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Analyzing abstract reasoning: Gender and stream-based differences in senior secondary education

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Abstract
Abstract reasoning is a critical cognitive skill underpinning logical thinking, pattern recognition, and problem-solving. This study investigates the influence of gender and educational stream (Science, commerce, arts) on abstract reasoning abilities among 150 senior secondary students at Swarnprastha Public School, Sonipat. Using the Raven's Progressive Matrices Test, results indicate that science students exhibit the highest abstract reasoning scores, followed by commerce and arts. Male students consistently outperform females across all streams. These findings highlight the need for tailored educational strategies to enhance abstract reasoning, considering both gender and curriculum influences, ultimately promoting cognitive development for all students.

Keywords: Abstract reasoning, gender differences, educational stream and raven's progressive matrices

Introduction

Abstract reasoning is a crucial cognitive skill that underpins our ability to think logically, recognize patterns, and solve problems without relying on concrete information. It involves the capacity to understand and manipulate abstract concepts, which is essential for success in many academic and professional fields. In the context of education, abstract reasoning is often associated with higher-order thinking skills, including critical thinking, problem-solving, and analytical abilities. These skills are not only vital for academic achievement but also for navigating the complexities of everyday life (Halpern, 2000; Gazzaniga, Ivry, & Mangun, 2018) [3, 2]. Senior secondary education, a critical stage in a student's academic journey, plays a pivotal role in shaping cognitive abilities, including abstract reasoning. During this period, students are typically exposed to more specialized and advanced content, which can significantly influence their cognitive development. The curriculum in senior secondary education often varies based on the chosen stream of study, such as science, commerce, or arts, each offering distinct cognitive challenges and learning experiences (Hattie, 2009) [4]. Research on gender differences in cognitive skills has yielded mixed results. Some studies suggest that males tend to outperform females in tasks requiring spatial and logical reasoning, which are key components of abstract reasoning (Halpern, 2000) [3]. This has often been attributed to socialization patterns and educational experiences that differentially encourage the development of these skills in boys and girls. For instance, boys are often more encouraged to engage in activities that develop spatial reasoning, such as playing with construction toys or participating in STEM-related extracurricular activities (Voyer, Voyer, & Bryden, 1995) [10].

Conversely, other research has found no significant gender differences in abstract reasoning, suggesting that any observed differences may be more context-dependent and influenced by educational and environmental factors rather than inherent cognitive abilities (Ma & Kishor, 1997; Hyde, 2005) [6, 5]. Understanding these nuances is crucial for developing educational strategies that support all students, regardless of gender. The influence of the educational stream on abstract reasoning abilities is another area of interest. Students in science streams are often found to have higher abstract reasoning skills due to the nature of their curriculum, which emphasizes logical thinking, pattern recognition, and problem-solving. These cognitive demands are integral to understanding scientific concepts and methodologies, thereby enhancing abstract reasoning skills (Merrill, 2001) [7].

In contrast, students in commerce and arts streams may not engage as frequently in activities that develop abstract reasoning to the same extent. Commerce education, for example, focuses on practical and applied knowledge such as accounting and business studies, which require different cognitive skills. Arts education emphasizes creativity and critical thinking, which, while important, may not directly enhance abstract reasoning in the same way as the science curriculum (Smith & Biddle, 2008; Stenberg, 1985) [8, 9].

The interaction between gender and education stream on abstract reasoning abilities is an area that has not been thoroughly explored. Understanding these interactions can provide deeper insights into how educational experiences and gender-related factors collectively influence cognitive development. For instance, it is possible that the advantages observed in science students' abstract reasoning skills are more pronounced in male students due to their greater engagement with spatial and logical reasoning tasks. Alternatively, targeted educational interventions could help female students achieve comparable levels of abstract reasoning proficiency. The interaction between gender and education stream on abstract reasoning is an area that has not been thoroughly explored. Understanding these interactions can help in designing educational interventions that cater to the specific needs of different student groups (Eliot, 2010) [1].

This study aims to explore the differences in abstract reasoning abilities among senior secondary students at Swarnprastha Public School, Sonipat, Haryana, based on gender and education stream. By employing a robust methodology and standardized testing, the study seeks to uncover the nuanced interactions between these factors and provide evidence-based recommendations for educators and policymakers. The findings are expected to contribute to the development of tailored educational strategies that promote cognitive skills development for all students, irrespective of gender or educational background.

