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Exploring Learning Gaps in the Functions Subtopic: A Study of Form 4 KSSM Additional Mathematics Pretest Results of Secondary School Students

Muhammad Haziq Iskandar Shah[1], Muhammad Faiz Anuar[1], Siti Munirah Mohd[1,*], Nurhidaya Mohamad Jan[1], Muhammad Riefdy Masrul Hisham[2], Fadzidah Mohd Idris[1], Hatika Kaco[1], Nakhma'Ussolikhah[3]

[1] Kolej PERMATA Insan, Universiti Sains Islam Malaysia, Bandar Baru Nilai, 71800 Nilai, Negeri Sembilan, Malaysia. Malaysia
[2] Sekolah Menengah Kebangsaan Bandar Saujana Putra, Jalan SP 4/4, Bandar Saujana Putra, 42610 Jenjarom, Selangor, Malaysia
[3] Universitas Islam Bunga Bangsa Cirebon, Jl. Widarasari III, Sutawinangun, Kec. Kedawung, Kabupaten Cirebon, Jawa Barat 45153, Indonesia

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ABSTRACT

Understanding functions is a crucial aspect of the Form 4 Additional Mathematics curriculum under the KSSM syllabus. However, many students struggle to grasp its core concepts, highlighting potential gaps in instructional effectiveness. This study aims to assess students' proficiency in the Functions subtopic through a diagnostic pretest administered to a group of talented students in secondary school. Methods included the analysis of pretest results to identify common misconceptions and knowledge gaps, using statistical tools to interpret student performance. The results revealed significant areas where students lacked understanding, particularly in inverse functions and composite functions. These findings underscore the need for targeted interventions in teaching methods. In conclusion, this study provides insights into students' challenges with functions and suggests strategies for improving learning outcomes. Future research may extend this approach to other mathematical topics to enhance overall student competency.

1. Introduction

The need for function has increased across fields [1–3]. According to Britannica [4], a mathematical function is defined as an expression, rule, or law that establishes the relationship between one variable, the independent variable, and another variable, the dependent variable. Given that these are foundational, students at the secondary level must develop a deep understanding of functions early in their studies, especially more advanced concepts such as inverses and composites, which play a pervasive role in higher mathematics [5-6]. Research in mathematics education has traditionally established functions as one of the most challenging concepts for high

* *Corresponding author.*
E-mail address: smunirahm@usim.edu.my

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school students and their teachers, mainly as the learning proceeds toward relatively advanced notions such as inverses and composites. In Wasserman's study [7], only two (2) out of the seven (7) interviewed high school teachers provided evidence of strong mathematically worthy conceptions of inverse functions. In addition, the findings in this study [8] showed that "most students in the final year of mathematics education scored below the 50% pass threshold for a test of function concepts at the school level, with an average percentage score of 27%. Globally, mathematics education has been identified as a cornerstone for developing critical thinking and problem-solving skills, which are essential for the Fourth Industrial Revolution. By addressing specific challenges faced by talented students, this study contributes to global efforts in refining STEM education strategies to meet future workforce demands.

1.1 Gaps in the Study

Despite these insights, several gaps still need to be addressed in the existing literature regarding students' understanding of functions, particularly among talented students. The need for targeted research in this area is crucial as these students are often expected to grasp these concepts more readily. Although functions are foundational in mathematics and crucial for understanding advanced STEM topics, limited research explores how high-achieving students conceptualize these ideas. Existing studies often focus on average or mixed-ability learners, leaving a critical gap in understanding the unique challenges faced by gifted students. For instance, a study by Hong and Thomas [9] focused primarily on average- or mixed-ability students, leaving a gap in understanding how high-achieving students approach the subtopic of functions and where they may need help. Furthermore, there is insufficient exploration of how these challenges influence broader educational outcomes, such as STEM readiness and global competitiveness in technology and engineering fields. Addressing this gap is vital to developing targeted interventions that cater to the needs of gifted learners and inform global educational policies.

