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Comparative Analysis of HSEE and PISA Mathematics Items: Cognitive Requirements and Levels

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Abstract

This study examines the alignment of mathematics items used in the High School Entrance Exam (HSEE) conducted in Turkiye with mathematical literacy proficiency levels identified for PISA. In line with curriculum reforms in 2018, the format and structure of HSEE have changed to enhance students' critical thinking and problem-solving skills, shifting from rote memorization to higher-order cognitive abilities. However, the extent to which HSEE math items align with PISA's mathematical proficiency levels remains an open question. Using a qualitative research approach, this study employs document analysis to classify 140 HSEE mathematics items from 2018 to 2024 based on six proficiency levels described in PISA. Two mathematics educators independently coded the items and achieved 80% agreement on the levels. Discrepancies were resolved through discussion, and final decisions were made accordingly. Findings indicate that HSEE primarily includes a moderate level of mathematical proficiency, with the majority of items classified at Level 3. The presence of Level 1 and Level 2 questions fluctuated over the years, while Level 4 questions showed inconsistent patterns. Notably, no questions were identified at Level 5 or Level 6, indicating a lack of high-level problem-solving tasks aligned with international standards. These results suggest that while HSEE has integrated more analytical questions compared to previous standardized exams, it remains insufficient in assessing advanced mathematical literacy. To better align with PISA and foster higher-order thinking skills, HSEE should include more complex, real-world problem-solving questions that require students to apply their mathematical reasoning skills. Future reforms in the Turkish national mathematics curriculum and assessment framework should emphasize the development of students' higher-order thinking skills, including mathematical literacy, for international benchmarks.

Keywords: PISA, High School Entrance Exam, mathematics, proficiency levels

Introduction

In Turkiye, students are placed in high schools according to their scores obtained from a standardized exam, namely the High School Entrance Exam (HSEE), which takes place at the end of the 8th grade. In 2018, the format and structure of HSEE were reformed. The low performance of Turkish students in international assessments,

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particularly in Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS), was one of the main reasons for the modifications made to HSEE (Ministry of National Education (MoNE), 2018). Among these assessments, PISA allows countries to compare their education systems on an international scale by providing detailed reports and categorizing different proficiency levels. Turkiye has participated in PISA regularly since 2003, but has not achieved the desired level of success among the participating countries. In 2003, Turkiye ranked 33rd among 41 countries, 43rd among 57 countries in 2006, 41st among 65 countries in 2009, and 44th among 65 countries in 2012. In 2015, Turkiye dropped to its lowest ranking, placing 50th among 72 countries (OECD, 2016).

Due to Turkish students' underperformance in PISA, the Ministry of National Education (MoNE) introduced changes in 2018 to both the curriculum and the standardized exam used for high school placement. While previous standardized exams mainly included questions at the knowledge and comprehension levels based on Bloom's taxonomy, recently, there are more application and analysis level items in HSEE. Previously, students only needed to apply their procedural knowledge to succeed in standardized exams. However, PISA does not aim to directly measure students' mathematical knowledge; rather, it assesses how they apply their mathematical thinking skills (reasoning, making connections, inference, problem-solving, and modeling) to real-life problem contexts. PISA results revealed that Turkish students particularly struggled with mathematical reasoning, problem-solving, and questions requiring higher-order cognitive skills (MoNE, 2018).

This realization led to increased awareness that standardized exams in Turkiye should be restructured to assess students not only on procedural knowledge but also on their critical thinking and problem-solving abilities. Consequently, it was emphasized that items should focus more on measuring students' higher-order thinking skills, such as analytical thinking, problem solving, and reasoning. The emphasis on higher-order cognitive skills in HSEE questions aimed to encourage students to move away from rote learning and improve their mathematical literacy. However, the extent to which this goal has been achieved and the degree to which HSEE mathematics items align with international standards remain a topic for exploration. In this regard, a comparative analysis of HSEE mathematics questions and PISA's mathematical literacy levels is crucial for evaluating Turkiye's progress in this area.