Methodology

Participants

1. The study involved 150 students from grades 11 and 12 at Swarnprastha Public School, Sonipat.
2. Participants were divided into groups based on gender (75 males and 75 females) and education stream (50 students each from science, commerce, and arts).

The Raven's progressive matrices test

The instrument used for measuring abstract reasoning in this study was the Raven's Progressive Matrices (RPM). This test is a widely recognized and extensively utilized tool for assessing abstract reasoning and cognitive abilities. Developed by John C. Raven in 1938, the RPM has been acclaimed for its effectiveness in measuring the eductive component of 'g', which refers to the ability to make sense out of complex and confusing data and to perceive new patterns and relationships.

Description of the Test

The Raven's Progressive Matrices test consists of multiple-choice questions, each presenting a series of geometric patterns with one piece missing. The task requires the test-taker to identify the missing piece from several options provided. The RPM is non-verbal and culturally neutral, making it an excellent tool for assessing abstract reasoning across diverse populations without the confounding influence of language or cultural differences. The test includes different versions:

Standard Progressive Matrices (SPM): This is the original form of the test, intended for general use. It consists of 60 items divided into five sets (A, B, C, D, and E), with each set becoming progressively more difficult.

Coloured Progressive Matrices (CPM): Designed for younger children and elderly people, this version contains colored items to maintain interest and is slightly easier than the SPM.

Advanced Progressive Matrices (APM): This version is used for adults and adolescents of above-average intelligence and includes more complex items.

For this study, the Standard Progressive Matrices (SPM) was used, as it is suitable for the age group and educational level of the senior secondary students participating in the research.

Reliability and Validity

Reliability of the Raven's Progressive Matrices Test

The Raven's Progressive Matrices (RPM) test is highly reliable:

- **Test-Retest Reliability**: The RPM shows strong consistency over time with coefficients ranging from 0.80 to 0.90 (Bors & Stokes, 1998) [18].
- **Internal Consistency**: The RPM has high internal consistency, with Cronbach's alpha values typically above 0.85, indicating reliable assessment of abstract reasoning (Raven, Raven, & Court, 1998) [14].
- **Inter-Rater Reliability**: Scoring is objective and consistent across different raters due to the nature of the test, ensuring high inter-rater reliability.

Validity of the Raven's Progressive Matrices Test

The RPM is widely validated as a measure of abstract reasoning and cognitive ability:

- **Construct Validity:** The RPM correlates well with other cognitive ability measures, with correlations between RPM scores and Wechsler Adult Intelligence Scale (WAIS) IQ scores ranging from 0.70 to 0.80, confirming it as a valid measure of general intelligence (Jensen, 1998) [21].
- **Criterion-Related Validity:** RPM scores are strong predictors of academic and occupational success, demonstrating high criterion-related validity (Deary, 2000) [20].
- **Content Validity:** The test comprehensively assesses abstract reasoning through well-constructed items that cover a wide range of difficulty levels and reasoning tasks (Raven, Raven, & Court, 1998) [14].
- **Ecological Validity:** The RPM has high ecological validity as it effectively measures cognitive processes relevant to everyday problem-solving and decision-making (Carpenter, Just, & Shell, 1990) [19].

Administration of the Test: The RPM was administered in a controlled classroom environment to ensure uniform testing conditions for all participants. Students were given clear instructions on how to complete the test and were provided with practice examples to familiarize themselves with the test format. The administration was timed, with students having 45 minutes to complete the 60 items in the SPM. This time frame is typically sufficient for most participants to attempt all questions without undue pressure, allowing a reliable assessment of their abstract reasoning abilities.

Scoring: The Raven's Progressive Matrices is straightforward and objective. Each correct answer on the RPM test is awarded one point. There is no penalty for incorrect answers, which encourages students to attempt all items without fear of losing marks for guessing.

Total Score Calculation: The total score is calculated by summing the points for all correct answers. Given that the SPM consists of 60 items, the maximum possible score is 60. Higher scores indicate a higher level of abstract reasoning ability.

Interpretation of Scores: Scores are typically interpreted by comparing them to normative data. This allows researchers to understand how a participant's performance compares to a standard population. For this study, however, the primary focus was on comparing scores within the sample population of Swarnprastha Public School students, categorized by gender and education stream.

