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GIFTED STUDENTS' PERFORMANCE ON ALGORITHMIC, CONCEPTUAL, AND GRAPHICAL QUESTIONS

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Abstract. *Several studies compared three different types of questions (conceptual, algorithmic, and graphical) across various topics, however, few focused specifically on gifted students. This study addressed this gap. The aim of the study, hence, was to determine whether there were notable differences in gifted students' performance in the three types of tests. The study involved 115 gifted students aged between 17 and 18 years old. They responded to the three different tests including 10 test items in each with the same content. Significant differences were observed in their performances between the conceptual versus algorithmic in favour of the conceptual test, the conceptual versus graphical in favour of the conceptual test, and the algorithmic versus graphical in favour of the algorithmic test. Moreover, the statistical analysis results revealed that the students performed markedly poorer performance on the graphical test in comparison to both the algorithmic and conceptual tests. These results suggest the need to enhance students' graphical skills to facilitate a better understanding of physics concepts. Proper steps should be taken to improve their proficiency in interpreting and analysing graphical representations.*

Keywords: *algorithmic understanding, conceptual understanding, graphical understanding, gifted students, physics education*

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Introduction

Scientific knowledge can be communicated through various forms of representation. They are mostly given as written texts, diagrams, simulations, graphs and so forth in the relevant literature (Airey & Linder, 2009; Guo, 2004). Each of these forms of representation possess unique characteristics that allow them to convey specific information and meaning (Lemke, 1990). Researchers (Jaipal, 2010; Kress et al., 2014; Tang et al., 2011, Tsui & Treagust, 2013) have explored the connection between the construction of scientific knowledge and the development of different types of representation. They have also investigated the cognitive requirements for learners to understand and make sense of these representations. In particular, the semiotic properties of graphs have been extensively studied by several researchers. It has been noted that graphs encompass both linguistic and symbolic elements and can be utilized for logical reasoning between variables or elements within a given knowledge unit (Tsui & Treagust, 2013). Consequently, interpreting graphs necessitates cognitive processes that differ from those involved in understanding linguistic elements (Tang et al., 2014). In physics learning, the comprehension of multiple forms of representation is often crucial, and conceptual learning is facilitated by utilizing the representations that provide the highest affordance. The ability to interpret graphs is a complex skill that requires contextual knowledge and the ability to translate unfamiliar graphs into verbal descriptions. This task can even challenge scientists who are unfamiliar with the specific subject matter (e.g., Guo, 2004; Tsui & Treagust, 2013). Thus, graph interpretation goes beyond mere visual understanding and entails a deeper understanding of the underlying concepts and their relationships.

Based on various forms of representation, different types of questions have been identified in the literature. These include conceptual questions (e.g., Nurrenbern & Pickering, 1987), algorithmic questions (e.g., Nakhleh & Mitchell, 1993), graphical questions (e.g., Coştu, 2007; 2010; Kurnaz, 2013), context-based questions (e.g., Kaltakci & Eryilmaz, 2011), and pictorial questions (e.g., Habiddin & Page, 2021). Numerous studies have been conducted to determine which types of questions students excel in. In the chemistry education literature, the initial comparison between conceptual and algorithmic questions was conducted on gas laws and stoichiometry, which revealed that most university students answered algorithmic questions correctly but struggled with conceptual questions (Nurrenbern & Pickering, 1987). This finding has been confirmed by many subsequent studies in chemistry education

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(e.g., Cracolice et al., 2008; Demircioğlu & Erçebi, 2013; Gultepe et al., 2013; Lin et al., 1996; Nakhleh, 1993; Nakhleh & Mitchell, 1993; Papaphotis & Tsaparlis, 2008; Park et al., 2011; Pickering, 1990; Stamovlasis et al., 2005; Yılmaz et al., 2005), indicating that most students show a preference for algorithmic questions over conceptual ones. Similar trends have been observed in physics education, although to a lesser extent (e.g., Coştu & Satılmış, 2020; Düzgün et al., 2001). In both physics and chemistry, there is a general tendency for students to focus on solving algorithmic questions without a sound understanding of the underlying concepts, although there are some contradictions to this trend. Over the years, several studies have compared students' performance on conceptual, algorithmic, and graphical questions in the fields of chemistry (e.g., Coştu, 2007, 2010), physics (e.g., Coştu & Satılmış, 2020; Kurnaz, 2013), and mathematics (e.g., Incikabi et al., 2015). These studies have shown that developing a "graphical understanding" is crucial for students to better comprehend these subjects. When comparing students' achievements on conceptual, algorithmic, and graphical tests, the results consistently indicate that students tend to perform better on algorithmic and conceptual tests but struggle with graphical tests. Furthermore, the emphasis on mathematics in chemistry and physics education can be attributed to the fact that mathematical representations have been an integral part of these subjects for a longer period (Schuchardt & Schunn, 2016; Steen, 2005).

