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DOES VISUAL-SPATIAL COGNITION AFFECT CHILDREN'S ASTRONOMICAL EXPERIENCES?

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Abstract:
Understanding of astronomical phenomena requires spatial reasoning skills. The current study examines the influence of spatial ability on conceptual understanding of secondary school students in elementary astronomy. The sample consisted of 38 ninth-grade students from a high school in Hyderabad. To evaluate participants' spatial ability, spatial reasoning test, Purdue Spatial Visualization Test: Visualization of Rotations and mental rotation tests were used. Mental Rotation, Spatial Perception, and Spatial Visualization are the types of spatial ability tested in this study. To understand learners conceptual understanding in astronomy, 30 probes on astronomical topics were administered. The research study was quantitative in nature. Correlational analysis showed that all three spatial sub-skills namely Spatial Orientation, Mental rotation and Spatial Visualization is associated with astronomy conceptual understanding. The correlation coefficient of overall spatial ability and conceptual understanding was 0.693 ($p < 0.05$). The result of an independent t-test suggested that there is no major impact of gender on spatial ability and conceptual understanding in astronomy. The researchers suggest that teachers should develop spatially enriched lessons that help students improve their spatial thinking skills and a deeper conceptual understanding of basic astronomical concepts.

Keywords: spatial ability, conceptual understanding, astronomy, spatial orientation, and spatial visualization

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1. Introduction

Elementary astronomy is taught as part of the science curriculum at middle schools in India. Concepts, for example, day and night, earth's motion, moon phases, solar eclipses, seasons and solar systems are part of this curriculum, and learners need a high degree of observation and cognitive skills to comprehend them. Astronomy is considered to be particularly spatially complex because it requires the use of a space-based perspective to explain phenomena that we see from an Earth-based perspective. Students have difficulty analyzing and understanding three-dimensional concepts and motions of celestial bodies as presented in two-dimensional diagrams. Many researchers have shown that alternative ideas prevail among Indian students (Mohapatra, 1991; Samarapungavan, Vosniadou, & Brewer 1996; Padalkar & Ramadas, 2008; Venkateshwaram, 2010). The crucial issue in teaching-learning astronomy is spatial thinking skill. This issue makes it more challenging for students to learn and understand the astronomical concepts and events accurately (Turk, 2016). Researchers have argued that the root of many alternate conceptions is students' lack of visuospatial thinking (Subramaniam & Padalkar, 2009; Padalkar & Ramadas, 2011). The ability to understand the astronomical phenomena and events requires to visualize events from multiple viewpoints, to observe objects in multidimensional space, to perceive patterns and understand celestial directions, and to focus on the external representations of phenomena provided by diagrams, maps, charts, representations of virtual reality, animation, models used in the classroom etc. The conception of the solar system to explain astronomical events such as lunar phases is an ambiguous procedure and challenging for learners, particularly for elementary school students (10 to 13 years), who belong to the formal operational period (Venkateshwaran, 2010). Traditionally, diagrams are the only tools used to convey astronomical core concepts. Such 2D diagrams usually enable the learner to grasp the three-dimensional relationship by positioning himself within the scene shown. More dynamic motions (such as the moon revolving around the earth) and its alignment (sun-earth-moon alignment leading to moon phases) that contribute to observable anomalies involve visualization of the three-dimensional universe. Besides, learners should be able to understand the changing reference frames and acquire the abilities to accurately capture the scale, location and orientation of the astronomical bodies to arrive at a sound knowledge of the spatial pattern. Therefore, to understand basic astronomical phenomena and events, sound spatial arguments, visualization and perceptions are necessary (Venkateshwaran, 2010).

2. Cognitive Abilities and Conceptual Understanding in Astronomy

Conceptual understanding refers to both a cognitive aspect ranging from knowledge to application and reasoning, as well as a content aspect that includes a scientific understanding of key concepts. It implies a profound understanding of the meaning of concepts; including knowledge of concepts, the skill to use this knowledge in diverse frameworks as well as in systems, including relationships with other concepts