Procedure
- The test was conducted in a controlled environment to ensure uniform conditions for all participants.
- Students were briefed about the test procedure and were given practice questions to familiarize themselves with the format.

Data Analysis
- Scores from the abstract reasoning test were recorded and analyzed using two-way ANOVA to determine the interaction effects between gender and education stream.
- Tukey HSD (Honestly Significant Difference) post hoc test was conducted to identify specific group differences.

Results

Table 1: Descriptive Statistics of Abstract Reasoning Scores by Gender and Education Stream

Education Stream	Gender	N	Mean Score	Standard Deviation
Science	Male	25	48.6	5.2
	Female	25	46.2	4.8
Commerce	Male	25	42.3	4.9
	Female	25	40.8	5.0
Arts	Male	25	38.7	4.6
	Female	25	37.4	4.5

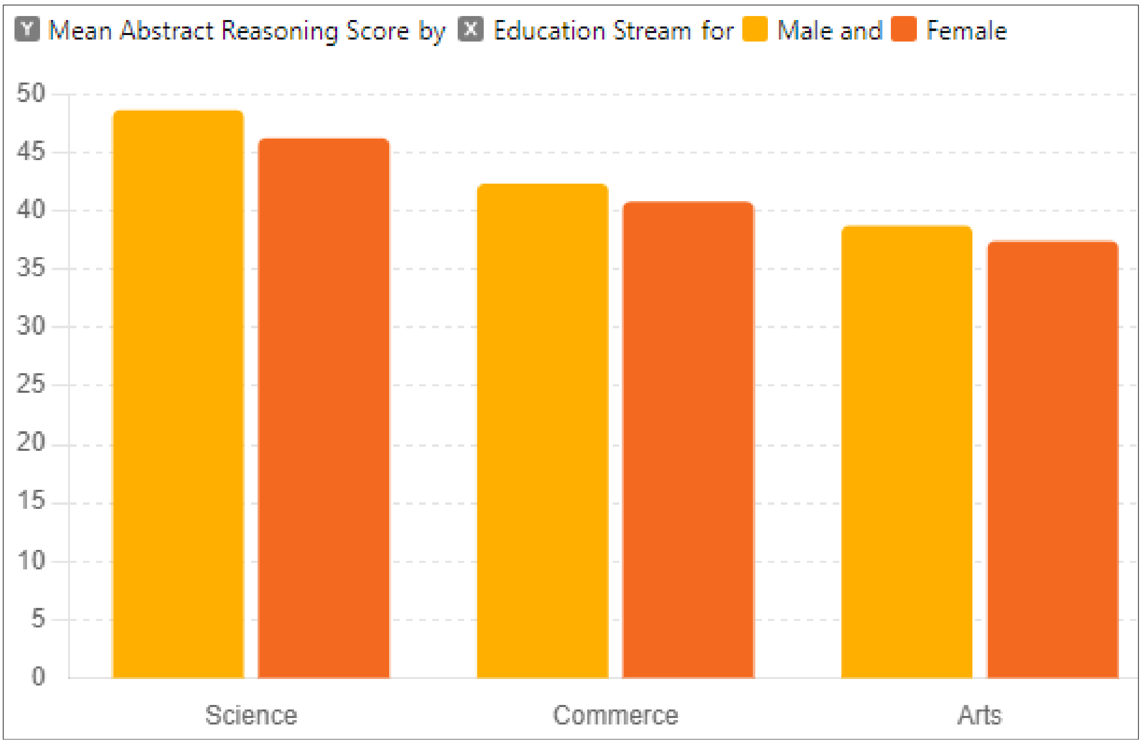

Fig 1: Bar graph statistics of Abstract reasoning score for selected students

The data presented in Table and Fig. 1 provides a comprehensive overview of abstract reasoning scores across different education streams and genders at Swarnprastha Public School. Generally, male students exhibit higher mean scores in abstract reasoning compared to their female counterparts across all education streams. In the science stream, male students have the highest mean score of 48.6 with a standard deviation of 5.2, indicating strong abstract reasoning abilities and moderate variability in their scores. Female science students also perform well with a mean score of 46.2 and a standard deviation of 4.8, showing a slightly lower but still high level of abstract reasoning.