As evident from the aforementioned literature, studies comparing students' performance in conceptual, algorithmic, and graphical questions have been conducted at the middle school, high school, and university levels. However, there is little research on gifted students in this area. Nonetheless, there is a growing recognition that gifted students need to develop skills in mathematical symbol reasoning and graphical thinking, given the rapid advancements in research technologies. Several papers have highlighted the importance of nurturing these skills among gifted students to enhance their understanding of complex scientific concepts and foster their success in science. For instance, Kurnaz (2018) conducted a study that demonstrated a strong correlation between mathematical and spatial skills and students' success in the field of science. These findings suggest that fostering mathematical and graphical reasoning skills should be a crucial component of gifted students' education to enhance their abilities. One approach to facilitate the development of gifted students' abilities is to tailor education to their specific needs, thereby motivating them to further enhance their talents (e.g., Dai & Chen, 2013; Kapıcı & Coştu, 2023). Providing appropriate challenges can increase their motivation to learn (Phillips & Lindsay, 2006), as gifted students often enjoy tackling complex problems due to their advanced problem-solving skills (Kapıcı & Coştu, 2023; Scager et al., 2013; Steiner & Carr, 2003). Based on these suggestions, there is a need to determine the extent to which gifted students possess algorithmic, conceptual, and graphical skills, which are crucial for teaching science concepts. Additionally, examining the performance of gifted students across the three question types can provide further insights into their specific learning challenges. Therefore, this study focuses on gifted students and aims to assess their proficiency in algorithmic, conceptual, and graphical understanding.

Therefore, the aim of the study was to examine whether significant differences exist in the performance of gifted students across three types of questions: namely "conceptual", "algorithmic" and "graphical". The study examined three research questions, which are as follows:

1. Are there any significant differences in gifted students' performance amongst conceptual, algorithmic, and graphical tests?
2. Do the gifted students show the best, the moderate and the worst performance on which of the question types?
3. Is there any positive connection amongst conceptual understanding, algorithmic understanding, and graphical understanding of the gifted students?

Research Methodology

Research Design

A quantitative descriptive research design was employed in this study, with a focus on statistical analysis of data collected through three types of tests. The quantitative descriptive research design is an approach used in educational research to systematically collect and analyse numerical data in order to describe or summarize a specific phenomenon or group. This design is widely utilized to address research inquiries related to the prevalence, patterns, and connection among variables within the field of education (Bloomfield, & Fisher, 2019; Cohen, Manion, & Morrison, 2017).

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Participants

The study included a total of 115 gifted students, aged between 17 and 18 years old, who were enrolled in the Science and Art Center (SAC) at five different high schools (anonymous). The sample size for this study was determined based on the population of gifted students enrolled in the SAC at five different high schools. This sample size was deemed appropriate and representative of the target population, allowing for sufficient statistical power to detect meaningful differences and draw reliable conclusions. The selection of participants from multiple high schools aimed to enhance the generalizability of the findings. However, it is important to note that the specific process and criteria for participant selection were not included in this paper. Ethical considerations were followed, and participant anonymity was maintained throughout the study. In the country, SACs serve as educational institutions specifically designed to offer advanced education in fields like science, mathematics, and art to gifted students (Şahin, 2013). These centres aim to foster the development of students' abilities in their areas of interest and support their personal and social growth. The curriculum at SACs is specifically tailored to meet the unique needs of gifted students, offering engaging and challenging courses (e.g., Kahveci & Akgül, 2014). Admission to SACs is based on a competitive entrance exam that assesses students' academic abilities and potential. Those who perform successfully on the entrance exam are granted admission to SACs, where they receive education from qualified teachers and engage in extracurricular activities aimed at enhancing their skills and knowledge. As a result, the participants in this study share similar backgrounds and possess comparable knowledge in the topics relevant to the study. It should be noted that the participants had previously studied the topics addressed in this research, indicating their familiarity with the subject matter.