(Wellington, Osborne & Wellington, 2001). To improve the conceptual knowledge of teachers and students, cognitive dimensions ranging from knowledge to application, to perception must be incorporated into the theoretical awareness of the most important astronomical concepts. Astronomical principles are taught in schools according to the degree of the students' cognitive growth. The abilities of school children are determined not just by the learning opportunities, but by basic cognitive learning abilities. Two children sharing similar learning environments may differ significantly in the knowledge and skills with which they start formal school, due to their different learning abilities. Cognitive ability is the 'ability to learn' (Spinath, Harlaar & Plomin, 2006). The performance in natural sciences and math depends on various skills, such as spatial skills, linguistic skills, mathematical skills and working memory (Halpern, Benbow, Geary, Gur, Hyde, & Gernsbacher, 2007). Cognitive abilities of children have substantially predicted their understanding of scientific material, and recent studies have shown that cognitive skills are a major predictor of academic achievement (Spinath et al., 2006). Astronomy concepts are particularly difficult to understand and explain, compared to other concepts in science. Therefore, students need upper-level 'cognitive skill' to comprehend these concepts.

3. Spatial Abilities and Conceptual Understanding in Astronomy

There is no agreement on the expressions used for spatial ability and the associated aspects of spatial ability. Throughout the literature, various terms such as spatial reasoning, spatial perception, spatial orientation, spatial relationships, spatial sense, spatial thinking, visuospatial ability and spatial intelligence were used to establish spatial ability.

In the broadest sense, spatial ability is referred to as the skill to rotate 2D and 3D objects in different ways and to keep an eye on the changing forms of these objects. Spatial ability is the *"mental capacity for manipulating visual patterns, as indicated by the level of difficulty and complexity in visual stimulus material that can be handled successfully"* (Carroll, 1993, p. 362). It is also defined as *"the perceptual and cognitive processes that enable humans to create and manipulate mental representations of the spatial properties that exist within and between physical or imagined objects, structures and systems"* (Cole, Cohen, Wilhelm & Lindell, 2018, p.1).

Linn and Petersen (1985) categorized spatial abilities into sub-skills based on cognitive tasks: spatial orientation, mental rotation, and spatial visualization:

- **Mental rotation**: defined as the skill to rotate a two- or three-dimensional figure in the thought process quickly and accurately without the help of external tools.
- **Spatial orientation**: ability to regulate spatial relations concerning the orientation of one's own body or in the context of distracting information.
- **Spatial visualization**: ability to manipulate 2-dimensional and 3-dimensional figures.

Several researchers have recognized that learners have trouble understanding astronomy concepts, as such these concepts require the use of spatial skills (Hans, Kali &

Yair, 2008; Padalkar & Ramadas, 2011). These skills include spatial orientation (i.e.) the manipulation of bodies in space (Rudmann, 2002; Black, 2005) and spatial visualization, the perception of objects from a different point of reference in space (Callison & Wright, 1993; Plummer, Wasko & Slagle, 2011). The spatial orientation facilitates learners to comprehend; for instance, day and night formation occur due to earth's spin. Spatial visualization enables people to understand complex relationships across the sun-earth-moon system. For example, an astronomer needs to visualize the arrangement of planets in the solar system and the movements of objects in it. Astronomical events are multi-dimensional, complex, and happen in a wide space and over a long time. Students must be able to correctly grasp the scale, dimension, position, movement and orientation of the objects. Some dynamic movements (such as the moon rotating around the earth) and its alignment (sun-earth-moon alignment leading to moon phases) that lead to observable phenomena involve visualization of the 3-D world. To understand the phenomena of celestial motion, learners should understand both "Earth-based" and the "Space-based" perspective and the skill to switch among these perspectives. To learn how to explain the apparent daily movement of the stars, it is necessary to imagine how the stars gently rise above us from an earth-bound perspective and that this movement is the result of earth revolving around its axis (space-based perspective). While many researchers have argued for interrelationships among spatial abilities and understanding of astronomy understanding, not many have conducted an empirical study that examines these interrelationships.

Research studies in astronomy indicate that students require high levels of spatial thinking. Spatial abilities are factors that explain the differences in student understanding of astronomy (Black, 2005; Wilhelm, 2009). Studies conducted in the past have also determined the relationship between student achievement in spatial tasks and their ideas about the earth (Sneider & Pulos, 1983). Another research by Callison and Wright (1993) explored the relationship between spatial abilities and conceptual changes when students learned more about astronomy concepts. Rudmann (2002) noted that the student ability to seek scientific models for the seasons to occur was constrained by their spatial abilities. Likewise, Wellner (1995) stated that when learners have a strong spatial sense, they tend to describe a correct cause for moon phases. Recent studies have reported that well defined spatial perception is important to understand the astronomical phenomena, such as celestial motions and moon phases (Plummer, 2014; Wilhelm, 2009; Wilhelm, Jackson & Sullivan, 2013). Further, studies conducted by Plummer and colleagues claimed that comprehending astronomic motion demands the ability to move between frames of reference (Plummer et al., 2011; Plummer, 2014).

