Shaping Spatial Intelligence: The Influence of Curriculum on Students' Spatial Ability

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ABSTRACT

Spatial ability plays a crucial role in mathematics and science learning, particularly in disciplines that require reasoning and problem-solving skills. The design of the curriculum significantly influences the development of students' spatial ability. This study aims to analyze the impact of curriculum design on students' spatial ability by comparing two curricula implemented in Indonesia: the 2013 Curriculum and the Merdeka Curriculum. A quantitative research approach was employed, involving 58 high school students majoring in science, with 27 following the Merdeka Curriculum and 31 following the 2013 Curriculum. Data were collected using a spatial ability test and analyzed using an independent two-sample t-test. The results indicate a significant difference in students' spatial ability between the two curricula, with students following the Merdeka Curriculum outperforming those following the 2013 Curriculum. This suggests that a more flexible and exploratory learning approach, as emphasized in the Merdeka Curriculum, can enhance students' spatial ability. The findings highlight the need for curriculum developers to integrate spatial reasoning into educational frameworks to improve students' cognitive and academic development. Further research is recommended to explore the long-term impact of curriculum design on spatial ability and to examine other factors, such as teaching methods and socioeconomic background, that may influence spatial skills development.

Keywords: spatial ability, curriculum design, Indonesian curriculum

INTRODUCTION

Spatial ability refers to the cognitive capacity to visualize and mentally transform objects in both two-dimensional and three-dimensional spaces (Lowrie et al., 2019). It involves key processes such as forming, maintaining, retrieving, and manipulating visual images, which are essential for problem-solving and analytical reasoning (Danişman & Erginer, 2017). This ability enables individuals to navigate their environments, interpret diagrams, and engage in abstract reasoning, making it a fundamental skill for academic success in spatially demanding disciplines (Atit et al., 2022).

Furthermore, spatial ability involves analyzing the structural features of objects through mental manipulation of visual stimuli, supporting analytical problem-solving (Mulligan et al., 2018). It also includes storing, retrieving, and transforming visual information related to spatial awareness and internal and external spatial representations (Xie et al., 2020). As such, spatial ability is vital in learning mathematics, science, and STEM, contributing to logical, critical, and problem-solving thinking (Schenck & Nathan, 2024).

Curriculum differences have a significant impact on students' spatial abilities. Research indicates that curriculum design and content can either support or hinder the development of spatial skills. A curriculum that emphasizes spatial reasoning has the potential to enhance gender equity and increase participation in STEM education (Cortes et al., 2022). A study on preschool children in Serbia revealed that several examined curricula were ineffective in fostering spatial skills, highlighting the need for curriculum improvements to strengthen spatial reasoning from an early age, which is crucial for future academic success (Đokić & Vorkapić, 2024). Similarly, (Şahingöz, 2021) found that the Turkish elementary science curriculum lacked a structured approach to spatial thinking skills, which may limit students' ability to engage effectively with geographical and scientific concepts. Furthermore, spatial reasoning is often overlooked in mathematics curricula, despite its critical role in enhancing student performance in STEM subjects (Gilligan-Lee et al., 2022).

This study aims to analyze the impact of curriculum design on students' spatial abilities, focusing on two curricula implemented in Indonesia: the 2013 Curriculum and the Merdeka Curriculum. The findings of this research are expected to provide valuable insights for curriculum developers, educators, and policymakers in optimizing spatial education within the learning system.

LITERATURE REVIEW

1. Theoretical Perspectives on Spatial Ability

Spatial ability is broadly recognized as the cognitive capacity to understand and manipulate spatial relationships. While the introduction has outlined its basic definition, this section elaborates on the theoretical underpinnings and components that define spatial ability in educational contexts. According to Gilligan-Lee et al. (2022), spatial ability encompasses recalling, generating, manipulating, and reasoning about spatial relationships. Atit et al. (2022) further emphasize that this includes the organization and understanding of both real and imaginary spaces. Xie et al. (2020) stress the importance of visual memory processes such as storing, retrieving, and transforming spatial information. Mulligan et al. (2018) highlight that spatial ability supports analytical problem-solving by enabling mental manipulation of visual stimuli.

2. Components of Spatial Ability in STEM Education

Spatial ability consists of several key components, including mental rotation, spatial orientation, and spatial visualization. Mental rotation refers to the capability to rotate objects mentally without changing one's own orientation (Kurt et al., 2023). Spatial orientation involves understanding spatial relationships relative to one's own position, such as perspective-taking (Fowler et al., 2024). Spatial visualization, on the other hand, refers to transforming and manipulating visual patterns into new arrangements (Gilligan-Lee et al., 2022). These components are essential in STEM learning and contribute to students' logical and problem-solving capacities (Winarti et al., 2024).

