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Research Article

Investigating the relationship among gifted students' spatial reasoning skills, their conceptual understanding of astronomy and academic achievement

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Abstract: The purpose of this research is to examine the relationship among sixth-, seventh-, and eighth-grade gifted students' spatial reasoning skills, conceptual understanding of basic astronomy topics, and science achievement. To achieve this, the study was designed as a multi-factor predictive correlational study. The research sample consists of 642 gifted middle school students enrolled in Science and Art Centers across 12 cities in Turkey. Data were collected using the Conceptual Understanding of Basic Astronomy Subjects Test, the Mental Image-Focused Spatial Reasoning Skill Test, and the Science Achievement Test. Path analysis was employed as the statistical method, and a path diagram was used to illustrate the explanatory relationships among the observed variables. The analysis revealed that grade level positively and significantly predicts static and dynamic spatial reasoning skills, conceptual understanding of basic astronomy topics, and science achievement among gifted students. Additionally, both static and dynamic spatial reasoning skills positively and significantly predict students' conceptual understanding of basic astronomy topics. Similarly, science achievement is positively and significantly predicted by students' static and dynamic spatial reasoning skills as well as their conceptual understanding of basic astronomy topics. Overall, the findings indicate positive and significant direct and indirect relationships between gifted students' grade level, static and dynamic spatial reasoning skills, conceptual understanding of basic astronomy topics, and science achievement.

1. INTRODUCTION

The pursuit of answers to complex questions about the universe, Earth and nature plays a crucial role in fostering a strong connection between astronomy and the natural sciences (Gündoğdu, 2014). Moreover, the interdisciplinary nature of astronomy is evident in its involvement with time measurement, calendars, daily and seasonal weather changes, the formation of day and night, the effects of sunlight, and tidal patterns (Kurnaz, 2012; Percy, 2006; Percy, 2009). Consequently, advancements in astronomy have contributed to progress in fundamental natural sciences such as physics, chemistry, and biology, while also enhancing the potential of gifted students who aspire to pursue academic careers in these fields by fostering creativity and

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innovation. Gifted students possess advanced skills such as solving scientific problems, generating innovative scientific ideas, making connections between scientific concepts and observed phenomena, thinking creatively and critically, engaging in scientific discussions, and sharing scientific ideas with their peers (Bailey *et al*., 2016; Gardner & Sternberg, 1994; Gilbert & Newberry, 2007). Such children have a significantly greater potential to become scientists, driven by their curiosity about natural phenomena and their willingness to apply scientific skills (e.g., observing, measuring, classifying, experimenting) to satisfy their curiosity (Pyryt, 2000). Accordingly, astronomy provides a valuable context by incorporating challenges that demand high-level thinking (Wallace *et al*., 2013). Moreover, astronomy can foster the development of advanced skills such as critical analysis, data-driven decision-making, questioning, and both critical and creative thinking, particularly in relation to gifted individuals' experiences and observations of daily life (Goodman *et al*., 2011; Percy, 2006; Prather *et al*., 2009; Wallace *et al*., 2013).

Astronomy plays a significant role in fostering academic success and promoting a positive attitude toward science across all age groups (Percy, 2009). Similarly, Baker (1987) describes astronomy as an effective tool for science education, providing gifted students with the motivation and willingness necessary for their learning processes. However, due to the abstract nature of astronomical concepts and the difficulty in structuring scientific explanations for them, numerous studies have identified astronomy as one of the most challenging subjects for students at all grade levels (Gazit *et al*., 2005; Lelliot & Rollnick, 2010; Plummer *et al*., 2014; Yair *et al*., 2003). Even gifted individuals with advanced cognitive skills exhibit misconceptions about astronomical topics, similar to other learner groups. For instance, in a study conducted by Kim *et al*. (2011), the conceptual understanding of lunar observations among seventh-grade gifted students was examined.

The results showed that students primarily focused on a single reference frame, particularly when depicting the Moon's position in their drawings of its phases. Additionally, some students exhibited conceptual misconceptions, such as believing that the Moon rotates clockwise and that its phases are caused by Earth's shadow. Similarly, Subaşı *et al*. (2015) conducted semi-structured interviews to explore seventh-grade gifted students' conceptual perceptions of basic astronomy topics. The interview responses were categorized into five levels: understanding, limited understanding, not understanding, misunderstanding, and no response. Findings indicated that students' understanding of the concept of orbit, in particular, contained scientific misconceptions, which pose a significant challenge in the science education of gifted students. Such misconceptions can hinder further learning, especially in astronomy, a multidisciplinary field that encompasses key scientific concepts and phenomena (e.g., gravity, energy, the electromagnetic spectrum, entropy, life, light, and reflection), particularly in relation to fundamental sciences such as physics, chemistry, biology, and geology. Therefore, fostering a strong conceptual understanding of astronomy is essential, as it serves as a critical context for developing high-level cognitive skills, including hypothetical, inductive, and deductive reasoning, as well as problem-solving-key objectives in the science education of gifted students (Hannust & Kikas, 2007; Taber, 2007).

Numerous studies in the literature focus on understanding the formation processes of concepts and phenomena in astronomy, aiming to identify the conditions that influence these observed challenges (Atwood & Atwood, 1997; Barnett & Morran, 2002; Brunsell & Marcks, 2005; Frede, 2006; Kanlı, 2014; Kanlı, 2015; Küçüközer, 2007; Mulholland & Ginns, 2008; Ogan-Bekiroğlu, 2007; Sadler, 1992; Stover & Saunders, 2000; Trumper, 2000; Trumper, 2001a; Trumper, 2001b; Trumper, 2003; Vosniadou *et al*., 2004; Young & Shavl, 2013; Zeilik *et al*., 1998). These challenges in understanding astronomy arise from the difficulty of visualizing vast structures and immense distances in three dimensions. (Bailey & Slater, 2003; Bretones & Neto, 2011; Coble *et al*., 2013; Eriksson *et al*., 2014; Padalkar & Ramadas, 2011). This challenge is recognized as a spatial reasoning problem. The mental processes involved in solving problems related to three-dimensional objects are referred to as spatial reasoning (NRC, 2006). Although spatial reasoning is a cognitive skill that can be learned at any age level, this situation may vary significantly among individuals and groups (NRC, 2006). Nowadays, it is possible that these differences can be identified with the help of frequently utilized psychometric tests such as "The Stanford-Binet Intelligence Scale-V (SB-5)" and "Wechsler Intelligence Scale for Children (WISC-V)". Spatial reasoning is recognized as a measure of giftedness in these tests. (Andersen, 2014). Accordingly, gifted students are expected to demonstrate high performance in spatial thinking processes such as visualizing, manipulating, and rotating objects presented in test content. However, the measurement of spatial reasoning skills remains problematic, as they are often assessed in isolation from context and are difficult to distinguish from general cognitive ability in both these tests and intelligence assessments. This highlights the need to revise the evaluation of spatial reasoning, a skill frequently utilized in daily life. Moreover, Maker (2005) and her colleagues' research studies on "Discovering Intellectual Strengths and Capabilities while Observing Varied Ethnic Responses" (DISCOVER) indicated that the current assessments of spatial ability have some problems in terms of figures' cultural bias. Therefore, there is a need to develop measurement tools that focus on measuring spatial performance in a specific context, both by focusing on mental images and using objects that are determined on the basis of proximodistal principle. According to Lee and Berdnarz (2012), this context can be provided with the help of scientific disciplines that include understanding of the nature, structure and functions of scientific phenomena on a microscopic and astronomical scale, apart from the objects interacted with in daily lives and living spaces. In this regard, spatial reasoning needs to be addressed by everyday objects and then by focusing on more distant objects and ultimately astronomical objects. The concept involving this situation is spatial reasoning based on mental imagination. Spatial reasoning based on mental imagination is the ability to decide on the static and dynamic states of three-dimensional objects in the minds of the individuals in a context, which is closely linked to the proximodistal principle (Al-Balushi & Coll 2013). So, in this study, spatial reasoning skill was handled as "spatial reasoning skill based on mental imagination" due to its more inclusive nature.