Bayraktar (2009) noted that substantial connections must be established between the types of abilities, to obtain the desired student results for conceptualizing the lunar phases: First, the students would understand the moon and earth motions and their relative positions in relation to the sun. Secondly, learners should know that the sun brightens the moon and that we can only see this illuminated part from the earth. In addition, when the earth and the moon shift their positions relative to the sun, this illuminated part of the moon changes its shape causing lunar phases. To have this knowledge and understanding students should have spatial skills of rotation and visualization.

In his study, Black (2005) examined the contribution of spatial skills of non-science students to the understanding of geoscientific concepts, including astronomy. His study included 97 students, 34 were men and 63 were women. Students were administered a multiple-choice questionnaire on earth science concepts prepared by the researcher to examine their conceptual understanding. To assess learners' spatial ability, "Purdue Spatial Visualization Test of Rotations (PSVT: R)" (Bodner & Guay, 1997), the "Group Embedded Figure test" and the "Differential Aptitude test: Spatial Relations" were administered. Correlation coefficients and regression analysis were used to validate the influence of spatial ability in understanding geoscientific concepts. The spatial skills assessed by the three tests contributed to one-third of the geoscience test variance. Results showed a reasonable correlation between conceptual understanding in earth science and all the spatial ability tests. Moreover, it was proved that the mental rotation was closely associated with several earth science misconceptions and conceptual difficulties.

Sneider, Bar and Kavanagh (2011) reviewed 41 studies on seasonal cycles. A "learning progression" (LP) has been suggested to teach the phenomenon of the seasons starting with day and night cycle, progressing to an "Earth-based" perspective and concluding with a "Space-based" perspective. The results showed that one reason for the difficulty of learning the causes of seasons was the lack of spatial reasoning ability.

The research conducted by Heyer, Slater and Slater (2012) explored the association among the students' ability to think spatially and their ability to learn astronomy. To systematically establish an empirical relationship, 86 undergraduate students were administered pre -and post- astronomy conceptual test and a test on spatial reasoning. They used the "Test of Astronomy Standards" (TOAST) and "What Do You Know (WDYK)" to assess students' understanding of astronomy. The spatial skills were tested using an assessment questionnaire based on the "Vandenberg Mental Rotation test" and the "Paper Folding Visualization test." A significant association was found between the TOAST- pretest and postest scores and the spatial assessment, indicating the link between spatial capacity and astronomical concept knowledge.

Plummer and Maynard (2014) administered an assessment questionnaire constructed on the reason for the seasons to 38 eighth grade students. The Rasch analysis was used to test concept maps that deal with the explanation for the cause seasons. For students to progress through the level and gain a more comprehensive understanding, they have to switch between "Space-based" and "Earth-based" perspectives. The findings showed that the relating earth-bound and space-based views creates a major challenge for the students to understand the apparent movement of the sky.

Concerning gender difference in spatial ability, researchers have concluded that there exists a gender gap in spatial skills. More precisely, the results of previous studies indicate that males usually outperform females in spatial ability tests (Al-balushi & Al-battashi, 2012; Halpern et al., 2007; Voyer, Voyer, & Bryden, 1995). Also, studies have indicated that the difference is greater for some types of spatial skills such as spatial perception and mental rotation than for spatial visualization (Voyer et al., 1995).

Linn (1985) used a meta-analysis approach to answer questions about gender gaps in spatial ability. The findings show that, first, gender differences exist in spatial orientation and mental rotation but not in spatial visualization. Second, there are significant differences between women and men only when calculating the mental rotation; thirdly, there are small variations between women and men in spatial perception.

Maeda and Yoon (2013) conducted a meta-analysis to measure the extent of the gender gap in the ability to change mentally and to analyze how variables related to the administration of the test affect varying the extent of the gender difference results. The results showed that men performed better in mental rotation tasks compared to the women participants in the study. Roberts and Bell (2002) concluded their study with the finding that gender-specific differences in spatial ability only exist in adolescence.