3. Curriculum and Its Impact on Spatial Development

Several studies have investigated the role of curriculum in shaping students' spatial skills. Research by Cortes et al. (2021, 2022) indicates that curricula emphasizing spatial reasoning foster increased STEM participation, especially among female students. Đokić & Vorkapić (2024) found that Serbian preschool curricula lacked effectiveness in developing spatial skills, underscoring the need for intentional curricular design. Similarly, Şahingöz (2021) criticized the Turkish elementary science curriculum for its failure to integrate structured spatial reasoning components. These findings indicate a global trend in which spatial reasoning is often overlooked in curriculum design, despite its proven relevance in STEM education.

4. Spatial Education in the Indonesian Context

In Indonesia, two curricula have been implemented in recent years: the 2013 Curriculum and the Merdeka Curriculum. The 2013 Curriculum emphasizes competency-based learning and structured knowledge acquisition (Pratycia et al., 2023). Conversely, the Merdeka Curriculum offers greater flexibility for educators to adapt learning to student needs, emphasizing character development and essential competencies (Ariga, 2023; Lestari et al., 2019). Rahmadayanti & Hartoyo (2022) argue that while the 2013 Curriculum provides a clear structure, it may not adequately support differentiated instruction or exploratory learning, both of which are important for developing spatial skills.

Although research directly comparing these curricula's impact on spatial ability remains limited, related studies suggest that curriculum flexibility and student-centered approaches may enhance cognitive skill development. Gutierrez et al. (2019), in a different context, found that integrated curricula significantly improved spatial reasoning among veterinary students. Moreover, Lowrie et al. (2019) demonstrated that spatial visualization training within a curriculum enhances both spatial skills and mathematical achievement.

5. Identified Research Gap

Despite growing recognition of spatial ability's importance, few studies have examined how national curricula influence its development, particularly in the Indonesian context. Existing research has predominantly focused on early childhood or isolated training programs. There is a lack of empirical analysis comparing the 2013 Curriculum and the Merdeka Curriculum in terms of their effectiveness in nurturing spatial ability. This gap underscores the need for research investigating the curricular structures that support or hinder spatial skill development in formal education.

This study seeks to address that gap by analyzing the influence of curriculum design—specifically the 2013 and Merdeka Curricula—on the development of students' spatial abilities in Indonesia.

METHOD

This study utilized a quantitative research approach to examine the impact of curriculum design on students' spatial abilities. The research sample comprised 58 science-track students from two senior high schools in Bandung, Indonesia, with 27 students following the Merdeka Curriculum and 31 students following the 2013 Curriculum. Data were collected using a spatial ability test developed by Ramful et al. (2023), specifically designed to assess students' spatial abilities based on two reference frames: egocentric and allocentric. The test consisted of 22 questions, which students were required to complete within 18 minutes. To analyze the data, an independent two-sample t-test was conducted to compare the spatial ability scores of students from both curricula. This statistical method was selected to determine whether a significant difference existed between the two groups. Data analysis was performed using statistical software to ensure precision and reliability in interpreting the results.

FINDINGS AND DISCUSSION

This section presents the results of students' spatial ability tests using the left-hand rule instrument and examines the impact of curriculum design on students' spatial abilities. Before analysis, normality and homogeneity tests were conducted to ensure that the data were normally distributed and had homogeneous variance. The results of the normality test are shown in Table 1.

Table 1:
Test of Normality

	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Score	C-Merdeka	0.139	27	0.193	0.930	27	0.071
	C-2013	0.158	31	0.046	0.937	31	0.070

The results in Table 1 indicate that the data from both samples are normally distributed. Since the assumption of normality is met, a homogeneity test was conducted, as presented in Table 2.

Table 2:
Test of Equality of Variances (Levene's)

	F	df_1	df_2	p
Score	0.898	1	56	0.348

The Levene's test results show a p-value of 0.348, indicating that the variance between the two groups is homogeneous. This confirms that the data meet the assumptions for further parametric statistical analysis. The results are presented in Table 3.

Table 3:
Independent Sample T-Test

	t	df	p
Score	2.998	56	0.004

Based on the results in Table 3, the p-value is less than 0.05, leading to the rejection of the null hypothesis. This indicates a significant difference in spatial ability between students following the Merdeka Curriculum and those following the 2013 Curriculum. To identify which group demonstrated superior spatial ability, descriptive statistics are presented in Table 4.

