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SPATIAL ABILITY AND SCIENCE EDUCATION: A REVIEW OF CORRELATIONAL STUDIES

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Abstract:
Out of the four approaches in researches on spatial thinking in undergraduate science curricula, viz. correlation studies, studies on training of spatial ability, focused studies and dynamic spatial representations studies; this paper reviews the correlational studies of spatial ability and science education. Spatial ability plays vital roles in participation and success of an individual in science. Researchers have found positive correlations ranging from 0.1 – 0.6 among spatial abilities and performance in different branches of science.

Keywords: spatial ability and science education, correlational studies

1. Introduction

Visuospatial thinking is vital and plays a central role in various scientific field, including applied sciences. For instance, in physics, one studies about motion of object through space. Similar, in chemistry, one seeks a relationship between chemical reactivity and molecular structure. On the other hand, geologists attempt to find reasons regarding earthly processes that bring about mountains and canyons. In order to represent the objects of a study in respective domains, theorists and scholars developed a range of spatial representation such as graphic diagrams, models, and among many others, maps.

The importance of spatial representations and thought process in sciences is highly emphasized. It is, therefore, not surprising to see spatial ability playing vital roles in participation and success of an individual in science. Longitudinal studies of intellectual talented students show that spatial ability account for a statically significant portion of differences in participation in science, above SAT verbal and mathematical scales (Webb, Lubinski, & Benbow, 2007; Shea, Lubinski, & Benbow, 2001;). Furthermore, an analysis of a longitudinal database consisting over 400,000 randomly

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selected students, indicated that individuals who received a degree in mathematics, physical science, and engineering along with who persuaded a scientific occupation had spatial ability at the age thirteen (Wai, Lubinski, & Benbow, 2009).

Spatial thinking in undergraduate science curricula can be classified under four types of approaches:

- *Correlation:* It examines the relationship between measurement of spatial ability and performance in science discipline.
- *Training:* This study tries to find out training aspect in spatial thinking ie how much spatial thinking can be developed/improved through training.
- *Focused studies:* It finds out the process through which students recognize precise spatial representations in science discipline.
- *Dynamic:* This involves those studies using dynamic spatial representations such as animations and visualization to endorse scientific construction.

2. Correlational Studies

Correlational studies study spatial abilities of students engaged in science class or laboratory work. It evaluates the correlation of these abilities with various aspects of achievements in the science classes. Presently, representative studies relating to correlation of abilities, in various subjects or fields are reviewed.

2.1 Biology

Correlational studies in biology subject tried to inspect the correlation of spatial ability with the ability of learning anatomical structure and imagining cross-sections of various organisms. Rochford (1985) observed the performance of some medical students in their practical exams and anatomy. He classified the test items of anatomy as spatial or non-spatial. It was found that spatial ability could not be predicted through those item which belonging to non-spatial category (correlation range: -.01 to 0.13), However, it could be predicted through items belonging to spatial category (correlation range: 0.14 to 0.39) and through performance in practical exams (correlation range: 0.13 to 0.47). It was also observed that anatomy students in the university succeeded in learning the structure of carpal bones either from key views or from multiple views of the anatomy. This feature could be predicted by spatial ability possessed by students (Garg, Norman, Sperotable, 2001; Garg, Norman, Spero, & Maheshwari, 1999).

Capability of drawing or identifying cross-sections of a 3D anatomical structure is correlated with spatial ability. Studying undergraduate students, Cohen & Hegarty (2007) found correlation between the ability of sketching cross-section of a 3D object with the mental rotation test ($r = 0.39$, $p < 0.05$) and ability to from perspective ($r = 0.59$, $p < 0.01$). Another study was conducted on students pursuing dentistry. It was noticed that spatial abilities of the students helped in predicting the accurate cross-section of both objects (correlation range: 0.37 to 0.52) and anatomical objects (e.g.: teeth, correlation range 0.29-0.37) (Hegarly, Keehner, Montello, & Khooshabeh, 2009). Spatial abilities also predict grades in practical classes of restorative dentistry. However, the same is not the case in anatomy classes.