It is known and expected that spatial reasoning skills could play an important role in the teaching-learning of astronomy. Nevertheless, there is little evidence to support this argument. In view of the minimal yet positive findings above, there is a good reason to test these hypotheses empirically.

4. Objectives of the Study

The main aim of this study is to explore the relationship between conceptual understanding in astronomy and spatial ability. Another aim of this research paper is to observe how boys and girls differ in their astronomical conceptual understanding and spatial abilities. The statement of the study is "Exploring the correlation between spatial ability and conceptual understanding in astronomy."

The following research questions guided this study:

1) Is there any relationship that exists between spatial ability and conceptual understanding in astronomy?
2) Does gender difference exist when spatial ability and conceptual understanding in astronomy are concerned?

5. Research Procedures

To achieve the objectives of this study, thirty-eight (36) students of class nine from a CBSE school in Hyderabad were selected. Out of 40 students, 18 were boys and 18 were girls. The sample was drawn through a purposive sampling technique which is a non-probability sampling technique. The reason for selecting this school was that the students at this school come from families of moderate socioeconomic status, of various cultural and ethnic origins. All these children had received formal instruction from the same teacher on basic astronomical topics under the unit "Stars and Solar system" in their previous academic year (8th grade). The research design adopted in this study was a correlational study. Correlation studies have been used to examine the association between two or more variables. They provide the ability to assess the trend and strength of current relationships and to establish hypotheses.

This study considers conceptual understanding in astronomy as the dependent variable and spatial abilities such as mental rotation, spatial orientation, and spatial visualization as independent variables. To assess learners' conceptual understanding in astronomy, the researcher administered thirty probes under five sections (Keely & Sneider, 2011) that focus on elementary astronomy to elicit students' ideas and data collection. The probe consisted of two parts, in the first part students are asked to select the correct claim from the list of statements given and in the second part to give their explanation as to why their claim is correct while supporting their claim with enough evidence, conceptual understanding and reasoning. The study participants' written responses to the probes were analysed quantitatively to get the level of conceptual understanding inherent in their explanations. The student explanations classified into 3 types based on the criteria of analysis as given in Table 1.

Table 1: Criteria for Scoring Student's Level of Understanding

Types of Explanations	**Analysis Criteria**
Naïve Explanations	These explanations are developed based on children's own perception and experience. This includes: • Correct claim /incorrect reason • Description of the phenomena • The knowledge received from sources like adults, myths, religion, culture • Incomplete and contradictory explanation
Partially Scientific Explanations	These explanations are developed through one's own experience and learned verbal knowledge. This includes: • Correct claim / partially correct reason statement • Factual knowledge received from teachers, textbooks, web • Correct explanation; mostly supports the response but has no concepts that support response
Accurate Scientific Explanation	These explanations closely match with scientific explanations and conceptual understanding. This includes: • Correct claim/ correct reason • The explanation is correct; includes relevant concepts that support response

To prepare the grading headings for the study, the researcher analysed the student responses based on the score parameters, collected examples of the answers that should have been graded as 1, 2, or 3, and established a grading manual/evaluation rubric for each probe. The researcher along with another expert in physics education separately scored the responses/ answers for each probe, and the inter-rater reliability coefficient for every probe was calculated by the researcher. According to this rubric, student's explanation for each probe received a score of '1' for pre-scientific/ naïve explanations based on one's everyday experience, '2' for those explanations which are partially scientific (synthetic) and '3' for the responses which have correct scientific explanations. Scores were not given for those who selected incorrect claim and wrong reason. Based on these criteria, a student can score a maximum score of '3', a minimum of '0' for each probe/question. The total score of six probes gives students' conceptual understanding in a particular domain. The cumulative score of all five sections was taken as the score for students’ conceptual understanding in Astronomy.

To determine learners' spatial abilities, the researcher conducted three paper and pencil assessments, which assessed three types of spatial abilities, based on the three categorizations listed by Linn and Petersen (1985). Spatial Reasoning Instrument (SRI) developed by Ramful, Lowrie and Logan (2016) consisting of 30 multi-choice elements based on three sub-skills (with 10 items per skill): Mental Rotation, Spatial Orientation and Spatial Visualization. For each incorrect response a score of 0 was given and for each correct answer a score of 1.