Table 4:
Descriptive Statistics

	Score	
	C-Merdeka	C-2013
Valid	27	31
Mean	8.370	5.613
Std. Deviation	3.874	3.127
Minimum	3.000	1.000
Maximum	17.000	12.000

Table 4 shows that the average spatial ability score of students in the C-Merdeka group (8.370) is higher than that of the C-2013 group (5.613). This indicates that students following the Merdeka Curriculum have better spatial abilities. Additionally, the larger standard deviation in the C-Merdeka group (3.874) compared to the C-2013 group (3.127) suggests greater variability in scores within this group.

The range of scores also highlights a notable difference between the two groups. The minimum score in the C-Merdeka group is 3, whereas in the C-2013 group, it is 1. Additionally, the maximum score in the C-Merdeka group reaches 17, which is higher than the maximum score of 12 in the C-2013 group. This variation in scores suggests that some students following the Merdeka Curriculum were able to achieve significantly higher spatial ability scores compared to those following the 2013 Curriculum.

These results indicate that students following the Merdeka Curriculum tend to have better spatial abilities than those following the 2013 Curriculum. The differences in curriculum design likely play a crucial role in the development of students' spatial skills, with the more flexible and exploratory approach of the Merdeka Curriculum potentially providing a more effective learning experience for enhancing these abilities.

These findings align with previous research, which suggests that curriculum differences have a significant impact on students' spatial abilities. Curriculum design and content can either support or hinder the development of spatial skills. A curriculum that emphasizes spatial reasoning has the potential to enhance gender equity and increase participation in STEM education (Cortes et al., 2022). The correlation between spatial ability and mathematical achievement underscores the importance of incorporating targeted spatial reasoning training into the curriculum (Gilligan-Lee et al., 2023; Kurt et al., 2023). The lack of emphasis on spatial thinking in mathematics curricula has been identified as a critical gap, highlighting the need for educational reforms that prioritize the integration of spatial reasoning across various subjects (Gilligan-Lee et al., 2022). Furthermore, spatial education has been shown to positively influence female students' participation and achievement in STEM fields, reinforcing the growing importance of integrating spatial reasoning into education (Cortes et al., 2021, 2022).

Overall, the findings of this study indicate that students following the Merdeka Curriculum have better spatial abilities compared to those following the 2013 Curriculum. This difference reflects the role of curriculum design in shaping students' spatial skills. The Merdeka Curriculum, with its more flexible and exploratory approach, appears to provide a more effective learning experience than the 2013 Curriculum, which is more structured and competency-based.

These findings are also consistent with previous research emphasizing that integrating spatial reasoning into the curriculum can enhance academic achievement, particularly in STEM fields. A curriculum that prioritizes spatial skills not only improves students' understanding of mathematical and scientific concepts but also contributes to gender equity in STEM education participation. Furthermore, the results of this study reinforce the view that the lack of spatial thinking elements in mathematics curricula represents a critical gap that must be addressed through educational reform.

Therefore, educators and curriculum designers must consider strengthening spatial aspects in learning. Integrating spatial education into the curriculum can help students develop better logical thinking, problem-solving skills, and an understanding of spatial relationships across various disciplines. Further evaluation and development of existing curricula are necessary to ensure that all students have optimal opportunities to enhance their spatial abilities, ultimately supporting their academic success in the future.

CONCLUSION

The study results indicate that curriculum design significantly influences students' spatial abilities, with students following the Merdeka Curriculum demonstrating superior spatial skills compared to those learning under the 2013 Curriculum. These findings reinforce the notion that the more flexible and exploratory approach of the Merdeka Curriculum provides a more effective learning experience for developing spatial abilities. Additionally, these results align with previous research, which suggests that integrating spatial reasoning into the curriculum enhances students' understanding of STEM subjects and contributes to increased academic participation, particularly among female students. The lack of emphasis on spatial skills in mathematics curricula has also been identified as a critical gap that requires urgent attention through educational reform. However, this study has several limitations, including a limited sample size and a research focus restricted to only two curricula in Indonesia, making it difficult to generalize the findings to broader educational contexts. Furthermore, the study relied solely on spatial ability tests as measurement tools, without considering other influential factors such as teaching methods, students' learning experiences, and socio-economic backgrounds, which may also affect the development of spatial skills. Therefore, further research with a larger sample size, a mixed-methods approach, and a deeper exploration of mediating factors between curriculum design and spatial ability is needed to achieve a more comprehensive understanding of this relationship.

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