1.2 Significance of the Research

This study holds significant importance, as it delves into a critical gap in our understanding of the learning difficulties experienced by high-achieving Form 4 students regarding the Functions subtopic within the KSSM Additional Mathematics syllabus. By explicitly examining students who generally excel in mathematics yet find themselves grappling with intricate concepts such as inverse and composite functions, this research underscores the urgent need for enhanced instructional strategies that extend beyond conventional teaching practices. The insights drawn from this study are to directly benefit mathematics educators by equipping them with a nuanced understanding of their students' misconceptions and specific areas of falter learning. Armed with this knowledge, teachers will be better positioned to design targeted interventions that cater to the unique needs of talented students, ultimately fostering deeper comprehension and alleviating the obstacles faced in mathematical learning.

Moreover, the results of this study could prove invaluable to KSSM curriculum developers and policymakers, as they strive to refine educational approaches and ensure adequate support for gifted learners. By shedding light on the specific challenges these students encounter, this research can guide the development of educational strategies that more effectively nurture their mathematical abilities. Finally, this research has the potential to lay the groundwork for further exploration in mathematics education. It offers a framework for investigating other complex topics within the syllabus and for creating innovative strategies to enhance learning outcomes for all students, ensuring that every learner is included in their mathematical journey.

1.3 Objective of the Research

This study aims to:

(a) Systematically examine the learning gaps in the Functions subtopic among Form 4 students enrolled in Additional Mathematics.
(b) Gain an in-depth understanding of the common misconceptions and areas of difficulty among students who are typically expected to excel.
(c) Categorize misconceptions and errors related to functions, particularly in inverse and composite functions.

2. Literature Review
2.1 Additional Mathematics

Additional Mathematics serves as a foundation for advanced mathematical thinking among high-achieving students, making it an essential focus for gifted education programs like those at Kolej PERMATA Insan. Unlike mathematics, which has clear and precise definitions, Additional Mathematics lacks specific definitions, with well-defined boundaries. According to the Merriam-Webster Dictionary [10], mathematics is about numbers, how they work together, and their relationships, patterns, and structures in space, including measurements and transformations. Additional Mathematics is an elective subject in Malaysian secondary education, which is a crucial component of STEM education [11-12]. According to Ong Hong Choon *et al.*, [11], Additional Mathematics is considered more advanced than Modern Mathematics and introduces new symbols and concepts that students often find challenging. Additional Mathematics enhances students' ability and confidence in applying mathematical concepts to various scientific and technological developments.

Additional Mathematics plays a pivotal role in developing advanced mathematical thinking and problem-solving skills, particularly among gifted students. As an elective subject within Malaysia’s STEM-focused education system, it challenges students to engage with abstract and complex concepts essential for future academic and professional pursuits. Moreover, the KSSM Additional Mathematics formulation is widely utilised in business formulas and models to optimise mathematical theories for practical applications [13]. For instance, excelling in Additional Mathematics can help students better comprehend and analyse intricate financial models in business decision-making. This advanced mathematical knowledge can provide them a competitive edge in finance, engineering, and data analysis.

2.2 Functions

The concept of a function has evolved significantly from its roots in ancient Babylonian and Greek mathematics, where relationships between quantities were explored through geometry and arithmetic. In the 17th century, Rene Descartes and Pierre de Fermat connected algebra with geometry through coordinates, paving the way for modern functional analysis. Gottfried Wilhelm Leibniz formalized the term "function" in 1694, and Leonhard Euler refined it in the 18th century with the introduction of $f(x)$ notation. By the 19th century, mathematicians like Dirichlet and Fourier expanded the idea to include discontinuous and non-algebraic relationships, while Georg Cantor's set theory provided a rigorous foundation for modern functional theory [14-16].