The spatial reasoning skill plays a crucial role in explaining the three-dimensional positions and movements of celestial bodies within the learning process of gifted students in basic astronomy subjects, such as the phases of the Moon, seasons, the formation of day and night, and solar and lunar eclipses (Bretones & Neto, 2011; Hegarty, 2010; Heyer, 2012; Plummer *et al*., 2014). This is because gifted individuals' conceptual understanding and academic achievement in astronomy are closely linked to their spatial reasoning skills (DeRoche, 1967; Türk, 2016; Wellner, 1995). A study conducted by Türk (2016) supports the finding that there is a strong correlation between achievement in astronomy and spatial thinking skills. Similarly, Rudmann (2002) stated that students' ability to explain astronomical phenomena, such as the cause of the seasons, is constrained by their spatial abilities. Wellner (1995) also emphasized that students with strong spatial perception were more likely to accurately explain the cause of the Moon's phases. According to Kozhevnikov *et al*. (2007), individuals with high spatial reasoning skills can more easily develop their conceptual understanding of scientific principles. Myron Atkin (1961) stated that gifted students in the fourth, fifth, and sixth grades possess the ability to comprehend many important astronomy concepts. In a study conducted by DeRoche (1967) on sixth-grade gifted students, a significant relationship was found between individuals' intelligence levels and their achievement in astronomy subjects. In this context, cognitive skills such as spatial reasoning are thought to have substantial potential in enhancing gifted students' conceptual understanding of basic astronomy topics and their overall academic achievement in science. Additionally, the development of spatial reasoning skills, which are central to the formal operational stage, can be more precisely observed among middle school students at various grade levels.

Consequently, the relationship between gifted students' spatial reasoning skills, their conceptual understanding of basic astronomy topics, and their academic achievement remains insufficiently explored in previous studies. In particular, the investigation of this relationship across different grade levels has been largely overlooked. Considering these factors, understanding the explanatory links between spatial reasoning, conceptual understanding of basic astronomy topics, and academic achievement in science is a crucial step toward addressing gifted students' misconceptions about astronomy and their challenges in science learning.

1.1 Spatial Reasoning and Astronomy for Gifted Learners

Gifted students generally demonstrate higher academic achievement and spatial thinking skills than their peers (DeRoche, 1967; Myron Atkin, 1961; Shea *et al*., 2001; Taber, 2010). However, in science education, they often learn concepts in isolation rather than making interdisciplinary connections. Interdisciplinary knowledge transfer—the ability to apply skills and knowledge across domains—can significantly enhance learning outcomes (Bailey *et al*., 2016; Sasson & Dori, 2012; Schönborn & Bögeholz, 2009). Astronomy serves as an ideal interdisciplinary science, integrating concepts from physics, chemistry, biology, and more, such as heat, temperature, light, DNA, gravity, and atmosphere. Despite this, gifted students often struggle with spatially complex astronomical topics, such as the phases of the Moon and the changing seasons (Hollow, 2005). Without proper attention, they may develop misconceptions similar to those of their peers (Kim *et al*., 2011; Kolar & Ho-Wisniewski, 2009)

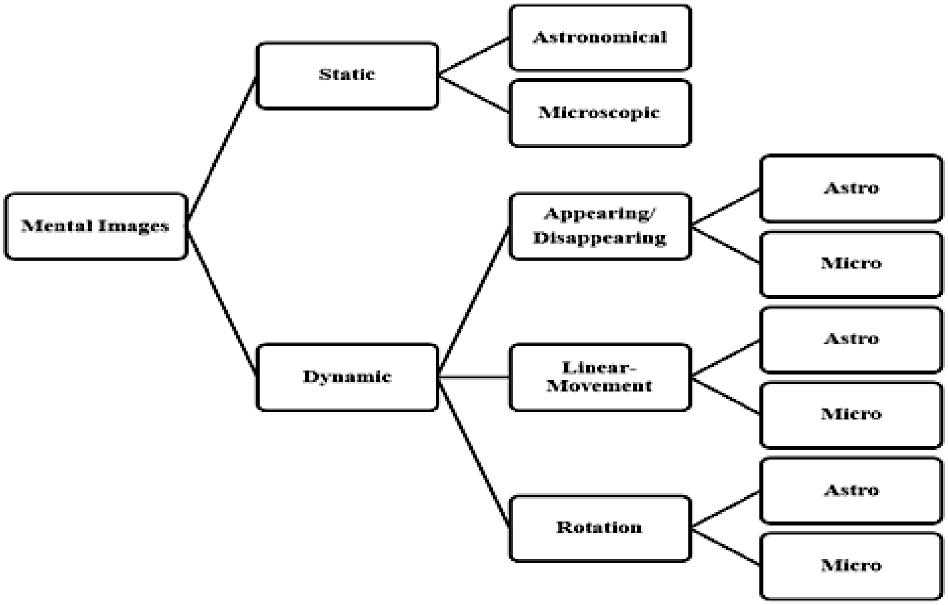
Recent research on astronomy education has focused on conceptual understanding across different age groups (Eriksson *et al*., 2014; Kalkan *et al*., 2014). Common misconceptions about basic astronomy topics include misunderstandings of the Earth-Sun-Moon system, the day-night cycle, the seasons, and the solar system. For example, many individuals mistakenly believe that the Sun revolves around the Earth or that the phases of the Moon result from Earth's shadow (Lelliott & Rolnick, 2010). Table 1 presents examples of notable topics and misconceptions identified in the literature.

Table 1. *Students' common misconceptions of astronomy.*

Subject	Misconceptions regarding Conceptual Understanding
The Earth-Sun-Moon System	- The Sun orbits the Earth. - The phases of the Moon result from the Moon's revolution around the Sun. - The phases of the Moon occur because the Moon enters Earth's shadow.
Day and Night Cycle	- Day and night occur due to Earth's revolution around the Sun. - The day-night cycle is caused by Earth's movement around the Sun. - The Moon influences the formation of the day-night cycle.
Seasons	- Earth's axial tilt varies from season to season. - Summer is warmer than winter because Earth is closer to the Sun during summer months. - The change of seasons is caused by variations in the distance between the Sun and Earth or by the relative positions of the Sun, Earth, and Moon.
The Solar System and Stars	- The sun is the center of the universe. - The Milky Way Galaxy is the center of the universe. - Stars reflect sunlight like planets.

Table 1 outlines common misconceptions about key astronomy topics among students. These misunderstandings reflect difficulties in comprehending the spatial and conceptual relationships of celestial phenomena, emphasizing the need for targeted educational interventions. Research indicates that many misconceptions arise from challenges in visualizing celestial phenomena in three dimensions (Al-Balushi & Coll, 2013; Plummer & Maynard, 2014). Figure 1 illustrates the concept of mental images as described by Al-Balushi and Coll (2013). Spatial reasoning plays a crucial role in overcoming these challenges, as it involves the mental manipulation of both static and dynamic states of objects—an essential skill for understanding astronomy (Barnett & Morran, 2002; Gazit *et al*., 2005)

Figure 1. *Mental images (Al-Balushi & Coll, 2013).*



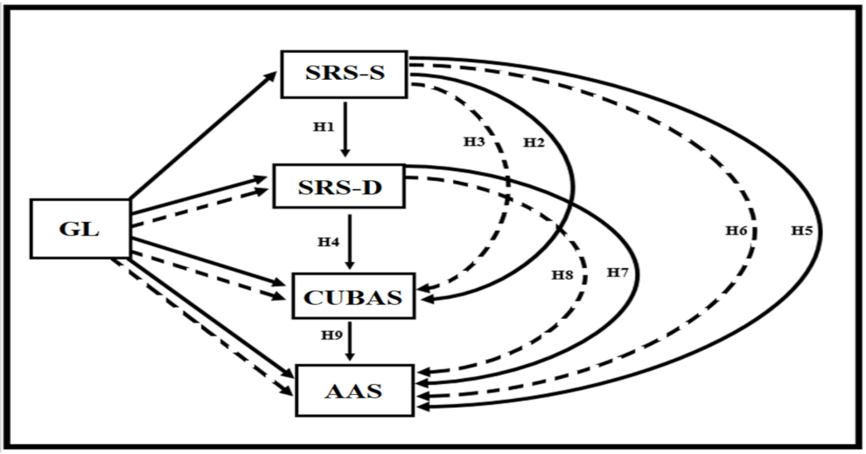
The model emphasizes the importance of assessing spatial reasoning within a specific context, progressing from familiar, everyday objects to distant, abstract astronomical entities. This approach aligns with the proximodistal principle, which supports students' ability to apply spatial reasoning progressively in increasingly complex scenarios. This model was chosen for the study due to its relevance in explaining spatial reasoning within scientific contexts, particularly its focus on the mental manipulation of objects that cannot be directly observed, such as celestial bodies. Gifted students exhibit varying levels of conceptual understanding. For instance, while some accurately associate Earth's rotation with the day-night cycle, others hold misconceptions about celestial movements (Plummer *et al*., 2011). Effective teaching methods incorporating kinesthetic and three-dimensional activities can enhance comprehension (Plummer *et al*., 2014). Furthermore, strengthening spatial reasoning skills at an early age has been linked to improved academic achievement in science (Shea *et al*., 2001).