Instruments

To address the research questions, the study employed three tests: the Conceptual test (C), the Algorithmic test (A), and the Graphical test (G) (Coştu, 2007; 2009; Kurnaz, 2013). Each test comprised ten multiple-choice items. These test items were developed by drawing from a variety of physics textbooks, theses, and question banks, specifically targeting the research topic outlined in Table 1.

Table 1
Specification of the Three Types of Test Items

Test items	Question peers*	The content of the items
Question 1	(1A-1C-1G)	Relative Motion
Question 2	(2A-2C-2G)	Newton's Laws of Motion
Question 3	(3A-3C-3G)	One-Dimensional Motion with Constant Acceleration
Question 4	(4A-4C-4G)	Two-Dimensional Motion with Constant Acceleration
Question 5	(5A-5C-5G)	Energy and Motion
Question 6	(6A-6C-6G)	Repulsion and Linear Momentum
Question 7	(7A-7C-7G)	Torque
Question 8	(8A-8C-8G)	Simple Machine
Question 9	(9A-9C-9G)	Uniform Circular Motion
Question 10	(10A-10C-10G)	Simple Harmonic Motion

Note. * "**A, C** and **G"** refers to algorithmic, conceptual and graphical, respectively.

An example of each of the three question types (specifically, questions 4C, 4A, and 4G) is provided in the Appendix. The study utilized three distinct types of question items. The first type, referred to as conceptual questions (4C, see Appendix), required students to demonstrate their understanding of the underlying concepts. Conceptual

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questions assess students' comprehension of the fundamental ideas and principles in a subject, rather than their ability to perform specific procedures or calculations. They aim to encourage critical and deep thinking, prompting students to apply their knowledge to solve problems and address questions, instead of relying solely on memorization of facts or procedures.

The second question (4A, see Appendix), known as an algorithmic question, prompts students to utilize a predetermined set of rules or procedures to arrive at a numerical solution for the given problem. Algorithmic questions involve applying established algorithms or procedures to solve problems or answer questions. Typically, these questions involve calculations or the manipulation of formulas and equations, assessing the student's proficiency in executing specific algorithms or procedures accurately. This question type aligns with the established definition of algorithmic questions found in the literature.

The final question type (4G, see Appendix) involved the utilization of graphical knowledge, interpretation, and thinking. A graphical question refers to a question that necessitates students to interpret or analyse information presented in the form of a graph or diagram. It assesses the student's capacity to comprehend and employ visual representations to solve problems or respond to inquiries. This question category aligns with the established definition of a graphical question as outlined in the literature.

Reliability and Validity

The three tests underwent a pilot phase with a separate group of 30 gifted students, distinct from the participants in the main study. The internal consistency of each test was evaluated by measuring the reliability using Cronbach's Alpha coefficient. The results indicated a reliability coefficient of .75 for the conceptual test, .77 for the algorithmic test, and .71 for the graphical test. The difficulty index (p) of the test items ranged from .34 to .70, while the discrimination index (d) of each item was equal to or greater than .27. These results suggest that the tests exhibit satisfactory internal consistency and can be considered reliable measurement tools for comparing the performance of gifted students across the different test types.

To ensure the validity of the tests, a panel consisting of two physics teachers and two science educators assessed the difficulty level of each test item and confirmed the overall validity of the tests.

Data Analysis Procedure

A total of 115 gifted students participated in the examination, completing all 30 test items within a single 45-minute session. A scoring system was developed to assess the students' performance, with incorrect or missing responses receiving a score of 0 points and accurate responses assigned a score of 1 point. The total scores for each student were calculated across the three tests.

Statistical analysis was conducted to compare the students' scores across the three test types. Descriptive statistics were initially performed to examine the distribution of scores for each test. The normality of the data was assessed using the Shapiro-Wilk test to determine whether parametric or non-parametric tests should be used. Based on the results of the normality assessment, either one-way ANOVA (for parametric data) or the Kruskal-Wallis H test (for non-parametric data) was employed to determine the significance of differences among the test types. Subsequently, multiple comparisons of the gifted students' test scores were conducted to identify specific significant differences between each test and the other two.

Furthermore, a specific set of criteria was utilized to compare the students' performance on one type of item with their performance on the other two test types, allowing for a more detailed analysis of their performance across different question categories.

Research Results

The responses of the gifted students in the three question types are presented in Table 2.