The second test administered is the redesigned “Vandenberg & Kuse Mental Rotation Test” (Peters et al., 1995). The Mental Rotation Test (MRT) comprises 24 items, six items on each page in the test booklet. Each item consists of a series of five-line drawings, including a geometric target figure on the far left. In each item, there were only two identical figures to the target figure and two wrong distraction figures. In this test, participants were shown a drawing of a cubic figure and had to decide which two figures were rotated versions of the target figure. The questionnaire was divided into two parts, each containing 12 questions. Participants were given 3 min to complete each part. The answer was only considered correct if both the figures were identified. The score was the number of items answered correctly and ranged from zero to 24.

The third test is the revised “Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT: R)” (Yoon, 2011) for measuring the 3D ability of children aged 13 years and older to mentally rotate in 20 minutes. The task of the participant at each level is to mentally rotate the figure in the direction shown in the instructions and select the correct figure from five available options. The score is achieved by giving one point for the correct object.

To investigate the potential relationship between independent variables, namely students’ spatial ability, and dependent variables such as conceptual understanding in astronomy, statistical tests of mean, standard deviation, independent t-test and correlation were computed. To answer the first research question, namely the relation between spatial ability and conceptual understanding in astronomy the researcher employed Pearson correlational analysis. To answer the second research question, independent t-test was used to study the effect of gender on conceptual understanding in astronomy and spatial ability.

6. Findings

Preliminary analysis was initially conducted in the form of an analysis of missing data to explore systematic errors in the data. Normality tests such as Shapiro Wilk had been employed to confirm if the data obtained were normally distributed. It was found that the data had been significantly normally distributed. Descriptive statistics for all variables have been presented in the following table:

Table 2: Descriptive Statistics for Variables

Measure	**Gender**	**N**	**Min**	**Max**	**M**	**SD**
Spatial Perception	Boys	18	9	24	17.33	5.11
	Girls	18	10	24	16.67	4.31
Mental Rotation	Boys	18	7	21	15.06	4.29
	Girls	18	7	19	14.22	3.38
Spatial Visualization	Boys	18	7	25	18.38	6.16
	Girls	18	8	24	17.66	4.56
Spatial Ability	Boys	18	24	70	50.78	14.87
	Girls	18	25	61	48.56	10.83
Conceptual Understanding In Astronomy	Boys	18	37	73	56.22	9.92
	Girls	18	40	63	52.22	5.85

The table above depicts the descriptive statistics of independent and dependent variables. It is seen from the mean scores of all three skills of spatial ability namely, mental rotation, spatial orientation and spatial visualization, boys have performed slightly better than the girls. Thus, in this study boys' performance was better compared to girls in all the three tasks of spatial ability. Concerning the conceptual understanding in astronomy boys mean scores is higher than girls, implying that boys have a better astronomy conceptual understanding than girls.

6.1 Correlation between Spatial Ability and Conceptual Understanding in Astronomy

Spatial ability is an important cognitive ability to understand the various concepts in elementary astronomy. To assess the relationship between children's conceptual understanding of astronomy and spatial ability the following hypothesis was framed.

H1: There exists a significant correlation between spatial ability and conceptual understanding of astronomy.

To test the statistical testing, this research hypothesis was translated into the null form. The table below gives the results of the Pearson product-moment correlation.

Table 3: Correlation between Spatial Ability and Conceptual Understanding in Astronomy

Variable		**Spatial Ability**	**Conceptual Understanding in Astronomy**
Spatial Ability	Pearson Correlation	1	.693**
	Sig. (2-tailed)		.000
	N	36	36
Conceptual Understanding in Astronomy	Pearson Correlation	.693**	1
	Sig. (2-tailed)	.000	
	N	36	36

** Correlation is significant at the 0.01 level (2-tailed)

As shown in Table 3, the correlation coefficient (r) equals .693 and the *p*-value is .000, which is less than .01. Thus, the null hypothesis is rejected. It is observed that there exists a significantly high positive correlation between spatial ability and conceptual understanding in astronomy ($r = .693$, $p < .01$).

6.2 Correlation between Skills of Spatial Orientation, Mental Rotation, Spatial Visualization, and Conceptual Understanding in Astronomy

Spatial ability comprises many skills which are needed for better conceptual understanding of various astronomical phenomena. To test if there exists any correlation between these three measures of spatial ability (spatial orientation, mental rotation, and spatial visualization) and astronomy conceptual understanding the following hypothesis was framed.

H2: There exists a significant correlation between spatial skill of spatial orientation, mental rotation, spatial visualization and conceptual understanding of astronomy.