Despite the importance of spatial reasoning, research on gifted students in this area remains limited. Existing literature indicates that spatial reasoning skills are often assessed in a decontextualized manner, detached from real-world experiences. Moreover, misconceptions about basic astronomy topics are not only prevalent among general students but also occur among the gifted. This study aims to examine the extent to which spatial reasoning contributes to gifted students' conceptual understanding and academic achievement in science, addressing a significant gap in the literature. Specifically, it explores the relationship between spatial reasoning, conceptual understanding, and academic achievement in science among gifted students. In conclusion, this research presents a unique model that investigates both direct and indirect relationships among gifted students' spatial reasoning skills, their conceptual understanding of basic astronomy topics, and their science achievement. The model developed in this study not only advances the literature but also fills a critical gap in understanding these interconnections. By doing so, it provides a framework for context-based assessments and instructional practices that foster deeper learning in astronomy and science education.

2. METHOD

This study employed a multifactorial predictive correlational design to test direct and indirect relationships between two or more predictive variables. Path analysis, a structural equation modelling technique, was used to examine explanatory relationships between variables within a confirmatory framework (Bayram, 2013; Büyüköztürk *et al*., 2016). The model, in which each hypothesis was tested according to the study's objectives, is presented in Figure 2.

Figure 2. *Hypothesis model.*



GL= Grade level; SRS-S= Mental imagery-focused spatial reasoning skill-static; SRS-D= Mental imagery-focused spatial reasoning skill-dynamic; CUBAS= Conceptual understanding related to basic astronomy subjects; AAS= Academic achievement in science.

In the model presented in Figure 2, hypotheses regarding indirect relationships between variables are represented by dashed arrows, while direct relationships are indicated by solid arrows. The hypotheses tested in the model are as follows:

H1: The static dimension of spatial reasoning skills in gifted sixth-, seventh-, and eighth-grade students directly and significantly predicts the dynamic dimension.

H2: The static spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students directly and significantly predict their conceptual understanding of basic astronomy topics.

H3: The static spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students indirectly and significantly predict their conceptual understanding of basic astronomy topics.

H4: The dynamic spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students directly and significantly predict their conceptual understanding of basic astronomy topics.

H5: The static spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students directly and significantly predict their academic achievement in science.

H6: The static spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students indirectly and significantly predict their academic achievement in science.

H7: The dynamic spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students directly and significantly predict their academic achievement in science.

H8: The dynamic spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students indirectly and significantly predict their academic achievement in science.

H9: The conceptual understanding of basic astronomy topics among gifted sixth-, seventh-, and eighth-grade students directly and significantly predicts their academic achievement in science.

According to the hypothesis model, grade level was identified as a predictor of all variables. Additionally, the SRS-S variable predicts the SRS-D variable, while both SRS-S and SRS-D predict the CUBAS variable. Similarly, SRS-S, SRS-D, and CUBAS predict the AAS variable, both directly and indirectly.

Due to the complex interplay of direct and indirect explanatory relationships among the examined variables, classifying them strictly as dependent or independent variables is not feasible. Therefore, within the framework of path analysis modelling, the variables were categorized as internal and external variables, as presented in Table 2.

Table 2. *Internal and external variables related to the model.*

Group	External Variables	Internal Variables
Gifted Students	Grade Level	SRS-S SRS-D CUBAS AAS

In Table 2, the external variable is modelled as dependent on the internal variables (SRS-S, SRS-D, CUBAS, and AAS). Internal variables are those that are explained directly or indirectly by other internal and external variables (Bayram, 2013).

2.1. Study Group

A total of 642 gifted students were selected for this study using the convenience sampling method. This method was chosen as it provides a practical and efficient way to access a specialized population, particularly when the target group is geographically dispersed, as recommended in educational and psychological research (Cohen *et al.*, 2018). Accordingly, students enrolled in Science and Art Centers (SACs) across various geographical regions of Turkey, including both large and small cities, were included in the study. These students were in the sixth, seventh, and eighth grades, attending SACs in 12 different cities (Elazığ, Erzincan, Malatya, Gaziantep, Şanlıurfa, Ankara, Adana, Antalya, Denizli, İzmir, Ordu, and Rize). They were officially identified as gifted through formal procedures and were eligible to enrol in these centers. Science and Art Centers are defined as “special education institutions that provide support education during extracurricular times to help students, who continue their formal education and are identified as gifted in the fields of general mental talent, visual arts, or music talent, to develop their capacities to the highest level” (General Directorate of Special Education and Guidance Services, 2019). Descriptive statistics on the grade level and gender distribution of the participants are presented in Table 3. According to Table 3, the majority of gifted students in the study are in the sixth and seventh grades, and the number of boys exceeds that of girls.

Table 3. *Descriptive statistics results related to the sample.*

Grade Level	***N***	**%**
6th	287	44.7
7th	264	41.1
8th	91	14.2
Gender		
Girl	249	38.8
Boy	393	61.2
Total	642	100

2.2. Data Collection Tools

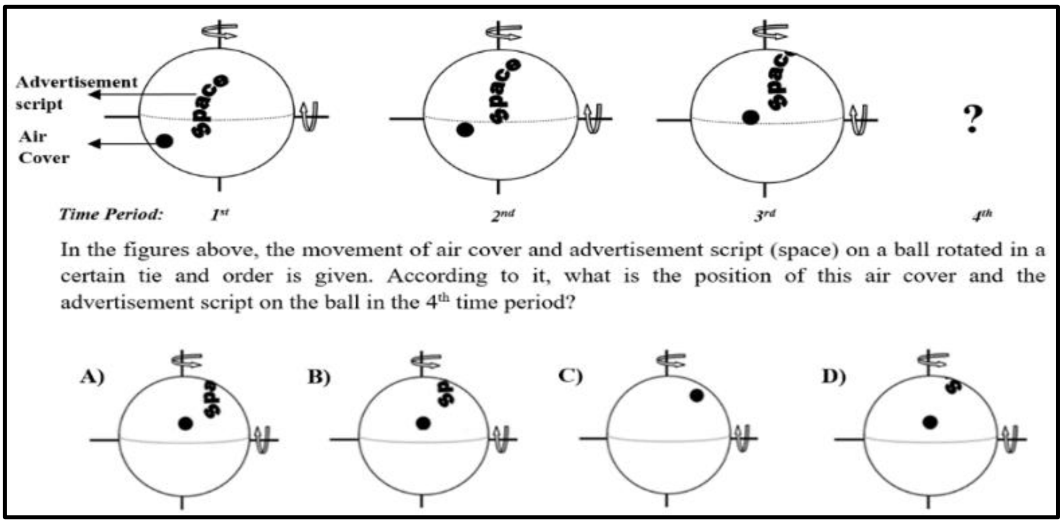
The data collection tools in this study included the Personal Information Form, the Mental Image-Focused Spatial Reasoning Skill Test (SRST), the Conceptual Understanding of Basic Astronomy Subjects Test (CUBAST), and the Science Achievement Test (SAT). The Personal Information Form was completed by students before the administration of the three tests to gather demographic information, such as gender, age, grade level, and the SAC they attended. To ensure the validity and reliability of the tests, a pilot study was conducted prior to the main implementation. A pilot study serves as a preliminary investigation to identify potential issues in the testing process and assess the suitability of the measurement tools for the research objectives (van Teijlingen & Hundley, 2002). This pilot study was carried out with 143 gifted students in the sixth, seventh, and eighth grades (*N* = 143) enrolled at Malatya SAC.