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Table 2
Gifted Students' Responses in Three Types of Test Items

Question items	Algorithmic test			Conceptual test			Graphical test		
	A1	A0	A-	C1	C0	C-	G1	G0	G-
1A-1C-1G	97	14	4	103	11	1	103	10	2
2A-2C-2G	77	27	11	102	11	2	65	48	2
3A-3C-3G	65	45	5	42	70	3	69	45	1
4A-4C-4G	100	8	7	99	14	2	93	21	1
5A-5C-5G	40	61	14	82	31	2	72	37	6
6A-6C-6G	91	22	2	90	24	1	28	84	3
7A-7C-7G	65	49	1	92	21	1	81	33	1
8A-8C-8G	94	19	2	100	10	5	104	6	5
9A-9C-9G	87	25	3	96	18	1	67	47	1
10A-10C-10G	108	5	2	104	9	2	50	63	2
Total	**824**	**275**	**51**	**910**	**219**	**20**	**732**	**394**	**24**

Note: **A1**, **C1** and **G1** refer to correct responses for algorithmic, conceptual, and graphical test items respectively.
A0, **C0** and **G0** refer to incorrect responses for algorithmic, conceptual, and graphical test items respectively.
A-, **C-** and **G-** refer to no response for algorithmic, conceptual, and graphical test items respectively.

Based on the results presented in Table 2, it is evident that gifted students faced greater challenges with graphical questions, as a lower percentage of students provided correct answers compared to other question types. Similarly, they encountered difficulties with algorithmic questions, as a higher number of students did not respond to them compared to other question types. In general, the average of the correct scores for all test items was 71.6, with a standard deviation of 12.6. On average, the percentage of correct answers for each test type was as follows: algorithmic test items - 71.5 (SD = 18.8), conceptual test items - 79.0 (SD = 14.3), and graphical test items - 64.3 (SD = 15.6).

To determine whether to use parametric or non-parametric tests, the normal distribution of the data was assessed using the Shapiro-Wilk test. The results indicated that all three tests followed a normal distribution ($p = .22 > .05$ for the algorithmic test, $p = .11 > .05$ for the conceptual test, and $p = .18 > .05$ for the graphical test). Therefore, a one-way ANOVA test was employed to compare the performance of gifted students on each test. Table 3 presents a statistical analysis of the differences in the results.

Table 3
Results of One-way ANOVA

	Sum of squares	*df*	*MS*	*F*	*p*
Between groups	12419.2	2	6209.6	23.15	.0001
In groups	92138.1	343.5	134.1		
Total	104557.2	344.5			

According to Table 3, there were significant differences in test scores ($p = .0001 < .05$). Based on the average achievement scores of all three test types, students performed the best in the conceptual test and the worst in the

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graphical test. In other words, students demonstrated the highest level of performance in conceptual questions compared to all other question types. Additionally, a post hoc (Tukey HSD) statistical analysis was conducted to identify the tests that showed significant differences. The results of the post hoc analysis are presented in Table 4.

Table 4.
Results of Multiple Comparisons of the Students' Test Scores (based on Tukey HSD)

(D) Test	(E) Test	Mean Difference (D-E)	In favour of	(p) Sig.
Algorithmic (A)	Conceptual (C)	(A-C) -7.48*	Conceptual	.0001
	Graphical (G)	(A-G) 7.22*	Algorithmic	.0001
Conceptual (C)	Algorithmic (A)	(C-A) 7.48*	Conceptual	.0001
	Graphical (G)	(C-G) 14.70*	Conceptual	.0001
Graphical (G)	Conceptual (C)	(G-C) -14.70*	Conceptual	.0001
	Algorithmic (A)	(G-A) -7.22*	Algorithmic	.0001

Note. * The mean difference is significant at the .05 level

The results of the multiple comparisons revealed a significant distinction between the conceptual test and the graphical test ($p = .0001 < .05$), favouring the conceptual test. Similarly, significant differences were found between the conceptual test and the algorithmic test ($p = .0001 < .05$), favouring the conceptual test. Likewise, significant differences were observed between the graphical test and the algorithmic test ($p = .0001 < .05$), favouring the algorithmic test. To categorize students as high or low performers, a score of over 50% was considered indicative of high performance (coded as H), while a score of less than 50% indicated low performance (coded as L). The codes assigned to each test item were determined based on the student's performance on each question within the pairs. Figure 1 illustrates all possible comparisons between the three test types. A specific set of criteria was utilized to compare the students' performance on the algorithmic test items with their performance on the conceptual and graphical test items. Figure 1 presents all potential outcomes of these comparisons. The distribution of the gifted students' total score is depicted in Figure 1 as follows: 59% in the HAHC category, 20% in the LAHC category, 13% in the HALC category, and 8% in the LALC category. These findings suggest that the majority of students displayed the capacity to successfully apply relevant concepts when solving algorithmic problems.