In general, the concept of a function represents a structured relationship between two sets, where each element in the first set (called the domain) is associated with exactly one element in the second set (called the codomain). This unique pairing is the defining feature of a function, which distinguishes it from other mathematical relationships. Mathematically, a function can be expressed as $f: X \to Y$, where X is the domain, Y is the codomain, and $f(x)$ is the unique output corresponding to each input x in X. Functions serve as the cornerstone of mathematics, bridging disciplines, such as algebra, geometry, calculus, and discrete mathematics. They provide a means of modeling and solving real-world problems by representing relationships in forms that can be analyzed, graphed, and computed. For example, in physics, functions describe how variables such as velocity or force change over time, offering insights into dynamic systems [17].

The topic of functions, consisting concepts like inverses and composites, is not only foundational to mathematics but also to various scientific and technological fields. For gifted learners, mastery of such topics is critical, as it fosters the analytical and creative thinking necessary for excelling in STEM disciplines. In Malaysia's Additional Mathematics curriculum, which is the KSSM, the topic of functions is divided into four main subtopics: basic function properties, composite functions, inverse functions, and problem-solving in function. Functions can be represented in various ways, such as through equations, tables, graphs, or words [18]. Understanding functions is a fundamental aspect of mathematics education as it serves as a basis for more advanced mathematical thinking [19]. Many students face significant challenges in understanding this concept. The difficulties often stem from common misconceptions, such as overgeneralizing that any ordered pair represents a function and misunderstanding of continuity and cognitive challenges [20]. While functions are a fundamental topic in mathematics, research highlights significant challenges faced by students, including talented learners. Misconceptions about functions, such as the overgeneralization of relationships or difficulties understanding inverse and composite functions, have been shown to hinder conceptual understanding and procedural fluency [20]. For gifted students, these challenges are particularly concerning as their cognitive abilities often predispose them to abstract thinking, which may lead to overcomplicating basic concepts or overlooking foundational principles. These gaps not only impact their performance in Additional Mathematics but also limit their readiness for advanced mathematical applications in fields like calculus, computer science, and engineering.

2.3 Gifted and Talented Students

Gifted and talented students have special educational needs due to their advanced cognitive, emotional, and social capacities. This group of students usually shows extraordinary intellectual capability, creativity, or commitment to tasks that set them apart from others. Researchers have noted that many of their often-espoused traits, such as curiosity, better memories, and a penchant for increasingly challenging activities, tend to yield ever-increasing demands in class for more advanced, differentiated instruction by their classroom teachers [21-22]. Moreover, the gifted population is diverse in nature, and their talents can span across academic, artistic, and even social domains, which suggests that the use of a dynamic approach to education in schools supports these students with a wide array of skill sets and intellectual strengths in an efficient manner [23]. Many characteristics define gifted and talented learners, including advanced intellectual ability, heightened creativity, and exceptional problem-solving skills. Among these tendencies are: an intense curiosity, preference for challenge, and an ability to learn both quickly and deeply. Most gifted learners reveal heightened sensitivity and strong intrinsic motivation, suggesting superior performance in specific domains related to academics, the arts, or social concerns. However, these characteristics can vary widely, because giftedness is not a monolithic construct, but encompasses diverse strengths and abilities [22].

Identifying gifted students requires a multifaceted approach in order to demonstrate their full potential. Traditional methods, usually standardized IQ tests such as the Wechsler Intelligence Scale for Children, are widely used, with certain limitations criticized, like those involving cultural and socioeconomic biases. Alternative approaches include nonverbal measures of intelligence, such as the Naglieri Nonverbal Ability Test or the Raven Progressive Matrices, which strive to eliminate linguistic and cultural biases. Schools may also utilize teacher and peer nominations, work portfolios, and rating for creativity or problem-solving abilities in identifying giftedness. One proposed model is a dynamic assessment that gauges the way students learn and rise to new challenges. This has been advanced as a better way of allowing often latent talents of individuals from underrepresented cultural or socioeconomic backgrounds to be recognized [24-25].