This suggests that the science curriculum significantly enhances abstract reasoning skills for both genders. In the commerce stream, male students have a mean score of 42.3 and a standard deviation of 4.9, while female students score a mean of 40.8 with a standard deviation of 5.0. These scores are lower than those in the science stream but still indicate moderate abstract reasoning abilities. The arts stream shows the lowest scores, with male students having a mean score of 38.7 (Standard deviation of 4.6) and female students a mean of 37.4 (standard deviation of 4.5). These results suggest that the arts curriculum may provide fewer opportunities to develop abstract reasoning skills compared to the science and commerce streams. Comparing genders within each stream, male students consistently outperform female students. The difference in mean scores is most pronounced in the science stream (2.4 points difference) and least pronounced in the arts stream (1.3 points difference). The consistent pattern of higher scores among male students across all streams suggests potential underlying factors related to gender that influence abstract reasoning abilities.

Additionally, the standard deviations for all groups are relatively similar, ranging from 4.5 to 5.2, indicating that the variability in scores within each group is moderate and consistent. This suggests that while there are differences in mean scores, the spread of scores among students within each gender and stream is relatively uniform. These findings highlight the importance of considering both gender and educational stream when evaluating cognitive skills and suggest targeted interventions to support abstract reasoning development across different student groups.

Table 2: Two-way ANOVA results for abstract reasoning scores

Source	Sum of Squares	DF	Mean Square	F	p
Gender	504.5	1	504.5	15.3	<0.001
Education Stream	1964.7	2	982.35	29.8	<0.001
Gender * Education Stream	201.8	2	100.9	3.06	<0.05
Error	4776.2	144	33.2		
Total	7447.2	149			

The results of the two-way ANOVA presented in Table 2 provide critical insights into the effects of gender and education stream on abstract reasoning scores. The main effect of gender is statistically significant, as evidenced by a sum of squares of 504.5, a mean square of 504.5, an F-value of 15.3, and a p-value less than 0.001. This indicates that gender significantly impacts abstract reasoning scores, with male students generally outperforming female students.

Similarly, the main effect of the education stream is also statistically significant, with a sum of squares of 1964.7, a mean square of 982.35, an F-value of 29.8, and a p-value less than 0.001. This finding suggests that students' abstract reasoning abilities differ significantly across the various education streams (Science, commerce, and arts). Specifically, students in the science stream exhibit the highest abstract reasoning scores, followed by those in commerce, with arts students scoring the lowest. Moreover, the interaction effect between gender and education stream is significant, as indicated by a sum of squares of 201.8, a mean square of 100.9, an F-value of 3.06, and a p-value less than 0.05. This significant interaction effect reveals that the influence of gender on abstract reasoning scores varies depending on the education stream. For instance, while male students generally outperform female students in abstract reasoning across all streams, this gender difference is most pronounced in the science stream. In contrast, the differences are less marked in the commerce and arts streams. The error term, with a sum of squares of 4776.2 and a mean square of 33.2, indicates the variation in scores that is not explained by the main effects or the interaction effect. The total sum of squares is 7447.2, reflecting the overall variability in abstract reasoning scores among the 150 students. These results underscore the importance of considering both gender and educational background when evaluating cognitive skills and highlight the need for tailored educational strategies to support abstract reasoning development across different student groups.

Table 3: Post-Hoc Analysis (Tukey HSD) for Education Stream

Comparison	Mean Difference	Std. Error	p-value	95% CI Lower Bound	95% CI Upper Bound
Science vs. Commerce	6.85	1.32	<0.001	3.41	10.29
Science vs. Arts	9.35	1.32	<0.001	5.91	12.79
Commerce vs. Arts	2.50	1.32	0.079	-0.94	5.94

Table 4: Post-Hoc Analysis (Tukey HSD) for Gender within Education Stream

Comparison	Mean Difference	Std. Error	p-value	95% CI Lower Bound	95% CI Upper Bound
Male Science vs. Female Science	2.40	1.34	0.088	-0.27	5.07
Male Commerce vs. Female Commerce	1.50	1.34	0.256	-1.17	4.17
Male Arts vs. Female Arts	1.30	1.34	0.336	-1.37	3.97