Figure 1
Categories Based on Algorithmic Questions versus Conceptual Questions, Graphical Questions versus Conceptual Questions and Algorithmic Questions versus Graphical Questions

<table>
<tr><td colspan="2"></td><td colspan="2">Conceptual Question</td></tr>
<tr><td rowspan="3">Algorithmic Question</td><td rowspan="2">High (H)</td><td>High (H)</td><td>Low (L)</td></tr>
<tr><td>Good at algorithmic test, good at conceptual test (HAHC) 59%</td><td>Good at algorithmic test, poor at conceptual test (HALC) 13%</td></tr>
<tr><td>Low (L)</td><td>Poor at algorithmic test, good at conceptual test (LAHC) 20%</td><td>Poor at algorithmic test, poor at conceptual test (LALC) 8%</td></tr>
</table>

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		Conceptual Question	
		High (H)	**Low (L)**
Graphical Question	**High (H)**	Good at graphical test, good at conceptual test (HGHC) 53%	Good at graphical test, poor at conceptual test (HGLC) 11%
	Low (L)	Poor at graphical test, good at conceptual test (LGHC) 26%	Poor at graphical test, poor at conceptual test (LGLC) 10%

		Graphical Question	
		High (H)	**Low (L)**
Algorithmic Question	**High (H)**	Good at algorithmic test, good at graphical test (HAHG) 48%	Good at algorithmic test, poor at graphical test (HALG) 23%
	Low (L)	Poor at algorithmic test, good at graphical test (LAHG) 17%	Poor at algorithmic test, poor at graphical test (LALG) 12%

For a detailed breakdown of the students' performance on each specific test item category (algorithmic test items versus conceptual test items), please refer to Table 5. The results presented in Table 5 reveal that gifted students in the HAHC category achieved the highest average percentage (68%) compared to the other performance categories. Conversely, students in the HALC category had a moderately lower average percentage (15%) among the other performance categories. This suggests that although these students performed well on algorithmic test items, they struggled with answering conceptual test items correctly. In summary, the categories of student performance are interconnected, and the results indicate that HAHC exhibited the highest percentages, while HALC showed slightly lower percentages, aligning with the statistical differences observed in Table 4. These consistent findings point to a positive correlation between the algorithmic abilities of gifted students and their conceptual understanding of physics topics.

Table 5
Percentages of Algorithmic Test Items versus Conceptual Test Items

	HC		LC	
	HA	**LA**	**HA**	**LA**
Question 1	86	16	10	3
Question 2	69	33	7	6
Question 3	23	19	42	31
Question 4	87	12	12	4
Question 5	31	52	9	23
Question 6	70	20	21	4
Question 7	54	39	11	11

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	HC		LC	
	HA	**LA**	**HA**	**LA**
Question 8	83	17	11	4
Question 9	73	22	15	5
Question 10	99	5	9	2
Average	**68**	**23**	**15**	**9**

Regarding the performance of gifted students on the conceptual test versus the graphical test, Figure 1 illustrates the distribution of students' total performance as follows: HCHG, 53%; HCLG, 26%; LCHG, 11%; and LCLG, 10%. These results indicate that the most students had a stronger conceptual understanding and were able to interpret graphs related to physics concepts correctly (i.e., HCHG 53%). However, students who achieved LCHG performance had the slightly lowest average percentage (11%) among the other performance categories, suggesting that although these students struggled with conceptual test items, they also answered graphical test items incorrectly. This finding supports the notion that there is a positive correlation between the gifted students' conceptual understanding and their graphical abilities. In other words, the stronger their conceptual understanding of physics topics, the greater their graphical abilities. For a more detailed analysis of each test item, the students' performance on conceptual test items versus graphical test items is provided in Table 6.