While the more traditional concept of giftedness focuses on an individual's high IQ score, contemporary frameworks also emphasize environmental factors and emotional intelligence in developing potential. This holds good in the belief that cognitive and non-cognitive characteristics, such as motivation and resilience, are considered equally important for fostering giftedness in countries such as Germany and the Netherlands. This perspective states that giftedness develops through individual predisposition-environment interactions, underscoring the relevance of appropriate special educational programs [26]. Meeting gifted students' needs can be tricky considering the many barriers that may prevent their educational success. Underachievement, often due to a lack of adequate academic challenges, can occur when gifted students are denied sufficiently challenging material or are undetected due to limited screening practices. Educators and policymakers are invited to consider more inclusive identification criteria and develop interventions considering academic and socio-emotional growth, especially for students from underrepresented groups in gifted programs [27-28].

By acknowledging the complex nature of giftedness, schools can consider more supportive and personalized learning environments to promote giftedness and talent in a way that allows them to exploit their potential in various domains [29].

Gifted students, despite their high cognitive abilities, may struggle with mathematics for various reasons. While they are often considered "genius," this label can be misleading and oversimplify their complex experiences [30]. According to a study using TIMSS data, students across different education systems, grade levels, and genders demonstrate persistent misconceptions and errors in key mathematics concepts, such as linear equations [30,39]. This asynchrony can lead to difficulties in social and emotional development, potentially affecting their academic performance. Additionally, gifted students may experience math anxiety, which can impact their problem-solving abilities and even basic arithmetic skills [30]. It's crucial to recognize that giftedness is multifaceted and that these students may require targeted support and interventions to fully realize their potential in mathematics [31].

This study also highlights the importance of recognizing learning gap in STEM education. This is because research suggests that STEM education practices are crucial in discovering and developing the perceptions and skills of gifted students, particularly in areas such as scientific inquiry, argumentation, technological inquiry, and creative thinking. Addressing these misconceptions early and providing appropriate STEM experiences can significantly impact their future STEM readiness [31,40].

2.3 Islamic Gifted Education Model (Kolej PERMATA Insan)

Kolej PERMATA Insan (KPI), previously known as Kolej GENIUS Insan (KGI), is a specialized institution dedicated to the education of Muslim gifted and talented students in Malaysia. The Islamic gifted education model at Kolej PERMATA Insan supports advanced mathematics learning through several innovative approaches. The institution implements an integrated assessment that combines naqli knowledge (Quran and hadith) with intellectual knowledge, including mathematics. This approach aims to produce well-rounded students with leadership skills, multilingual abilities, and research capabilities [32]. The integration of revealed and acquired knowledge (INAQ) concept is applied to all subjects, including mathematics, which allows students to connect Quranic verses with mathematical concepts [33]. Interestingly, this Islamic Gifted Education Model takes a different approach to hone the students with mathematical skill. The Al-Khawarizmi Number Basis Module has been developed as an intervention tool to enhance students' understanding and achievement in mathematics. This module, which covers topics like rational numbers, factors and multiples, and standard form, is complemented by a game card called "Find and Match: Al-Khawarizmi Robot of Number (Riz and Ron)" to make learning more engaging [34].

As a school that caters to academically advanced learners, KPI provides a unique environment where students often excel in challenging subjects, such as Additional Mathematics. This study specifically focuses on KPI students because they represent a population with high cognitive abilities and advanced academic potential. By examining learning gaps in the Functions subtopic within this group, this study aimed to uncover common misconceptions or challenges that may not be as apparent in the general student population. The insights gained from this group can contribute to a better understanding of the unique learning needs of talented students and inform targeted instructional strategies that can help them reach their full potential in mathematics. Additionally, the findings from this study may provide valuable insights for other gifted education programs seeking to enhance support for high-achieving students in mathematics.

Studying a gifted population, as opposed to the general population, offers unique insights into the specific challenges and needs of high-achieving students, which are often overlooked in standard educational research. Gifted students frequently encounter different types of learning challenges because of their advanced cognitive abilities and heightened capacity for complex thought. For instance, while general population studies often focus on foundational skill acquisition, research on gifted students can delve into deeper, more abstract difficulties such as misconceptions in advanced topics such as functions. By focusing on a gifted population, this study can identify unique misconceptions or cognitive barriers that may be less visible in a general classroom setting, allowing educators to develop more effective and tailored instructional approaches for advanced learners [35].