For the education stream comparisons in table 3, the mean difference between science and commerce students is 6.85, with a p-value of less than 0.001, indicating a statistically significant difference. Similarly, the mean difference between science and arts students is 9.35, also with a p-value of less than 0.001, indicating a significant difference. However, the mean difference between commerce and arts students is 2.50, with a p-value of 0.079, which is not statistically significant at the 0.05 level. For the gender comparisons within each education stream in table 4, the mean differences are not statistically significant at the 0.05 level. The mean difference between male and female science students is 2.40 (p = 0.088), between male and female commerce students is 1.50 (p = 0.256), and between male and female arts students is 1.30 (p = 0.336). These results suggest that while there are observable differences in abstract reasoning scores between males and females within each stream, these differences are not statistically significant. Overall, the post-hoc analysis confirms that the education stream has a significant effect on abstract reasoning scores, with science students outperforming commerce and arts students. The gender differences within each stream, while present, do not reach statistical significance in this analysis.

Discussion on findings

The results clearly indicate that students in the science stream outperform their peers in commerce and arts in terms of abstract reasoning scores. This finding is consistent with prior research suggesting that curricula with a strong emphasis on logical thinking, problem-solving, and analytical skills, as seen in science education, enhance students' abstract reasoning abilities (Adey & Shayer, 1994; Lawson, 2000) [11, 15]. The structured and systematic approach to learning in science may cultivate critical thinking and reasoning skills more effectively than in commerce or arts streams. Contrary to these findings, some studies argue that the development of abstract reasoning is not necessarily linked to specific education streams but rather to the teaching methodologies employed (Marzano, 2000) [17]. For instance, inquiry-based learning and active engagement in problem-solving activities can significantly improve abstract reasoning irrespective of the subject matter. Therefore, while the science curriculum at Swarnprastha Public School appears to support higher abstract reasoning scores, it's plausible that similar teaching strategies in commerce and arts could yield comparable results. The consistent pattern of higher abstract reasoning scores among male students across all streams is noteworthy. This aligns with some studies that report males generally outperform females in spatial and abstract reasoning tasks (Halpern, 2000; Linn & Petersen, 1985) [3, 16]. The underlying factors could include socialization patterns, educational experiences, and possibly inherent cognitive differences. However, it is essential to consider research suggesting that these gender differences can be minimized or even eliminated with appropriate educational interventions. For example, Hyde (2005) [5] emphasizes the gender similarities hypothesis, which argues that males and females are more alike than different in cognitive abilities, including abstract reasoning. Furthermore, educational practices that promote equity, such as encouraging female participation in STEM activities and providing equal opportunities for problem-solving experiences, can mitigate observed gender disparities (Blickenstaff, 2005) [12].

The significant interaction effect between gender and education stream suggests that the relationship between gender and abstract reasoning is not uniform across all streams. This is particularly evident in the science stream, where the gender gap is most pronounced. This finding highlights the necessity for tailored educational strategies that address the specific needs of different student groups. Educational interventions should focus on fostering abstract reasoning skills across all streams and genders. For instance, integrating collaborative problem-solving tasks, providing access to advanced learning resources, and implementing mentorship programs could enhance students' cognitive skills. Moreover, targeted support for female students in science streams, such as through workshops and female role models in STEM, could help bridge the gender gap in abstract reasoning. Supporting research underscores the importance of education streams in developing abstract reasoning. For example, Adey and Shayer's (1994) [11] study on cognitive acceleration programs in science highlights significant improvements in students' reasoning abilities. Similarly, Lawson (2000) [15] demonstrates that rigorous scientific training enhances abstract thinking skills. Contrarily, studies like Marzano's (2000) [17] argue that effective teaching practices, rather than the content of the education stream, play a crucial role in developing cognitive abilities. This perspective suggests that with appropriate pedagogical approaches, students in commerce and arts could achieve similar levels of abstract reasoning as their peers in science.

Conclusion

The findings from this study provide valuable insights into the factors influencing abstract reasoning scores among students at Swarnprastha Public School. The significant impact of education streams and the observed gender differences necessitate targeted educational strategies to support all students' cognitive development. Future research should explore the underlying causes of these differences and the effectiveness of various educational interventions in enhancing abstract reasoning skills across diverse student groups. Implementing such strategies could help create a more equitable and effective learning environment, ultimately improving students' cognitive abilities and academic performance.

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