Table 4: Correlation between Skills of Spatial Orientation, Mental Rotation, Spatial Visualization, and Conceptual Understanding in Astronomy

Variable		**Spatial Orientation**	**Mental Rotation**	**Spatial Visualization**	**Conceptual Understanding in Astronomy**
Spatial Orientation	Pearson Correlation	1	.743**	.822**	.583**
	Sig. (2-tailed)		.000	.000	.000
	N	36	36	36	36
Mental Rotation	Pearson Correlation	.743**	1	.795**	.738**
	Sig.(2-tailed)	.000		.000	.000
	N	36	36	36	36
Spatial Visualization	Pearson Correlation	.822**	.795**	1	.629**
	Sig.(2-tailed)	.000	.000		.000
	N	36	36	36	36
Conceptual Understanding in Astronomy	Pearson Correlation	.583**	.738**	.629**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	36	36	36	36

** Correlation is significant at the 0.01 level (2-tailed)

The results of the correlation between the measures of spatial ability are represented in Table 4. As can be seen, spatial skills such as mental rotation, spatial orientation and spatial visualization have made a significant correlation with astronomy conceptual understanding. From Table 3, it is observed that there exists a significant moderate correlation between spatial orientation and conceptual understanding in astronomy (r = .583, *p* <.01). Similarly, for mental rotation and astronomy conceptual understanding the value of r = .738 and p = .000, which is less than .01 (r= .738, p<.01) and for spatial visualization the value of r is .629 and p is less than .01 (r= .629, p<.01). Therefore, the null hypothesis is rejected, and we concluded that there exists a significantly high correlation between the different subskills or measures of spatial ability (spatial orientation, mental rotation, and spatial visualization) and conceptual understanding in astronomy.

6.3 Gender Differences in Spatial Ability

All the learners are unique and have specific abilities to understand and comprehend what is taught. Learners who are good in their spatial abilities understand the concepts of astronomy in a better way. It is evident from previous research studies that males perform better than females in spatial ability tasks. To test this assumption following hypothesis was framed and independent t-test was computed to examine whether gender has any influence on spatial ability.

H3: There is a statistically significant difference in the mean scores of boys and girls in spatial ability.

The above hypothesis was translated into a null form for statistical testing. The result of an independent t-test is given in Table 5.

Table 5: Gender Differences in Spatial Ability

Variable	Gender	Mean	Standard Deviation	SE Difference between Means	df	t-value	p-value
Spatial Ability	Boys	50.78	14.87	4.33	34	.512	.215
	Girls	48.56	10.83				

From Table 5, it can be observed that the p-value is .215 which is greater than the chosen level of significance i.e. 0.05. This means that the mean scores between the two groups are not significant and the null hypothesis is accepted at 5% significance level. Therefore, we can conclude that there exists no significant difference in the mean scores of boys (M = 560.78, SD = 14.87) and girls (M = 48.56, SD = 10.83) spatial ability; t (34) = .512, *p* >.05. This result suggests that gender does not have any effect on learners' conceptual understanding in astronomy.

6.4 Gender Differences in Conceptual Understanding in Astronomy

Concerning gender differences in astronomy conceptual understanding, previous studies had reported that boys demonstrate better understanding than girls. To test this assumption, the following hypothesis was formulated, and t-test was computed to assess whether gender has any influence on conceptual understanding in astronomy.

H4: There is a significant difference in the mean scores of boys' and girls' conceptual understanding in astronomy. (H0: μ boys = μ girls).

Table 6: Gender Differences in Conceptual Understanding in Astronomy

Variable	Gender	Mean	Standard Deviation	SE Difference between Means	df	t-value	p-value
Conceptual Understanding in Astronomy	Boys	56.22	9.92	2.717	34	1.47	.058
	Girls	53.22	5.85				

From Table 6, it can be observed that the p-value is .058 which is slightly greater than the chosen significance level $\alpha = 0.05$ which means that the mean scores between the two groups are not significant. Therefore, the null hypothesis is accepted at 5% significance level and the difference between two means is not statistically significant (Boys : M =

56.22, SD = 9.92) (Girls: M = 53.22, SD = 5.85) conceptual understanding in astronomy; t (34) = 1.47, $p > .05$. Hence, it is concluded that gender does not have any effect on learners' conceptual understanding in astronomy.