3. Methodology

3.1 Pretest Procedure

Figure 1 describes the flow and implementation of a pretest to understand the students and identify the knowledge gaps regarding the subtopic of functions. The methodology involved six steps and was adapted from The Compass for SBC 2022 [37]. Every step was carefully framed so that the pretest was highly effective and matched the purposes of the study.

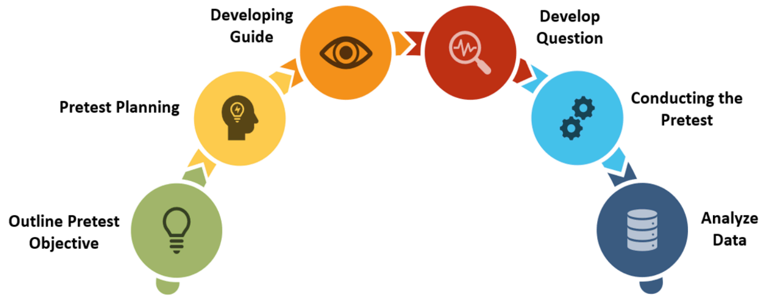

Fig. 1. Pretest procedure structure

3.2 Development of Question Set

In the pretest, fourteen (14) questions are key topics and concepts within the Functions subtopics: basic function properties, composite functions, inverse functions, and integrated functions (HOTS). Table 1 outlines the proposed distribution of questions:

Table 1
Question distribution

Topic	No. of Question	Type of Question	Level of Difficulty
Function (Concept/Fundamental)	3	Closed-Ended	Easy, Moderate
Composite Function	4	Closed-Ended	Easy, Moderate, Challenging
Inverse Function	4	Closed-Ended	Easy, Moderate, Challenging
Integrated Function (HOTS)	3	Closed-Ended	Moderate, Challenging

The questions were reviewed by subject matter experts which is Kolej PERMATA Insan's Additional Mathematics lecturer, to hold the following characteristics before it is passed to the students to be answered, such that the question is in line with the learning outcomes in the KSSM syllabus and the pretest must include all the topics stated in Table 1.

The experts assessed key criteria to ensure the pretest questions were developed rigorously and aligned with the study objectives. The experts assessed:

(a) Content alignment with the KSSM syllabus to ensure that the questions adhered to the prescribed learning outcomes.
(b) Cognitive complexity to match the intended difficulty level.
(c) Clarity and accuracy to prevent ambiguity or misinterpretation by students.

Before implementation, the pretest was piloted with a small group of students (not included in the main study) to evaluate question clarity and timing. Feedback from the pilot test led to further adjustments, particularly for the HOTS questions. Feedback from the pilot test revealed that some HOTS questions required rephrasing for clarity and timing adjustments were made to ensure that the test could be completed within the allocated time.

3.3 Data Sampling and Testing

A census method was chosen to provide a comprehensive understanding of performance trends across the entire cohort, ensuring that no subgroups were excluded. Digital census approaches have shown to be more accurate and reliable than traditional paper-based systems, with fewer errors and inconsistencies [38]. This study investigates all 93 students aged 14 who have been studying additional mathematics under the KSSM syllabus for two years in Kolej PERMATA Insan, Universiti Sains Islam Malaysia (USIM). The gender distribution consisted of 45 males (47%) and 49 females (53%). The test was conducted for one hour on a typical school day in a student's classroom. These students were part of a specialized educational program for talented individuals, indicating a higher-than-average aptitude for mathematics.

3.4 Data Analysis

The results of the pretest are carefully analyzed for each question by using Microsoft Excel to identify patterns in students' responses. This analysis involves measuring students' performance by calculating the percentage of those who achieved full marks for each question, indicating they answered correctly, as well as the percentage of students who received a zero mark, showing they could not provide a correct answer. Additionally, the analyzed data is systematically organized according to key topics, allowing for a clearer understanding of performance trends and areas that may require further attention.