Mathematical literacy skills

Mathematical literacy is defined as "an individual's capacity to reason mathematically and to formulate, employ, and interpret mathematics to solve problems in a variety of real-world contexts. It includes concepts, procedures, facts and tools to describe, explain and predict phenomena" (OECD, 2023a, p. 22). Based on this description, PISA assesses students' mathematical knowledge and skills through six proficiency levels, ranging from Level 1 (the lowest) to Level 6 (the highest). These proficiency levels were established by experts in mathematics education and assessment and were validated using data from previous PISA assessments (OECD, 2023b). A brief description of each proficiency level is given in Table 1.

Table 1. Proficiency level description of PISA items

Level	*Task description*
L1	Answers questions involving simple contexts where all the information needed is present, and the questions are clearly defined Responds to questions involving easy-to-understand contexts where all the information needed is given in a simple representation Responds to questions involving easy-to-understand contexts where all relevant information is given in a simple, familiar format
L2	Recognizes situations where they need to design simple strategies to solve problems, including running straightforward simulations involving one variable as part of their solution strategy
L3	Devises solution strategies Interprets and uses representations derived from different information sources
L4	Engages with aspects of critical thinking Selects and integrates different representations of information Constructs and communicates explanations based on interpretations and reasoning
L5	Develops and works with models for complex situations Applies systematic, well-structured problem-solving strategies to address challenging tasks Uses mathematical knowledge that is not directly provided
L6	Works through abstract problems by demonstrating creativity and flexible thinking to develop solutions Connects various information sources and representations using tools like simulations Uses advanced mathematical operations

Table 1 presents a very brief description of the six proficiency levels in mathematical literacy as defined in PISA. Each level represents a progressively more advanced ability to comprehend, interpret, and apply mathematical concepts in real-world contexts. Lower levels (L1 and L2) focus on basic comprehension and routine problem-solving, while higher levels (L5 and L6) require abstract reasoning, creativity, and the ability to integrate multiple representations. These proficiency levels serve as a framework for evaluating students' mathematical thinking skills and their ability to apply mathematical knowledge beyond procedural tasks (OECD, 2023b).

When analyzing mathematical literacy scores, Turkiye's average performance is observed to be below that of other countries (Ersoy & Öksüz, 2016). In PISA, students performing at Level 2 and below are classified as "low performers", while those performing at Level 5 and above are considered "high performers" (OECD, 2023a). In the most recent PISA 2022 assessment, 1.8% of participating students in Turkiye performed at Level 5 or above in mathematics, while 9.4% performed at Level 2 or below (OECD, 2023a). A similar trend is also observed in students' performance in the HSEE mathematics exam. The average number of correct answers out of 20 items between 2018 and 2024 was 6.99, 5.09, 9.36, 7.56, 4.74, 5.95, and 6.54, respectively (MoNE, 2024). This indicates that the percentage of correct answers given by students to the HSEE mathematics items ranges between 24% and 47%.

The study

In this study, mathematics questions from the HSEE exams administered between 2018 and 2024 were classified according to PISA's mathematical literacy proficiency levels. This study employed a qualitative research approach using document analysis. Document analysis involves examining written materials relevant to the research topic (Yıldırım & Şimşek, 2018). The PISA mathematical literacy proficiency levels (OECD, 2023b) were used in the document analysis of HSEE mathematics questions.

A total of 140 HSEE mathematics questions from 2018 to 2024 were examined by two mathematics educators, and discussions were held regarding their alignment with PISA proficiency levels. Independent analyses resulted in an 80% agreement rate between the experts. For questions where opinions differed, solutions were reanalyzed, and a consensus was reached regarding the required skills and proficiency level. By re-examining the questions, agreement among the experts was ultimately achieved.

Coding

In determining the levels (L1, L2, L3, L4, L5, L6) of the HSEE mathematics items, a full description of PISA mathematics proficiency levels was taken into consideration, and also, sample released items were carefully analyzed. Table 2 includes the HSEE mathematics items identified at levels L1, L2, L3, and L4, together with the corresponding descriptions that guided the level assignment process.

