to get the correct and simplest answer.
- Interview Results
  M3 subjects explained that they did not understand the last step in solving the problem and felt rushed to solve the problem. This indicates that even though they understand the initial steps, they do not fully pay attention to every detail in solving the problem to the end, which makes them not achieve the right result.

M4 Subject

- Mistakes Occurred
  The M4 subject made an error in the reduction operation and also did not simplify the results correctly.
- Interview Results
  Subject M4 admitted that he had difficulty understanding the concept of complex number reduction, especially when dealing with negative numbers. They also realize that the lack of precision in simplifying the end result also contributes to the mistakes they make. Complex number reduction does require extra attention in handling negative signs, and the lack of precision causes M4 subjects to not succeed in simplifying the results correctly.

M5 Subject

- Mistakes Occurred
  Subject M5 entered the wrong initial value, which is to write 2 + 3i, when the correct value is 2 - 3i. In addition, they also make mistakes in reduction operations.
- Interview Results

M5 subjects admitted that mistakes occurred because they were not careful in reading the questions and often made mistakes in entering the grades given. They also admit that they often forget the rules in complex operations and don't fully focus on each step. This shows that a lack of concentration when working on a problem can lead to errors, even if they have a basic theoretical understanding.

M6 Subject

- Mistakes Occurred
  Subject M6 also entered the wrong initial value, writing 2 + 3i, when the correct one was 2 - 3i.
- Interview Results
  M6 subjects admitted that this error occurred because they lacked concentration when working on the problem and often made mistakes in entering known data. They also revealed that this difficulty was related to their tendency to feel rushed to solve problems without making sure that all the grades entered were correct.

CONCLUSION OF THE INTERVIEW

From the results of this interview, some common patterns of difficulties seen in students are as follows:
Lack of Meticulousness in Entering Values
Some students, such as M5 and M6, experience errors due to a lack of precision in entering known grades. This indicates the importance of paying more attention to detail when working on questions.
Difficulties in Reduction Operations
Errors in the reduction operation appear on M2 and M4 subjects. They admitted that they had difficulty in dealing with negative signs and did not fully understand the rules of complex number subtraction.
Limited Understanding of Settlement Steps
M3 and M4 subjects have difficulty in solving the problem until the end. They feel rushed or do not understand certain steps well, which results in incomplete work on the questions.
Lack of Concentration and Rush
The hurried and unfocused factors are also the main reasons for the error, as seen in the M3, M5, and M6 subjects. This shows that good time management and concentration are essential in solving problems correctly.

Overall, this interview shows that the mistakes made by students not only come from a lack of understanding of concepts, but also due to the factors of precision, concentration, and time management that need to be paid more attention to in the process of solving mathematical problems, especially complex number algebra.

Based on the findings from the students' answers and the results of the interviews, the errors that occurred in solving complex number algebra problems were mostly related to students' basic understanding of basic mathematical operations, such as addition, subtraction, and multiplication of complex numbers. These findings are in line with previous research that shows that a lack of understanding of basic concepts is often a major obstacle to solving math problems, especially in more complex topics such as complex numbers (Dovgodilin, 2022; Götze et al., 2016; Richter, 2021).

Previous research by (Alhasan et al., 2023; Bugeaud & Evertse, 2009; Strzeboński, 1997) also revealed that students often make mistakes due to inaccuracy in the calculation process and lack of sufficient practice. Therefore, training that focuses on strengthening basic concepts and getting used to more diverse questions can help reduce mistakes that are often made. In this case, training based on a more active and contextual approach, such as those proposed by (Al-Mahrooqi & Denman, 2020; Chan et al., 2022; He et al., 2023), has the potential to improve students' understanding and skills in working on complex number algebra problems more accurately and efficiently.

Limitation And Future Research Directions

Some of the limitations found in this study include the limited number of samples used, which may not be representative of the entire student population, and the limited scope of one type of complex number algebraic material. In addition, the methodology used can also be considered to be refined, for example by using a more varied approach or involving more diverse data collection techniques.

Future research directions can focus on several aspects, such as deepening the analysis of more specific factors that affect students' mistakes in solving problems, including understanding basic concepts and applied learning strategies. In addition, further research can develop and test the effectiveness of more innovative and adaptive teaching approaches, for example by using technology or problem-solving-based approaches to help students overcome the difficulties they face. By expanding the sample and methodology, future research can provide a more comprehensive picture and wider applications in mathematics education.

CONCLUSION

Based on the results of the research and discussion that has been carried out, it can be concluded that students' mistakes in solving complex number algebra problems are mostly caused by a lack of basic understanding in mathematical operations, such as addition, subtraction, and multiplication of complex numbers. Some errors also arise due to inaccuracy in incorporating known values into the solution or not solving the problem until it reaches its simplest form. However, interviews with students showed that factors such as lack of practice, confusion in understanding basic concepts, and limited time in working on problems also affected the results obtained. This research provides important insights for the development of more effective teaching strategies, especially those that can help students in understanding the basic concepts of complex number algebra and overcoming frequent errors.

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