In order to test the validity and reliability of the tests to be used in the research, a pilot study was performed before the actual implementation. Pilot study is the preliminary study that is significant in terms of identifying the problems that may arise in the implementation process before the main study and providing the opportunity to test the appropriateness of the measurement tools for the purpose of the research in a practical way (van Teijlingen & Hundley, 2002). The pilot study was conducted with gifted students in 6th, 7th, and 8th grade (*N* = 143) who were studying in Malatya SAC.

2.2.1. *Mental image-focused spatial reasoning skills test*

To determine the subject scope of the test, studies in the literature on spatial thinking, mental imagery, spatial reasoning, and mental rotation were first examined (Al-Balushi & Coll, 2013; Bektaşlı, 2006; Heyer, 2012; Shipley & Gentner, 2013; Weakly, 2010). Based on this review, the theoretical framework of the measurement tool was developed according to the model proposed by Al-Balushi and Coll (2013), which focuses on the mental visualization of events that cannot be perceived by the naked eye at microscopic and astronomical scales. Unlike the original model, this test incorporates the synthesis of static and dynamic mental imagery in both the macro-world and astronomy, with a particular emphasis on high-level spatial reasoning skills, aligning with the study's objectives. The test items were designed using a three-stage, context-based approach grounded in the proximodistal principle. In the first step of these stages, the objects (such as apples, insects, pieces of faience, etc.) commonly encountered in daily life were used. While in the second step, larger-scale objects and environmental structures in the individual's surroundings (e.g., lakes, islands, seashores, fields) were used, in the third step, celestial and space objects located at the greatest distance from the individual (e.g., planets, constellations, satellites, meteorites). For each acquisition type, three question formats were developed, resulting in a total item pool of 36 questions. A sample question is presented in Figure 3.

Figure 3. *Sample question item (Dynamic-Rotation-Prediction).*



As a result of the item analysis, six questions (items 14, 31, 12, 35, 2, and 14) with discrimination index values below .20 were excluded from the test. In the final version of the test, item difficulty levels ranged from .25 to .97, while discrimination indices were between .20 and .49. Item analysis was re-conducted for the static (14 questions) and dynamic (16 questions) sub-dimensions separately. The results indicated that the discrimination index for the static sub-dimension ranged from .31 to .55, while for the dynamic sub-dimension, it varied between .23 and .53. The difficulty levels of the items remained consistent with the overall analysis, regardless of the number of items. Additionally, the sub-dimensions of the test demonstrated a significant, strong, and positive correlation with both the total test score and each other ($r_{static\text{-}dynamic} = .42$, $p < .00$; $r_{static\text{-}total} = .80$, $p < .00$; $r_{dynamic\text{-}total} = .88$, $p < .00$). Based on this information, the developed test demonstrates construct validity and effectively differentiates gifted students with varying levels of spatial reasoning ability in both static and dynamic dimensions. To assess the reliability of the total test score and sub-dimension scores, the KR-20 internal consistency coefficient, formulated by Kuder and Richardson (1937), was calculated. The KR-20 reliability coefficient for the overall test (SRST) was .72. Additionally, the reliability coefficients for the static (SRS-S) and dynamic (SRS-D) sub-dimensions were .55 and .60, respectively. Following the pilot study, the final version of the test includes 30 items, has a maximum completion time of 40 minutes, and demonstrates sufficient reliability (Wells & Wollach, 2003).

2.2.2. *Conceptual understanding of basic astronomy subjects test*

To determine the scope of the measurement tool, fundamental astronomy textbooks (Arny, 1994; Aslan *et al*., 1996; Fucili, 2009; Moche, 2009) and review studies on astronomy education across different time periods were examined (Bailey & Slater, 2003; Bretones & Neto, 2011; Lelliott & Rollnick, 2010). Based on these sources, the test content was structured around four core astronomy topics: The Earth-Sun-Moon System, Day and Night Cycle, Seasons, and The Solar System and Stars. Furthermore, studies on diagnostic tests designed to identify misconceptions and individuals' existing knowledge on these topics were reviewed, leading to the formation of a 20-item question pool (Agan, 2004; Atwood & Atwood, 1997; Baxter, 1989; Dove, 2002; Gündoğdu, 2014; Jeffrey, 2001; Küçüközer, 2007; Ogan-Bekiroğlu, 2007; Sharp, 1996; Trumper, 2000; Trumper, 2001a; Trumper, 2006; Trundle *et al*., 2002; Trundle *et al*., 2007; Young & Shawl, 2013; Zeilik *et al*., 1998). Content validity was ensured through expert opinions, a table of specifications, and a comprehensive literature review. The expert panel included a science education teacher and two doctoral researchers specializing in science education with a focus on astronomy. The table of specifications was prepared as an additional method to strengthen content validity. The distractor options in the test items were derived from common misconceptions about fundamental astronomical concepts, phenomena, and principles that individuals acquire from various sources (Agan, 2004; Baxter, 1989; Dove, 2002; Dunlop, 2000; Jeffery, 2001; Küçüközer, 2007; Sadler, 1992; Ogan-Bekiroğlu, 2007; Trundle *et al*., 2007; Trumper, 2001a; Trumper, 2006; Vosniadou & Brewer, 1990; Zeilik *et al*., 1998). Figure 4 presents a sample question from the CUBAST.

Figure 4. *Sample question item.*

What causes the formation of day and night on the Earth?
A) As a result of the Sun rotating around the Earth once a day, day and night occur.
B) As a result of the Earth rotating around the Sun once a day, day and night occur.
C) As a result of the Earth entering into and leaving the shadow of the Sun, night and day occur respectively.
D) Day and night occur as a result of the Earth rotating around its own axis.

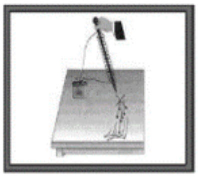
As a result of the item analysis, three questions (items 8, 14, and 20) with discrimination index values below .20 were excluded from the test. In the final version, discrimination indices ranged from .20 to .58, while item difficulty levels varied between .12 and .92. Considering these values collectively, the test demonstrates sufficient construct validity (Downing & Haladyna, 2006; Gronlund & Linn, 1990; Osadebe, 2015). The KR-20 reliability coefficient for the test was calculated as .61. Reliability and validity values for multiple-choice tests designed to assess mental processes should be interpreted together (Downing & Haladyna, 2006; Kubiszyn &

Borich, 2013). The Conceptual Understanding of Basic Astronomy Subjects Test (CUBAST) consists of 17 questions and has a maximum administration time of 20 minutes. Overall, these findings indicate that the test has a moderate difficulty level, exhibits internal consistency, and effectively differentiates gifted sixth-, seventh-, and eighth-grade students based on their conceptual understanding of basic astronomy topics.

2.2.3. *Science achievement test*

To assess the science achievement levels of gifted sixth-, seventh-, and eighth-grade students, the Science Achievement Test (SAT) developed by Aşut (2013) was used. The test consists of 45 multiple-choice questions, each with four answer options. Its content includes questions that assess high-level cognitive skills such as applying, analyzing, and evaluating, as well as fundamental skills like understanding. Thus, the test effectively measures the academic achievement of gifted students by requiring high-level cognitive processing. In the pilot study involving 143 participants, item analysis was conducted to determine the difficulty and discrimination indices of the test questions. Items with a discrimination index below .20 were re-evaluated, and five questions (items 1, 9, 11, 13, and 18) were removed from the original test. Figure 5 illustrates a sample question from the SAT.

Figure 5. *Sample question item (physical events- electricity in daily life- evaluating).*



In the given figure, Teacher Ayşe prepared an experimental setup based on electromagnetism in the science course. A student wants to increase the number of needles that attracted by this electromagnet setup. Accordingly, which of the following changes should this student make?

A) The student should use longer nails.

B) The student should change the poles of the generators.

C) The student should increase the number of turns.

D) The student should reduce the current passing through the wire by changing the voltage of the generator.