Table 2. Sample coding of HSEE items in terms of proficiency levels

Level	*HSEE item*	*Explanation*
L1	(HSEE 2024, Q1) Which of the following algebraic expressions represents the perimeter, in centimeters, of a square with side length (x + 2) cm? A) x+8 B) 4x+2 C) 4x+4 D) 4x+8	It requires comprehending information given in a simple representation (the side length of a square), and employing a basic algorithm or procedure (the perimeter formula of a square) to find the correct algebraic expression. The problem is a simple, one-step routine problem that involves directly applying a well-known geometric formula.
L2	(HSEE 2024, Q2) When operating at full capacity, the Akkuyu Nuclear Power Plant, which will meet a significant portion of Turkiye's electricity demand, is expected to prevent 21×10^8 times tons of carbon emissions over 60 years. Accordingly, which of the following is the scientific notation of the amount of carbon emissions, in kilograms, that the Akkuyu Nuclear Power Plant will prevent in one year when operating at full capacity? A) 3.5×10^7	It requires solving a simple routine problem involving one variable (calculating annual carbon emissions prevented), comprehending a two-dimensional representation (understanding the relation between total and annual emissions), and understanding proportional relationships between quantities (dividing total emissions by the number of years). Although it involves basic arithmetic and scientific notation, the problem requires recognizing and

<table>
<tr><td></td><td>B) 3.5×10^{10}
C) 21×10^{7}
D) 2.1×10^{10}</td><td>interpreting the relationship between quantities in a real-life context.</td></tr>
<tr><td>L3</td><td>(HSEE 2023, Q7)
Both Efe and Kuzey have more than 50 marbles, and they each have the same number of marbles. Efe has placed all of his marbles equally into 3 bags, while Kuzey has placed all of his marbles equally into 4 bags. When Efe and Kuzey exchange one bag of marbles with each other, what is the minimum possible total number of marbles Kuzey will have?
A) 55
B) 65
C) 78
D) 80</td><td>It requires solving a routine but multi-step problem that involves identifying a common number divisible by both 3 and 4 and greater than 50. Moreover, it requires interpreting and using multiple representations, such as understanding the division of marbles into equal groups and the process of exchanging bags. The student needs to analyze the given information to determine the minimum total number of marbles.</td></tr>
<tr><td>L4</td><td>(HSEE 2024, Q19)
Each of the numbers 1, 2, 3, 4, 5, 6, 7, 8, and 9 is placed into one of nine identical boxes, with one number in each box, as shown in the table below. Some of these boxes are covered with blue cards.
<table><tr><td>Blue</td><td>4</td><td>Blue</td></tr><tr><td>5</td><td>Blue</td><td>Blue</td></tr><tr><td>7</td><td>Blue</td><td>6</td></tr></table>It is known that:
In the first row, the probability of randomly selecting a number less than 3 is greater than the probability of selecting a number greater than 3.
In the third row, the probability of randomly selecting an odd number is less than the probability of selecting an even number.
Accordingly, what is the sum of the numbers hidden under the blue cards in the second row?
A) 17
B) 12
C) 11
D) 3</td><td>It requires solving a problem involving two variables in a complex situation, evaluating the reasonableness of possible solutions without direct computation, and interpreting multiple representations, such as the table and probability statements, to determine number placements.</td></tr>
</table>

Table 2 includes only sample items at Levels 1, 2, 3, and 4, along with explanations regarding their levels, since there are no items that fall into Level 5 or Level 6 in the HSEE.

Results

When analyzing the distribution of HSEE mathematics questions according to PISA proficiency levels from 2018 to 2024, it was observed that the exam primarily focuses on assessing moderate-level cognitive skills. Table 3 presents a frequency table showing the distribution of mathematics questions in the HSEE exam according to PISA proficiency levels.