Table 6
Percentages of Conceptual Test Items versus Graphical Test Items

	HC		LC	
	HG	**LG**	**HG**	**LG**
Question 1	96	6	10	3
Question 2	59	43	6	7
Question 3	25	17	45	28
Question 4	83	16	10	6
Question 5	58	25	14	18
Question 6	20	70	8	17
Question 7	68	25	14	8
Question 8	94	5	11	5
Question 9	58	37	10	10
Question 10	47	58	4	6
Average	**61**	**30**	**13**	**11**

As observed in Table 6, students performing at the HCHG level achieved the highest percentage in most questions, with the exception of questions 3, 6, and 10. These findings indicate that students with strong conceptual understanding also tend to have a good grasp of graphical concepts, aligning with the results from the total scores presented in Figure 1.

Regarding the students' overall performance on the algorithmic test compared to the graphical test, there was a distribution of total performance among the students: HAHG, 48%; LAHG, 17%; HALG, 23%; and LALG, 12%, as shown in Figure 1. This distribution suggests that a majority of the gifted students were able to apply algorithmic thinking to comprehend and interpret graphical questions related to physics. To examine this in more detail, a breakdown of the students' performance on each individual item (pertaining to conceptual test items versus graphical test items) is presented in Table 7.

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Table 7
Percentages of Algorithmic Test Items versus Graphical Test Items

	HA		LA	
	HG	LG	HG	LG
Question 1	90	6	16	3
Question 2	49	28	17	21
Question 3	42	23	28	22
Question 4	82	17	11	5
Question 5	30	10	42	33
Question 6	22	69	6	18
Question 7	46	19	36	14
Question 8	88	6	17	4
Question 9	54	34	14	13
Question 10	48	60	3	4
Average	**55**	**27**	**19**	**14**

As observed in Table 7, students who demonstrated HAHG performance achieved the highest percentage in most questions, with the exception of questions 5, 6, and 10, as reflected in the overall results presented in Figure 1. This finding suggests a correlation between students' algorithmic problem-solving skills and their understanding of graphs. In other words, most students were able to solve the problems and interpret graphs correctly. Furthermore, the high percentages in the LG category for almost every question indicate that the graphical skills of the gifted students were significantly inadequate.

Discussion

The overall analysis of the gifted students' performance on the three physics tests indicated a significant difference in their scores. Specifically, the students performed significantly worse on the graphical test compared to the conceptual and algorithmic tests. These findings align with previous studies conducted on chemistry topics (e.g., Coştu, 2007; 2010) and physics topics (e.g., Coştu & Satılmış, 2020; Kurnaz, 2013) involving non-gifted students. However, they are inconsistent with prior research on chemistry topics (e.g., Mason et al., 1997; Nakhleh, 1993; Niaz, 1995; Pickering, 1990; Pushkin, 1998; Sawrey, 1990) and physics topics (e.g., Düzgün et al., 2001), which suggest that non-gifted students may employ algorithms without a significant level of conceptual understanding. These discrepancies in the literature may be attributed to students employing non-conceptual strategies when solving algorithmic questions in multiple-choice test items (Sung et al., 2022).

For a comprehensive analysis, let's address the first research question of the study. The results revealed statistically significant differences among the three test scores. The gifted students exhibited the highest performance on the conceptual test, while their performance on the graphical test was the lowest. Multiple comparisons indicated statistically significant differences between the conceptual and algorithmic test scores, favouring the conceptual test. Similarly, there were statistically significant differences between the graphical and algorithmic test scores, favouring the algorithmic test. Additionally, there were statistically significant differences between the graphical and conceptual test scores, favouring the conceptual test. These findings contradict previous studies conducted on chemistry (e.g., Mason et al., 1997; Nakhleh, 1993; Niaz, 1995; Pickering, 1990; Pushkin, 1998; Sawrey, 1990) and physics topics (e.g., Düzgün et al., 2001), but are consistent with more recent literature (Coştu, 2007; 2010; Coştu & Satılmış, 2020; Kurnaz, 2013) that suggests many non-gifted students are capable of solving algorithmic problems with conceptual understanding. One possible reason for these results could be attributed to giftedness (e.g., Godor, 2019; Kapıcı & Coştu, 2023), as there exists a strong association between conceptual understanding and giftedness in science education. As discussed in the literature, gifted students are individuals with exceptional skills and intellectual abilities, often demonstrating above-average proficiency

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in academic subjects such as math, science, and language (e.g., McCoach et al., 2001; Steiner, & Carr, 2003, Tosun, 2022). Furthermore, the study suggests that contemporary teaching methods, such as constructivism, may have contributed to these findings. In our country, teaching methods and assessments have been aligned with international exams like TIMSS and PISA (e.g., MoNE, 2018), which frequently include algorithmic questions requiring solid conceptual understanding. Additionally, learning based on semiotics considers knowledge as a dynamic process, aligning with modern teaching approaches rather than a static structure to be memorized (e.g., Uden et al., 2001). As a result, the gifted students demonstrated greater success in the conceptual test than in the algorithmic test, contrary to the prevailing literature (e.g., Düzgün et al., 2001; Mason et al., 1997; Nakhleh, 1993; Niaz, 1995; Pickering, 1990; Pushkin, 1998).