The discrimination indices of the test items ranged from .20 to .51, while the item difficulty levels varied between .16 and .95. When these values are analyzed collectively, the test appears to be sufficient in terms of construct validity for assessing achievement (Downing & Haladyna, 2006; Osadebe, 2015). The KR-20 reliability coefficient for the test was calculated as .84, which is close to the .92 value reported by Aşut (2013). Additionally, the mean item difficulty index (.54) and mean discrimination index (.37) suggest that the measurement procedures for assessing academic achievement, a cognitive trait, are valid (Murphy & Davidshofer, 2005; Tuckman & Harper, 2012). As a result, the Science Achievement Test (SAT) consists of 40 items, with a maximum administration time of 40 minutes.

2.3. Implementation Process

This study aimed to examine the relationship among Spatial Reasoning Skills, Conceptual Understanding of Basic Astronomy Topics, and Academic Achievement in Science among gifted sixth-, seventh-, and eighth-grade students. To achieve this, three multiple-choice tests (SRST, CUBAST, and SAT), each with four answer options, were administered. Based on data from the pilot study, an item analysis was conducted, and the tests were finalized. Considering the challenges encountered during the pilot phase, the tests were revised and refined for the main implementation. In the main study, while the sequence of test administration remained consistent with the pilot phase, the duration of each test was adjusted based on the number of questions.

The test administration sequence during data collection was structured to align with students' cognitive load. The SRST was administered first, followed by the CUBAST, and finally, the SAT. Due to variations in the number and content of questions in each test, administration durations were adjusted accordingly. Each student completed the tests independently, with completion times varying based on individual cognitive capacity. To minimize fatigue, a five-minute break was provided between tests.

The implementation was conducted in Science and Art Centers (SACs), specialized education institutions that provide supplementary instruction for gifted students. To ensure consistency and high-quality administration of the measurement instruments across different implementers, the researcher developed an Administration Guide and an Administration Process Checklist. The Administration Guide provided detailed instructions on test procedures and time allocation, ensuring clarity and uniformity in administration. The Administration Process Checklist served as a practical tool for implementers to verify the completion of each procedural step and provided the researcher with systematic feedback on the administration process. By following this structured approach, the study aimed to enhance the reliability and validity of the collected data, minimizing potential biases and procedural inconsistencies.

2.4. Data Analysis

Each test in the study was administered by SAC teachers in two sessions. The skewness-kurtosis coefficients and histogram curves of the average test scores indicated a normal distribution. Additionally, trimmed mean values for the lower and upper 5% of participants were compared with actual mean values, showing minimal differences. This confirmed that outliers had no strong effect on the mean, further supporting the normality of the data (Pallant, 2016; Yerdelen-Damar & Aydın, 2015). Consequently, parametric tests were used in inferential statistical analyses. Path analysis was conducted to develop a theoretical model by examining the direct and indirect relationships between internal and external variables. Before performing the path analysis, the Pearson Product-Moment Correlation Coefficient was calculated to determine the direction and strength of the relationships between variables. Additionally, Mardia's (1970) multivariate kurtosis coefficient was computed to test the assumption of multivariate normality. Bentler (2005) suggested that a value below 5 indicates a normal distribution of multivariate data. In this study, the calculated multivariate kurtosis coefficient (1.337) confirmed that the data met this assumption, allowing for path analysis. Further statistical analyses were conducted using AMOS 21 and LISREL 8.7. Path coefficients, representing standardized regression coefficients, were calculated to explain the interdependent variation of variables (Çokluk *et al*., 2012; Loehlin, 2004). Direct, indirect, and total effects between internal and external variables were analyzed using these coefficients. The alpha value for inferential statistical analyses was set at .05. To assess model fit, different indices (χ^2/df, RMSEA, SRMR, GFI, AGFI, CFI, and NFI) were calculated. Model fit was evaluated based on these indices to determine its compatibility with the observed data.

3. FINDINGS

In this quantitative study, findings were presented under four main categories: (1) identifying the mental imagery-based spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students, along with their conceptual understanding of basic astronomy topics and academic achievement in science; (2) descriptive analysis findings examining the direct and indirect exploratory relationships among these variables; (3) path analysis findings; and (4) findings related to predictive relationships and the direct and indirect relationships between variables.

3.1. Findings of Descriptive Analysis

Descriptive analysis and reliability coefficient values for the average scores of gifted sixth-, seventh-, and eighth-grade students (N = 642) on SRS, SRS-S, SRS-D, CUBAS, and AAS are presented in Table 4. An examination of Table 4 shows that the mean skewness and kurtosis values of participant scores for each measurement tool range from 0.01 to 0.18 and 0.05 to 0.21, respectively. Based on these values, the mean scores for each test exhibit a normal distribution (Tabachnick & Fidell, 2013). Additionally, the mean scores for the static and dynamic sub-dimensions of the SRS were 10.42 out of 14 and 9.90 out of 16, respectively. Similarly, the mean CUBAS score was 10.50 out of 17, while the mean AAS score was 23.06 out of 40.

Table 4. *Descriptive analysis results.*

Value	Test				
	SRS	SRS-S	SRS-D	CUBAS	AAS
N	642	642	642	642	642
M	20.33	10.42	9.90	9.90	23.06
SD	3.96	2.17	2.43	2.76	6.95
Min	5	1	1	1	4
Max	29	14	16	17	39
Skewness	0.17	0.18	0.13	0.14	0.01
$SE_{skewness}$	0.09	0.09	0.09	0.09	0.09
Kurtosis	0.20	0.21	0.17	0.05	0.17
$SE_{kurtosis}$	0.19	0.19	0.19	0.19	0.19
KR-21	.72	.55	.60	.61	.84

The descriptive analysis of the mean scores for SRS, SRS-S, SRS-D, CUBAS, and AAS by grade level is presented in Table 5. It shows that the mean scores for SRS, SRS-S, and SRS-D increase consistently with grade level. Additionally, the maximum scores of gifted students across different grade levels for CUBAS and AAS are similar, while their mean scores also show an upward trend with increasing grade level, similar to other measurement tools.

Table 5. *Descriptive analysis results according to grade levels.*

Grade Level	Value	Test				
		SRS	SRS-S	SRS-D	CUBAS	AAS
6	*N*	287	287	287	287	287
	Mean	19.58	10.17	9.41	9.69	18.78
	SD	3.94	2.26	2.37	2.61	5.18
	Min	6	1	2	2	4
	Max	28	14	16	16	36
7	*N*	264	264	264	264	264
	Mean	20.59	10.51	10.09	10.67	24.87
	SD	3.78	2.07	2.32	2.70	5.81
	Min	6	4	2	1	9
	Max	29	14	15	16	37
8	*N*	91	91	91	91	91
	Mean	21.90	10.98	10.92	12.56	31.29
	SD	4.00	2.06	2.57	2.20	4.88
	Min	5	3	1	5	12
	Max	28	14	15	17	39

3.2. Findings of Path Analysis

Before testing the hypothesis model, the relationships between variables were examined for multicollinearity, singularity, and linearity. Accordingly, the correlation matrix illustrating these relationships is presented in Table 6. An examination of Table 6 reveals that correlation values range from .22 to .88. Accordingly, a significant and positive relationship exists among SRS-S, SRS-D, CUBAS, and AAS. However, while SRS is significantly and positively correlated with its sub-dimensions, SRS-S and SRS-D, the high correlation coefficients indicate a singularity issue (Pallant, 2016; Tabachnick & Fidell, 2013). To address this, SRS-S and SRS-D were analyzed separately instead of the overall SRS variable, as they demonstrated a strong relationship while ensuring the path analysis assumptions in the hypothesized model.