Table 3. Frequencies of HSEE mathematics items according to PISA proficiency levels

Year of HSEE	*Proficiency Levels*					
	L1	L2	L3	L4	L5	L6
2018	2	7	8	3	0	0
2019	1	7	8	4	0	0
2020	0	6	8	6	0	0
2021	1	4	12	3	0	0
2022	2	5	7	6	0	0
2023	3	5	10	2	0	0
2024	4	5	9	2	0	0
Median	2	5	8	3	0	0

In 2018, there were 2 questions at Level 1, 7 at Level 2, 8 at Level 3, and 3 at Level 4, while there were no questions at Level 5 or Level 6. A similar pattern continued in 2019 and 2020, with 2020 notably containing no Level 1 questions. In 2021, the number of Level 3 questions reached its highest frequency (12 items), while there were 3 items at Level 4. The increase in the number of Level 1 items from the year of 2022 to 2024 indicates a deviation from the initial goal of incorporating items entailing more higher level of mathematical proficiency skills.

HSEE has consistently contained more questions at Level 3, approximately 8 items. The number of Level 4 questions increased from 3 in 2018 to 6 in 2020 and 2022 but then dropped back to 2 in 2023 and 2024, indicating a decrease in the exam's difficulty level over time. One of the most striking findings is that no questions at Level 5 or Level 6 were included in any of the examined years. This suggests that HSEE either avoids assessing the highest-level mathematical literacy skills defined by PISA or that the nature of the exam is not appropriate for such questions, since Level 5 or Level 6 type of items entail explanations for the solution or justification of the answer but multiple-choice items are not appropriate to elicit such complex skills.

If the goal is to foster advanced mathematical reasoning and problem-solving skills, it may be necessary to incorporate more questions assessing higher cognitive levels. The fluctuations in the number of lower-level questions (Levels 1 and 2) over the years, particularly their increase in 2023 and 2024, further suggest a decrease in the overall

difficulty level of the exam. To better align HSEE with PISA standards, incorporating more high-level questions appears to be necessary. The current exam structure primarily focuses on assessing moderate-level mathematical skills, indicating that Turkiye's mathematics curriculum needs further steps to develop students' highest-level cognitive abilities.

Conclusion

The findings of this study indicate that between 2018 and 2024, HSEE mathematics questions primarily assessed moderate-level proficiency skills, concentrating mostly on Levels 2 and 3 as defined by PISA. Although HSEE was structured with the expectation of integrating higher-order thinking skills into the assessment of curricular reforms, the distribution of questions over the years reveals that the exam has not fully aligned with international assessment frameworks. No questions at Levels 5 or 6 were included in any of the examined years, suggesting that advanced mathematical reasoning, abstraction, and problem-solving skills were not assessed. Additionally, the increase in Level 1 questions from 2022 to 2024 indicates a shift away from high-level cognitive requirements.

Based on these findings, incorporating higher-level questions into HSEE is crucial for fostering advanced mathematical reasoning and problem-solving skills among students. PISA Level 5 and 6 questions require strategic problem-solving, flexible mathematical thinking, and the ability to integrate multiple representations. These competencies are essential for academic success as well as for real-world applications. However, the absence of such questions in HSEE raises concerns about whether it was a deliberate action or whether the nature of the exam is inherently unsuitable for such questions. If the latter is the case, revisions to the exam framework are necessary to accommodate more complex, multi-step, and non-routine problem-solving tasks.

Furthermore, the role of instruction and its impact on students' mathematical proficiency should not be overlooked. To improve students' performance in both HSEE and international assessments like PISA, changes are required not only in the exam structure but also in teaching practices. Instead of focusing solely on procedural knowledge, instruction should emphasize reasoning, inference-making, and problem-solving strategies. Teachers can play a crucial role in fostering these skills by incorporating open-ended questions, real-world applications, and exploratory learning activities into their lessons. Moving away from rote memorization and encouraging students to explore and apply mathematical concepts is essential.

In conclusion, the current structure of HSEE primarily focuses on assessing low to moderate levels of mathematical skills, limiting students' opportunities to develop higher-order cognitive abilities. To align the Turkish mathematics education system more closely with international standards, both standardized exam content and instructional practices must be restructured. Incorporating more high-level mathematical literacy tasks into the exam system would not only enhance students' problem-solving skills but also improve their overall performance in international assessments like PISA.

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