2.2 Chemistry

The subject of chemistry specifically deals with spatial structure of molecules and their relations with reactive properties. Therefore, researchers have attempted to study the relationship of performance in chemistry in school and spatial ability. Bodner and McMillan (1986) uncovered significant correlations (0.29 to 0.35) of spatial visualization with the flexibility of the course. It also correlated with the performance in introducing organic chemistry courses. Late studies have indicated minute yet significant correlations (0.2 to 0.3) between spatial ability measures and college course performance in general chemistry (Carter, LaRussa, & Bodner, 1987) as well as organic chemistry (Pribyl & Bodner, 1987). Correlation could be observed in case where in students are required to manipulate any representation of molecules mentally and solve problems. This also includes problems, which are not of spatial nature, such as stoichiometry problems. It is important to note that spatial ability was not significant in correlations where in the item involved rote knowledge or applications of simple algorithms.

The significant difficulty for chemistry students was the ability to connect and translate between representations. Keig and Rubber (1993) researched the effects of knowledge of representation, and spatial ability and reasoning ability. The effects affected pre-college chemistry's tasks, such as: translate between formula, ball-stick models, and electronic configuration diagrams. It was observed that reasoning abilities and knowledge help predicting translation performance. However, if these factors are controlled it was found that spatial ability could not factor into predictive ability.

There is a significant effect of spatial ability (ranging r=0.32 to 0.38) on the ability to translate between different diagrammatize representations in organic chemistry (Stull, Hegarty, Dixon, & Stieff, 2010). The representations differ because of viewpoint from where a molecule is seen. These representations also use different diagrammatic convention. For example, to show third dimension and therefore translation between such representations may specifically require spatial transformation.

2.3 Geosciences

In case of geosciences, problems related to spatial thinking include understanding spatial structures and understanding internal features of structured from visible blocks. Emphasis is also made in understanding spatial processes, such as: plate tectonics and air mass circulation. Orion, Ben-Chaim, and Kali (1997) found significant correlation (r=0.35 to 0.51) between spatial visualization measures and performance in introductory classes of geology. Liben, Kastens, and Christensen (2009) also found correlation and concepts in geology. In water level task, individual is shown picture of bottle at different orientation. They are required to draw a line indicating orientation level of liquid in the bottle. Perhaps, it has been observed, that many adults faced difficulty in performing this task. Based on water level task they classified the participants into three categories: good, medium, and poor.

2.4 Physics

Physicists have found correlations between mechanical problem solving skill and spatial ability. For example, Kozhevnikov and Thornton (2006) found a correlation of .28 to .32 between spatial visualization ability and physics problem solving. It included relating motion and force along with graph interpretations of the same. In another study by Kozhevnikov, Hegarty, and Mayer (2002), conducted on a sample of psychology undergraduates, a correlation was found between spatial visualization and their performance on qualitative problem. This involved shifting the reference frame and extrapolation. Mental rotation speed remained uncorrelated in the same study. Lastly, a laboratory study with another sample of psychology students, researchers found correlation of spatial ability with the ability to understand motions of various machine parts (Hegarty & Sims, 1994). This is known as mental animation. Conversely, Issac and Just (1995) showed that students with poor spatial visualization ability fell prey to illusions of rolling motion.

3. Issues with Correlational Studies

Although reliable evidence is gathered through correlational studies for spatial skills in different domains of science, but it is necessary to view and interpret them critically. Firstly, large number studies conducted to this day consist of a small sample and studies a specific task. Secondly, the correlations of achievements in science with spatial ability are significant yet small. Furthermore, there are many other factors, apart from spatial ability that contribute to success in science. Thirdly, non-significant effects are not likely to be published, while which get published display exaggeratingly the relationship between performance and spatial ability. Fourth, general intelligence and spatial ability is correlated. Recent longitudinal studies argue against some issues in which there is a large sample with controlled mathematical and verbal ability, and studied valid measurements of achievements in science.

Possible differences in the spatial demands caused due to variances of different sciences have been largely untouched by research. Recent studies, in fact, inquired whether every science is equal in the demand of spatial ability. For example, Hegarty, Crookes, Dara-Abrams, and Shipley (2010) administered an online self-report measure to gather preliminary data from scientists, from different disciplines, for their spatial ability. With sample of 700 individuals, significant differences were found. For example, the highest self-report ratings belonged to geoscientists in both small-scale and environmental spatial abilities. On the contrary, geographers reported high self-ratings for environmental spatial ability while engineers had high small-scale spatial ability self-rating. Apart from these, the remaining did not significantly differ from one and other. Self-rating for verbal ability was found to be high amongst the humanities specialists. Lastly, correlational studies do not specify cause-effect relationship, i.e. good spatial abilities lead one to perform best at science, or vice versa.

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