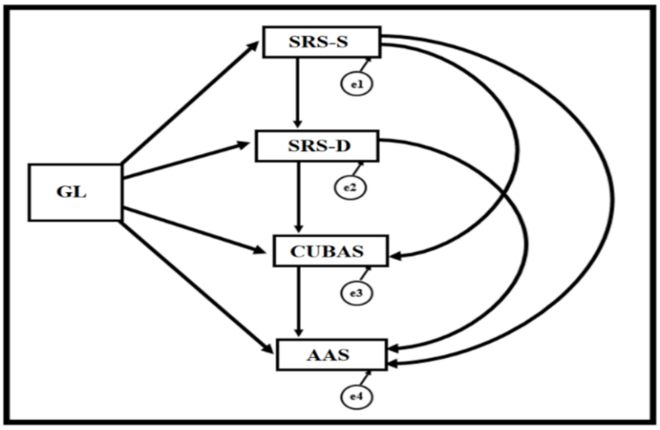
Table 6. *Correlation matrix.*

Variable	SRS	SRS -S	SRS -D	CUBAS
SRS	-			
SRS -S	.85*	-		
SRS -D	.88*	.48*	-	
CUBAS	.34*	.26*	.32*	-
AAS	.28*	.22*	.27*	.47*

$^{*}p<.05$

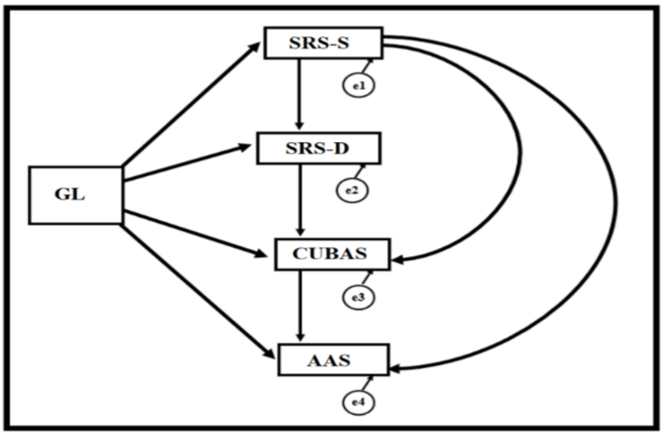
The path diagram illustrating the direct and indirect relationships between the examined variables is presented in Figure 6. An analysis of the fit values for the hypothesis model indicates that the data did not support the model (χ^2/df = 74.95; p < .05; RMSEA = .34). Furthermore, an examination of the path coefficients reveals that SRS-S and SRS-D do not significantly predict AAS (βSRS-S =.06, t = 1.81, p > .05; βSRS-D = .04, t = 1.24, p > .05). Based on this finding, the model was revised by removing the path representing the direct relationship between SRS-D and AAS.

Figure 6. *Path diagram related to the hypothesis model.*



The modified model is presented in Figure 7. An examination of Figure 7 shows that, in the modified model, the explanatory relationship between SRS-D and AAS is established only indirectly, unlike in the hypothesis model.

Figure 7. *The modified model.*



To determine whether to accept or reject the modified model and to evaluate the fit between the covariance matrices of the model and the observed data, model fit indices were analyzed. Since fit indices are sensitive to sample size and each represents different criteria, they should be evaluated collectively (Byrne, 2010; Kline, 2011). Accordingly, the fit index values for the modified model are presented in Table 7.

Table 7. *Fit index values regarding the modified model.*

Fit Indexes	*p*	χ^2/df	RMSEA	SRMR	GFI	AGFI	CFI	NFI
Modified Model	.22*	1.53	.03 (.000-.114)**	.01	.99	.98	.99	.99

*p >.05, **90% probability confidence interval values

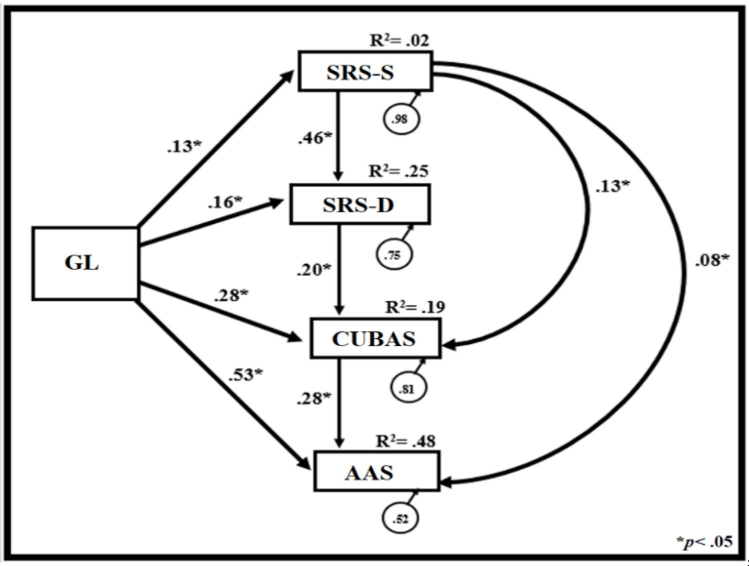
An examination of Table 7 indicates that, based on the chi-square goodness-of-fit index and significance level values, the modified model exhibits a perfect fit with the observed data (χ^2/df = 1.53; p >.05) (Byrne, 2010).The Goodness-of-Fit Index (GFI) represents the ratio of the sum of squared differences between the theoretical model and the covariance matrices of the data, similar to the R^2 value in multiple regression (Schumaker & Lomax, 2010; Tabachnick & Fidell, 2013). The Adjusted Goodness-of-Fit Index (AGFI) adjusts the GFI for degrees of freedom and reduces the impact of sample size. GFI and AGFI values range from 0 to 1, with values of .95 and above indicating a perfect fit (Çokluk *et al*., 2012). In this study, the GFI (.99) and AGFI (.98) confirm a strong model-data fit. The Root Mean Square Error of Approximation (RMSEA) index estimates the confidence interval for the mean square error of approximation, ranging between 0 and 1. Unlike GFI and AGFI, lower RMSEA values are preferred, with values close to 0 indicating better fit. RMSEA was calculated as .03, which, being below .05, signifies a perfect model-data fit (Bayram, 2013; Schumaker & Lomax, 2010). The Standardized Root Mean Square Residual (SRMR) measures the standardized difference between the observed data and the covariance matrices of the theoretical model. An SRMR value below .08 is acceptable, while values below .05 indicate a perfect fit (Byrne, 2010). The SRMR value in this study (.007) confirms that the model exhibits a perfect fit. Comparative Fit Index (CFI) and Normed Fit Index (NFI) evaluate model fit by comparing the theoretical model with an independent model assuming no relationships between variables (Çokluk *et al*., 2012). A CFI value above .97 and an NFI value above .95 indicate a perfect fit (Byrne, 2010). The CFI (.99) and NFI (.99) values in Table 7 further confirm the strong fit between the modified model and the observed data.

In conclusion, when evaluated collectively, the fit indices confirm that the modified model exhibits a perfect fit with the observed data. However, model fit alone is not sufficient to fully establish the validity of the modified model. Therefore, it is essential to further examine the degree, direction, and direct and indirect effects of the predictive relationships between the variables.

3.3. Findings for Predictive Relationships among Variables

To further examine the modified model, path coefficients among the re-analyzed variables and the explained variance ratios (R^2) for the predicted variables were calculated. The results are presented in Figure 8. An examination of Figure 8 indicates that the explanatory relationships among internal and external variables in the modified model are statistically significant, with path coefficients (β) ranging from .08 to .53 (p < .05). In the model, the path coefficients among the external variable, grade level, and the internal variables (SRS-S, SRS-D, CUBAS, and AAS) are βGL→SRS-S = .13 (t = 3.22, p < .05), βGL→SRS-D = .16 (t = 4.49, p <.05), βGL→CUBAS = .28 (t = 7.62, p < .05), and βGL→AAS = .53 (t = 17.37, p <.05). Additionally, 2% of the variance in SRS-S is explained solely by grade level (R^2 = .02), while 48% of the variance in AAS is accounted for by the remaining variables (R^2 = .48). The path coefficient between SRS-S and SRS-D was found to be β = .46 (t = 13.29, p < .05), indicating a significant and explanatory relationship between these two variables. Based on this finding, Hypothesis 1, formulated by the researcher, was confirmed. Furthermore, 25% of the variance in SRS-D is explained by both grade level and SRS-S (R^2 = .25)

Figure 8. *The path coefficients among the variables in the modified model and R^2 values (* p <.05).*



According to the path coefficients calculated in the modified model, independent changes in SRS-S and SRS-D were associated with significant changes in CUBAS, with βSRS-S→CUBAS = .13 (t = 3.11, p < .05) and βSRS-D→CUBAS =.20 (t = 4.87, p < .05). Based on these findings, Hypothesis 2 and Hypothesis 4, formulated by the researcher, were confirmed. Additionally, 19% of the variance in CUBAS is explained by both external (Grade Level [GL]) and internal (SRS-S and SRS-D) variables (R^2 = .19).