4. Result and Discussion

4.1 Basic Function Properties

The result indicates that many students perform well on this topic, with a significant percentage achieving full marks. Figure 2 displays the percentage of students who answered questions on basic function properties accurately. The data shows that students excel on more straightforward questions; however, they encounter some difficulty with questions of medium complexity, leading to minor confusion in this area.

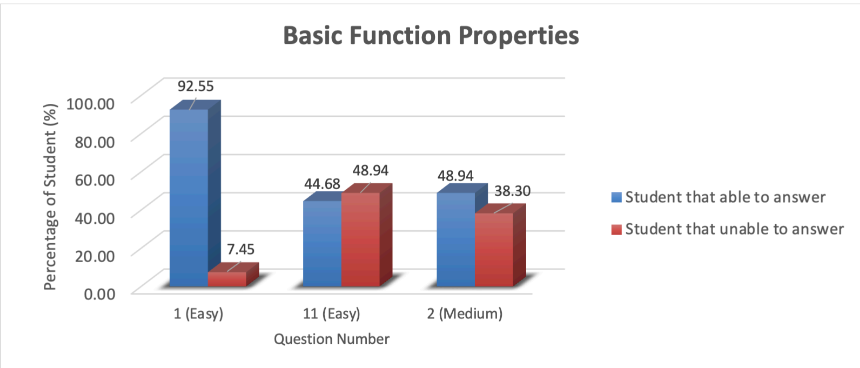

Fig. 2. Graph of student answer analysis on basic function questions

4.2 Composite Function

Figure 3 reveals that students struggled with this question, by making many minor errors that led to a loss of marks, even on more straightforward questions. These small mistakes significantly impacted their overall scores, highlighting areas where additional clarification may be needed.

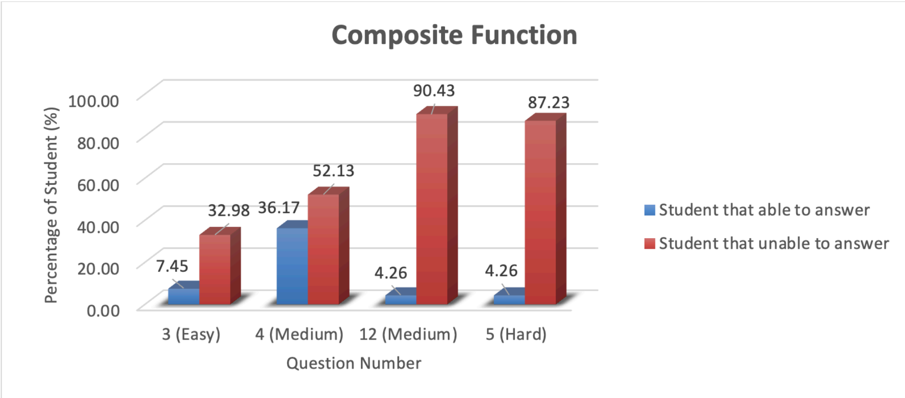

Fig. 3. Graph of student answer analysis on composite function questions

4.3 Inverse Function

Figure 4 illustrates that nearly all students could not answer the question correctly, except for the easy question, which was answered accurately by about half of the students. This indicates a clear area of confusion among students when tackling the topic of inverse functions.