Regarding the second research question of the study, the results indicated that gifted students performed the poorest on the graphical test, achieved moderate performance on the algorithmic test, and demonstrated the highest performance on the conceptual test. The statistical analysis and comparisons of the students' performance in all three tests highlight that gifted students' overall performance on the graphical test was the lowest. This finding aligns with previous studies conducted on chemistry topics (Coştu, 2007; 2010) and physics topics (Coştu & Satılmış, 2020; Kurnaz, 2013). Both this study and previous research suggest that both non-gifted and gifted students encounter difficulties with graphical questions and struggle to effectively utilize their graphical skills, particularly in reading and interpreting graphs. This challenge is not specific to the test items themselves but rather stems from students at all levels struggling with various graphical skills, including drawing, reading, interpretation, extrapolation, and interpolation, as evidenced by previous studies (Bowen et al., 1999; Bowen & Roth, 2005; Coştu et al., 2017; Dori & Sason, 2008; Ercan et. al., 2018; Ergül, 2018; Gardner et al., 2021; Glazer, 2011; Pols et al., 2021; Potgiether et al., 2008; Stefanel, 2019; Tairab & Khalaf Al-Naqbi, 2004). In the context of the semiotic construction of scientific knowledge, the poor performance of gifted students on graphical questions can be attributed to their struggle in transitioning from one semiotic system to another, as suggested by relevant literature (e.g., Duval, 2006; Lemke, 1998; Tang et al., 2011; Tsui & Treagust, 2013; Volkwyn et al., 2020). Therefore, it is essential to enhance graphical skills in order to foster a better understanding of physics concepts. To achieve this goal, computer-based instruction (e.g., Dori & Sasson, 2008; Sari et al., 2019) and instructional strategies (Altun et al., 2011; Harsh & Schmitt-Harsh, 2016; Stefanel, 2019) should be employed, as suggested in the literature.

To address the third research question of the study, comparisons were made between the two types of tests. This comparison yielded two major findings. Firstly, the results indicated that the highest-performing category among all the categories was the HAHC category, where gifted students were able to effectively utilize their conceptual understanding to solve algorithmic questions. This finding suggests that the extent of students' conceptual understanding of physics concepts positively correlates with their algorithmic abilities. This result is consistent with certain relevant studies (e.g., Ateş & Cataloglu, 2007; Chiu, 2001; Coştu, 2007; 2010), but inconsistent with others (e.g., Lythcott, 1990; Mason et al., 1997; Nakhleh, 1993; Nurrenbern & Pickering, 1987; Sawrey, 1990). Secondly, it was observed that there were positive relationships between gifted students' graphical understanding and their algorithmic and conceptual understanding compared to the relationships with the other two types. Proficiency in "algorithmic understanding" was associated with success in "graphical understanding". Similarly, strong "conceptual understanding" was linked to good "graphical understanding". Therefore, it is important to enhance both algorithmic and conceptual understanding in order to improve students' graphical understanding.

Conclusions and Implications

The results demonstrated that the gifted students performed significantly worse on the graphical test than on the other two tests. Graphs contain both linguistic and symbolic components and can be used to establish logical connections between variables or elements within a specific domain of knowledge. The interpretation of graphs requires cognitive processes that are distinct from those involved in comprehending linguistic elements. The ability to interpret graphs is also a complex skill that requires contextual knowledge and the ability to translate unfamiliar graphs into verbal descriptions. Therefore, it can be concluded that both non-gifted and gifted students demonstrate lower achievement in questions that involve graphical elements. In the literature, students at all academic levels have been found to face difficulties with various aspects of graphical skills, such as drawing, reading, interpretation, extrapolation, and interpolation, as evidenced by previous studies. In order to enhance these

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graphical skills, computer-based instruction and various instructional strategies should be used so as to promote sound understanding of physics concepts. In the process of learning physics, it is often essential to understand and grasp multiple forms of representation. The comprehension of concepts is greatly enhanced by utilizing the representations that offer the greatest potential for learning.