The path coefficients between AAS and its explanatory variables, SRS-S and CUBAS, were calculated as βSRS-S→AAS = .08 (t = 2.59, p < .05) and βCUBAS→AAS = .28 (t = 8.83, p < .05), respectively. These results indicate that AAS is directly predicted by both CUBAS and SRS-S, independently and in a statistically significant manner. Accordingly, Hypothesis 5 and Hypothesis 9, formulated by the researcher, were confirmed. However, in the modified model presented in Figure 8, SRS-D did not significantly and directly predict AAS. Therefore, Hypothesis 7 was not supported. Additionally, approximately half of the variance in AAS (R^2 = .48) was explained by external and internal variables in the model.

3.4. Findings regarding Analysis of Direct and Indirect Relations

In the model, the predictive relationship between two variables can occur directly or indirectly through a third variable. Direct effects are represented by path coefficients in the path diagrams, while indirect effects occur when an internal or external variable influences the explained variable via another variable. Indirect effect values are calculated by multiplying the path coefficients between the explanatory variable, the mediating variable, and the explained variable (Çokluk *et al*., 2012). The total effect of an explanatory variable on the explained variable is the sum of its direct and indirect effects. Accordingly, the direct, indirect, and total effects among the variables in the model are presented in Table 8. An examination of Table 8 reveals that the external variable, Grade Level (GL), has a direct impact on all internal variables and an indirect effect on SRS-D, CUBAS, and AAS. In the indirect effect of GL on SRS-D (βSD→SRS-D = .06), SRS-S serves as a mediating variable. Similarly, in the indirect effect of GL on CUBAS (βSD→CUBAS = .06), SRS-D acts as a mediator. Lastly, in the indirect effect of GL on AAS (βSD→AAS = .10), CUBAS functions as a mediating variable.

Table 8. *The direct, indirect and total effect values among variables.*

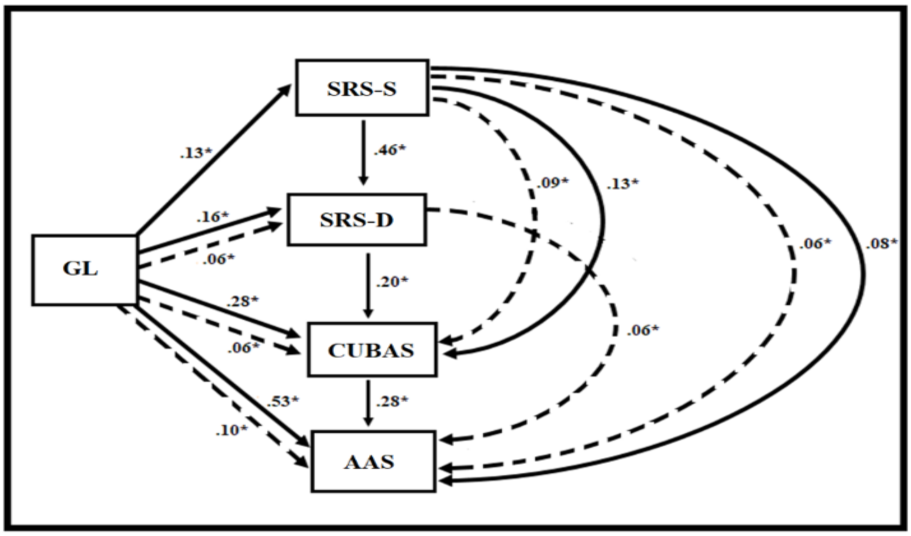
The Explained Variable		SRS-S			SRS-D			CUBAS			AAS		
Impact Type		Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Explanatory Variable	GL	.13*	-	.13*	.16*	.06*	.22*	.28*	.06*	.34*	.53*	.10*	.63*
	SRS-S	-	-	-	.46*	-	.46*	.13*	.09*	.22*	.08*	.06*	.14*
	SRS-D	-	-	-	-	-	-	.20*	-	.20*	-	.06*	.06*
	CUBAS	-	-	-	-	-	-	-	-	-	.28*	-	.28*

*$p < .05$

The variables SRS-S and SRS-D have a total effect of .22 and .20, respectively, on CUBAS. Additionally, .09 of the total effect of SRS-S on CUBAS is indirect, mediated through SRS-D. Similarly, SRS-S indirectly influences AAS (.06) through SRS-D and CUBAS. Based on these findings, Hypotheses 3, 6, and 9, formulated by the researcher, were confirmed.

Finally, it was observed that all external and internal variables in the model had either direct or indirect effects on AAS. The SRS-D variable exerted an indirect effect on AAS (.06) through CUBAS, confirming Hypothesis 8, formulated by the researcher. As a result, CUBAS was identified as a mediating variable in the indirect predictive relationship between AAS and both SRS-S and SRS-D. The final model, developed based on the values in Table 8, was confirmed by its fit with the obtained data and the direct and indirect explanatory relationships between the variables. This model, determined by the researcher, is presented in Figure 9.

Figure 9. *The final model (*p <0 .05).*



In the final model presented in Figure 9, indirect relationships between variables are represented by dashed arrows. The model developed by the researcher demonstrates significant direct and indirect explanatory relationships between gifted students' grade levels, their static and dynamic spatial reasoning skills, their conceptual understanding of basic astronomy topics, and their academic achievement in science.

4. DISCUSSION and CONCLUSION

This study conducted an exploratory investigation to determine the relationship between the spatial reasoning skills of gifted sixth-, seventh-, and eighth-grade students, their conceptual understanding of basic astronomy topics, and their academic achievement in science. It makes a significant contribution to the existing literature by examining the interplay between spatial reasoning, conceptual understanding of astronomy, and science achievement in gifted students. Unlike previous research, which often relies on decontextualized assessments, this study employs context-based tools specifically designed for astronomy, offering a more nuanced perspective on how spatial reasoning supports learning (Al-Balushi & Coll, 2013). The path analysis performed for this purpose yielded several findings regarding the explanatory relationships between the examined variables. One key finding revealed that grade level significantly explained changes in both static and dynamic spatial reasoning skills, positively predicting gifted students' spatial abilities as they advanced in grade level. Additionally, 25% of the variance in dynamic spatial reasoning was explained by both grade level and static spatial reasoning. Similarly, Kikas (2006) and Türk (2016), who conducted studies with pre-service science teachers, found that spatial reasoning skills improved as grade levels increased. Moreover, their findings indicated that conceptual understanding of basic astronomy topics also improved with grade progression. This result aligns with the findings of Göncü (2013), who examined fifth- and seventh-grade students, and Padalkar (2010), who studied fourth- and seventh-grade students. Both studies concluded that students in higher grades demonstrated a more sophisticated conceptual understanding of astronomy.

In this study, static spatial reasoning skills were identified as a predictor of dynamic spatial reasoning, both of which are defined as sub-dimensions of spatial reasoning. Accordingly, changes in static spatial reasoning- which involves thinking processes related to features such as the shape and size of three-dimensional objects-explain variations in dynamic spatial reasoning, which includes thinking processes related to movement, such as distance, appearance/disappearance, linear motion, and rotation. D'Oliveira (2004), in a study conducted with 104 university students, administered nine different spatial tests and applied explanatory and confirmatory factor analysis techniques to the collected data. Consistent with the findings of the present study, D'Oliveira (2004) proposed that spatial skills consist of two fundamental structures: static and dynamic.