7. Discussion and Conclusion

As stated earlier, a few studies have shown that spatial ability is a factor influencing the knowledge of astronomy. Using correlation analysis, the researcher found a significant correlation between spatial ability and conceptual understanding in astronomy. The results of the current study emphasized that spatial ability was another important cognitive ability needed for better conceptual understanding in astronomy. The results also underscore the importance of students' spatial abilities in determining the extent of conceptual understanding in astronomy. Such outcomes are informative to help develop effective teaching-learning resources and intervention strategies that can help reduce or even eliminate later difficulties in teaching and learning astronomy.

For a better understanding of astronomical concepts and events such as moon phases, eclipses, day and night cycles, rotation/revolution, etc. learners should have well developed spatial abilities. It is easier for high spatial learners to view, imagine and visualize objects that are not seen and understand abstract concepts (Chan Lin, 2000). However, learners with less spatial ability require many other cognitive functions, skills and additional knowledge to perform the same. The findings of this study suggest an opportunity to enhance the knowledge and conceptual understanding of astronomy by developing suitable curriculum and intervention strategies that rely heavily on spatial aspects of concepts. The practices to develop this ability are not much part of this school curriculum. In particular, school-based curriculum intends to enhance linguistic skills and competence; however, space-based activities do not exist. As a consequence, students face challenges in subjects that demand high spatial skills, such as astronomy, physics and mathematics (Black, 2005). Therefore, this aspect should be considered in teaching-learning of science especially astronomy, and suitable strategies should be used which would help both students with high and low spatial abilities.

It is clear that if we understood better how and which curricula and teaching environments affect students ' comprehension of science and astronomical content and processes, we might deliver more focused approaches that promote spatial and analytical thinking and eventually contribute to the successful preparation of all STEM students (Wilhelm, Toland & Cole, 2017).

Previous research has shown that the largest and most stable variations in gender are found in spatial ability (Halpern, 2011). The results of this study are inconsistent with the previous findings. Hoffman, Gneezy, & List (2011) stated that the "*gender gap could be the result of nurture rather than nature.*" Such a gender gap in spatial capacity did not exist in their study conducted in a remote community in India where women have equal rights or more than men. The findings of this study show that "*nurture plays an important role in the gender gap in spatial abilities*" (pg. 14788). Our results also suggest that providing equal educational opportunities for girls will reduce the gender difference. Many of the participants of this study had completed the PSVT: R before the given time (20 min) expired. This could have reduced the ability of the test to assess the skill of participants to mentally rotate objects quickly and accurately in a Gestalt-holistic form than analytically. This time frame may also have given enough time to the girls in our study who prefer to use analytical strategies to carry out the test well. The study results showed a non-significant male gain in PSVT: R refutes much of the findings that men have a substantial advantage in all mental rotation studies. While gender differences are widely recognized in spatial abilities, some researchers have argued that gender-specific differences have vanished over time due to social changes in attitudes and gender roles. Previous gender-specific differences in spatial ability, measured by mental rotational tasks, have significantly decreased due to the exposure of computer and video games.

These findings also underline the need for educators to be mindful of the students who lack spatial skills and to schedule lessons that consider both the content knowledge and spatial thinking in the discipline in which all students have the opportunity to learn astronomy successfully. Spatial thinking should be taught to learners as early to minimize gender-specific differences and to provide learners with the same opportunities to improve their spatial cognition needed to excel in science disciplines.

Due to the importance of spatial skills in many scientific fields and the current finding that supports the influence of spatial skills on the conceptual understanding of astronomy, we recommend putting more emphasis on promoting spatial skills within the curriculum. The training should include the improvement of processing strategies for visual stimuli using computer technology (simulations and augmented reality) and targeted teaching approaches. Previous research finding has suggested the use of computer modeling, a 3D object imagining and mental manipulation, gestures (Padalkar & Ramdas, 2011), using spatial language, drawing 3D objects (Halpern et al., 2007) and kinaesthetic techniques to advance the spatial ability of the learners. Educators should be conscious of the significance of spatial ability in teaching-learning astronomy besides using the best practices to overcome the difficulties in teaching the spatial content. They should also integrate both "domain-general" and "domain-specific" spatial tasks that are significant to the understanding of astronomical concepts. While many cognitive factors are correlated with understanding the concepts of Earth science and astronomy, it is important not to neglect the role of spatial ability indicated by these findings.

Conflict of Interest Statement

The authors have no conflicts of interest to declare. We have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is our original work and is not under review at any other publication.

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