The results also demonstrated that gifted students effectively applied their conceptual understanding to solve algorithmic problems and interpret graphs. This finding suggests a positive correlation between students' conceptual comprehension of physics concepts and their proficiency in algorithmic and graphical skills. To enhance students' problem-solving and graphical skills, it is imperative to prioritize the development of their conceptual understanding. Conceptual understanding is of utmost importance in science education as it focuses on developing a deep understanding of underlying concepts and principles rather than solely memorizing facts or procedures. It involves making connections, recognizing patterns, and applying knowledge to new situations. Conceptual learning enables students to develop critical thinking skills, problem-solving abilities, and a more comprehensive understanding of the subject matter. It promotes higher-order cognitive skills, creativity, and the ability to transfer knowledge to real-world contexts. By fostering conceptual learning, students acquire a solid foundation that allows them to build upon their knowledge, make meaningful connections, and engage in lifelong learning.

In this study, the performance of gifted students was examined across different question types, revealing a lower achievement in graphical questions. However, the specific graphical skills that posed challenges for these students could not be identified, thus indicating a limitation. Future research should aim to comprehensively explore the specific graphical skills that gifted students encounter difficulties with.

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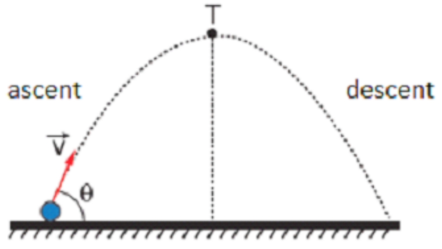
Appendix.

Example of the three types of questions (namely question 4C, 4A and 4G)

Sample of the conceptual question type (4C)

In an environment where air friction is negligible, a body thrown obliquely at an angle θ with the horizontal follows a trajectory as shown in the below figure.



According to this, about the motion of the object,

I. The velocity of the shot and the velocity of impact with the ground are equal.
II. The velocity of the object is zero at T (vertex).
III. The ascent time of the object is equal to the descent time.

Which of these statements are true?

A) Only I **B)** Only II **C)** Only III **D)** I and II **E)** II and III

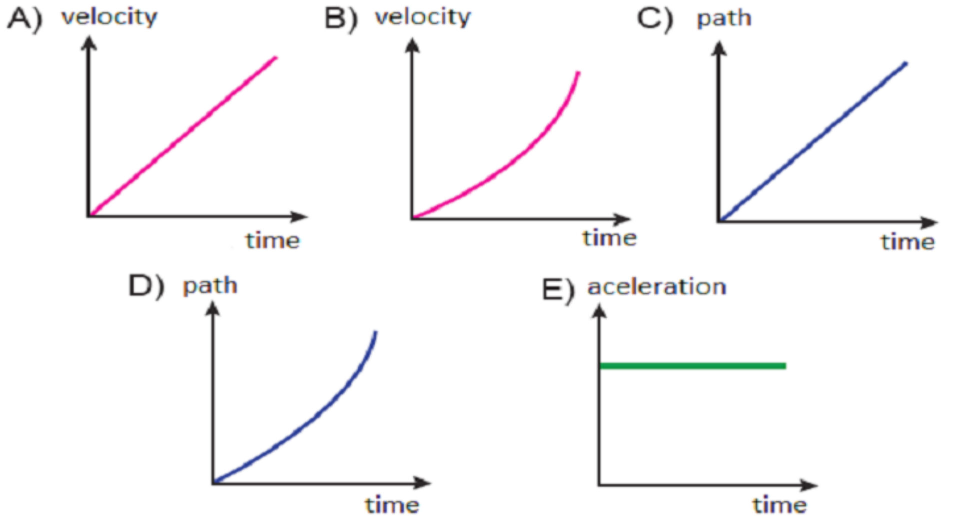
Sample of the algorithmic question type (4A)

In an environment where friction is negligible, how many meters is the maximum height that an object thrown obliquely at a speed of 50 ?2 m/s at an angle of 45° with the horizontal? ($g=10\ m/s^2$)

A) 180 **B)** 155 **C)** 135 **D)** 125 **E)** 80

Sample of the graphical question type (4G)

Which of the following could be one of the graphs of the horizontal motion of a stone thrown horizontally from the top of a building? (Air friction is insignificant)



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