Another key finding of this study was that gifted students' static and dynamic spatial reasoning skills positively and significantly predicted their conceptual understanding of basic astronomy topics. Additionally, static spatial reasoning skills indirectly influenced conceptual understanding through dynamic spatial reasoning. Similarly, Heyer (2012) found a strong relationship between spatial reasoning skills and conceptual understanding of astronomy among university students, with spatial skills accounting for approximately 25% of the variance in conceptual understanding. From this perspective, one of the key contributions of this study is its dual-dimensional approach, which examines both static and dynamic spatial reasoning and their distinct impacts on conceptual understanding and academic achievement. This expands upon previous research (Heyer, 2012) by focusing on gifted middle school students, highlighting developmental differences across grade levels. Kikas (2006) suggested that secondary school students' spatial skills play a crucial role in structuring astronomy-related concepts and phenomena scientifically. Similarly, Plummer *et al*. (2016) observed that students aged 7–9 with high levels of spatial reasoning could easily explain complex astronomical topics, such as the visible motion of the Sun and the seasons, by shifting between reference frames. Wilhelm (2009) also found that secondary school students' understanding of the phases of the Moon and the relative positions of the Sun, Earth, and Moon was linked to their spatial skills. Furthermore, Rudmann (2002) demonstrated that students' academic performance in astronomy was positively and significantly related to their spatial abilities. This finding aligns with Türk (2016), who reported a strong correlation between science teacher candidates' spatial skills and their academic achievement in astronomy. It also supports Wilhelm *et al*. (2013), who found that sixth-grade students needed advanced spatial skills to develop a scientific understanding of astronomical phenomena. Additionally, Yen *et al*. (2013) highlighted that university-level spatially focused applications effectively facilitated learning about the phases of the Moon.

Similarly, Wilhelm *et al*. (2017) found that instructional approaches emphasizing spatial skills in sixth-grade students significantly enhanced their scientific understanding of basic astronomy topics. Overall, these findings reinforce the importance of spatial reasoning as a crucial variable in developing an understanding of fundamental astronomy concepts. Moreover, this study addresses the limited research on gifted populations in the literature, providing insights into how their advanced cognitive abilities influence learning in complex scientific domains. The results align with and extend the work of Rudmann (2002) and Wilhelm *et al*. (2013), underscoring the essential role of spatial reasoning in science education.

Another variable that explains static and dynamic spatial reasoning skills is the academic achievement of gifted students in science. Static spatial reasoning skills have both a direct effect on academic achievement in science and an indirect effect through conceptual understanding of astronomy. In contrast, dynamic spatial reasoning skills influence academic achievement in science only indirectly through conceptual understanding of astronomy. These findings suggest that effectively structuring astronomy topics involving dynamic processes can contribute to increased academic achievement in science. These results support the conclusion of Black (2005), who found that university students' spatial skills were a crucial factor in developing a scientific understanding of astronomy and improving science achievement. Similarly, Wai *et al*. (2009), in a long-term longitudinal study conducted with students aged 9–12, highlighted that spatial skills play a critical and significant role in science achievement, particularly among gifted students. Hegarty (2010) also emphasized that university students' spatial thinking skills were linked to their academic performance in fundamental science fields such as chemistry, physics, biology, and geology. Additionally, studies by Taylor and Huttn (2013) with fourth-grade students and Miller and Halpern (2013) with university students suggested that spatially focused instructional practices enhance academic achievement in science. Maker (2020) further indicated that spatial ability assessments could be a practical tool for identifying gifted students in science. Moreover, numerous studies in the literature support these findings, demonstrating a positive and significant relationship between spatial skills and academic achievement in science (Hegarty *et al*., 2010; Jones & Burnett, 2008; Kozhevnikov *et al*., 2007; Sorby, 2001; Webb *et al*., 2007; Wu & Shah, 2004).

Therefore, the positive changes in static and dynamic spatial reasoning skills of gifted students—linked to their grade levels—contribute to an enhanced conceptual understanding of basic astronomy topics, ultimately leading to higher academic achievement in science. As a result, the hypothetical model derived from the analysis of this study provides a crucial framework for understanding the nature of these variables and their explanatory relationships. This model is instrumental in addressing challenges gifted students face in spatial reasoning within the fields of astronomy and science. Moreover, the validated path model offers a theoretical foundation for understanding the direct and indirect relationships among these variables, enriching both theoretical discourse and practical applications in cognitive development and gifted education. It also supports the integration of spatially rich, interdisciplinary learning environments to optimize the educational experiences and STEM potential of gifted students (Wai *et al*., 2009).

This study makes a significant contribution to the literature by providing a context-specific exploration of spatial reasoning and its role in enhancing gifted students' understanding of astronomy and their academic achievement in science. Unlike previous studies that focus on general populations or rely on decontextualized assessments, this research highlights the importance of context-based spatial reasoning (Al-Balushi & Coll, 2013). By examining static and dynamic subdimensions within gifted learners, the study uncovers developmental nuances and their implications for tailored instructional design. The validated model further deepens the theoretical understanding of cognitive variable interactions, offering a robust framework for future research and practice in gifted education.

4.1. Discussion of Study Limitations

The study's limitations and potential avenues for future research are closely intertwined, highlighting areas for both improvement and further exploration. This section comprehensively addresses these limitations to provide a cohesive understanding of the challenges encountered and the opportunities they present for advancing research in this field.

The hypothetical model developed through the path analysis technique primarily focused on spatial reasoning and conceptual understanding. However, it could be expanded by incorporating additional cognitive factors, such as memory and problem-solving skills, as well as affective factors like motivation, attitudes, and interest in astronomy. Integrating these elements could offer a more comprehensive understanding of the relationships between observed and latent variables, further enriching the model's explanatory power.

While this study primarily focused on gifted sixth-, seventh-, and eighth-grade students, it did not explicitly examine the potential influence of gender differences on spatial reasoning and astronomy understanding. Future research could explore this aspect by developing and testing models that integrate gender as a variable, allowing for comparisons across different grade levels to uncover nuanced differences in spatial reasoning and conceptual understanding.

This study included gifted students attending Science and Art Centers (SACs) in 12 provinces (Elazığ, Erzincan, Malatya, Gaziantep, Şanlıurfa, Ankara, Adana, Antalya, Denizli, İzmir, Ordu, and Rize). To enhance generalizability, future research could expand the sample by including SACs from additional provinces or incorporating students from other educational institutions. Additionally, comparative studies involving non-gifted students could highlight significant contrasts and provide broader insights into the role of spatial reasoning in astronomy education. Furthermore, the Conceptual Understanding of Basic Astronomy Subjects Test (CUBAST) used in this study was limited to specific astronomy topics. Expanding its content to cover additional topics could provide a more comprehensive measure of students' conceptual understanding. Moreover, incorporating qualitative methodologies, such as interviews or observations, could complement the quantitative findings, offering deeper insights into gifted students' thought processes and learning strategies.

This study was conducted within a specific educational and cultural context, focusing on Turkish gifted students. Future research could replicate the study in different cultural or educational settings to examine how contextual factors influence the relationships explored in the model. Such an approach would enhance the cross-cultural applicability and relevance of the findings, providing deeper insights into the role of spatial reasoning in astronomy education across diverse learning environments. By addressing these limitations, future research could refine the proposed model and contribute more comprehensively to the literature on gifted education, spatial reasoning, and astronomy learning. Expanding the scope, increasing sample diversity, and incorporating varied methodological approaches would offer a richer and more holistic understanding of the factors that shape gifted students' learning experiences in science education.

In conclusion, this study makes a significant contribution to the literature by offering a context-specific exploration of spatial reasoning and its essential role in enhancing gifted students' understanding of astronomy and science achievement. Unlike previous research, which often focuses on general populations or employs decontextualized assessments, this study highlights the importance of context-based spatial reasoning (Al-Balushi & Coll, 2013). By examining the static and dynamic subdimensions within gifted learners, it uncovers developmental nuances and their implications for tailored instructional design. The validated model further enriches the theoretical understanding of cognitive variable interactions, providing a robust framework for future research and educational practice in gifted education. Despite its critical role in identifying gifted students, spatial reasoning often receives less emphasis than verbal or quantitative skills in curricula. This study underscores the need for context-based enrichment learning environments that prioritize spatial reasoning development, leveraging the explanatory relationships identified to better support the cognitive and academic growth of gifted students.

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Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in IJATE belongs to the authors. **Ethics Committee Number**: Inönü University, 27250534-605-E.13323632, 25.12.2015.

Contribution of Authors

Pelin Ertekin: Research Design, Literature Review, Methodology, Data Collection, Data Analysis, and Writing. **Mustafa Serdar Köksal**: Research Design, Methodology, Data Analysis, Supervision, Writing and Critical Review.

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