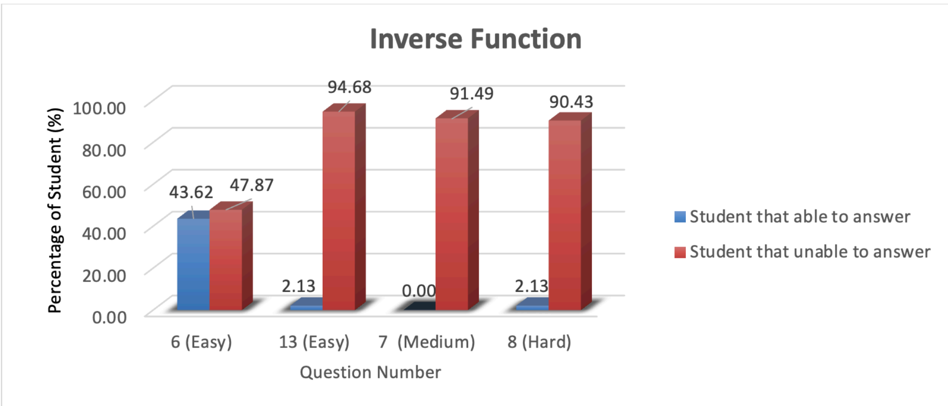

Fig. 4. Graph of student answer analysis on inverse function questions

4.4 Integrated Function (HOTS)

Unlike traditional diagnostic tools that focus on general student populations, this study specifically addresses the learning gaps of gifted students in the topic of functions. By utilizing a targeted pretest that includes higher-order thinking skills (HOTS) questions, this research provides valuable insights into the specific challenges these students face when learning complex mathematical concepts.

Figure 5 demonstrates that nearly all students struggled to answer questions that combined composite and inverse functions. Many appeared highly confused, with many opting to leave the question unanswered.

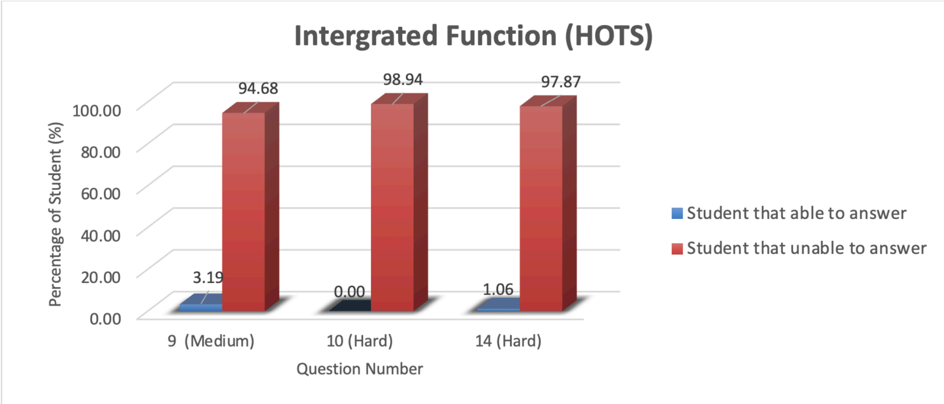

Fig. 5. Graph of student answer analysis on integrated function (HOTS) questions

5. Conclusions

The research reveals that students demonstrate a strong understanding of basic function properties, consistently performing well in these areas. However, as the complexity of the questions escalates, their performance tends to decline significantly. Concepts such as inverse and composite functions emerge as formidable challenges, frequently resulting in small mistakes that adversely impact their overall scores.

Given that talented students often require enriched and varied approaches, incorporating creative thinking techniques could yield insights into their understanding of Functions and suggest methods for addressing learning challenges specific to this group [25]. These findings have important implications not only for enhancing mathematics education at Kolej PERMATA Insan but also for addressing broader challenges in STEM education globally. The findings also highlight the need for policymakers to integrate targeted interventions into curricula that address advanced learners' unique needs. Such policies could standardize approaches to nurturing gifted students, ensuring equitable access to high-quality education. Educators can leverage these findings to design teacher training programs that enhance their capacity to identify and address learning gaps in high-achieving students. Moreover, integrating these insights into digital platforms could provide scalable solutions for personalized learning.

By equipping educators with strategies to address misconceptions in functions, this research supports the development of future STEM leaders who will drive innovation and economic growth. Future studies could extend this approach to other mathematical topics or diverse student populations, ensuring that advanced learners worldwide benefit from improved educational practices.

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