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ACT and STEM in Education: A Huge Gap

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ABSTRACT

Spatial abilities have been shown to have significant input in nurturing Science, Technology, Engineering, and Mathematic expertise. However, little is done to systematically nurture STEM skills in education let alone investigate innovative approaches to help develop them in students. This paper utilized seminal work in the spatial abilities literature to investigate the extent to which ACT test scores for mathematics and science are used to recruit STEM students. The findings indicate that geometry-related items on the ACTs focus on static, two-dimensional space, recall, and interpretation of graphs. The tests highlight a big gap in nurturing and assessing the use of visual imagery in both mathematics and science. These findings underscore the need for including visual imagination skills in the school curriculum in general and in early childhood in particular.

Keywords: Spatial abilities, STEM education, ACTs, Mental Rotation

Introduction

STEM education has become the focus of this century. STEM fields are beginning to experience brain drainage because the majority of STEM experts are of retirement age and very few young people are joining the field. Attracting more students to the field has become a global challenge. The challenge has been created primarily by a marked decrease in the number of students who enroll in STEM subjects during high school education. Newcombe (2010) argues for spatial visualization as the key to nurturing more STEM experts. Newcombe buttresses her argument by referring to brain studies of scientists and argues that students with visual-spatial abilities stand a greater chance of becoming successful STEM experts. She also asserts that the majority of STEM fields require the use of visual-spatial abilities. In this paper, we focus on how ACTs are used to determine students' potential for joining STEM-related fields. More specifically, we look at whether students' visual-spatial reasoning is assessed during the process. In doing so, we analyzed the National ACTs of graduating high school students using criteria developed from the visual-spatial abilities literature.

Visual-spatial thinking refers to the internalization of a visual experience (Beaumont, 2013). Vision and imagery are the fundamentals of understanding visual-spatial thinking (Mathewson, 1999). Using eyes to recognize position, reason about objects, and familiarize ourselves with the world is defined as vision (Newcombe, 2010). Imagery is about forming images and then scrutinizing, transforming, and maintaining them in the "mind's eye" in the absence of a visual stimulus (James, 1984; Mathewson, 1999). In the mind, prior information is compared to the percolated image formed by the eye. Visual-spatial thinkers surpass others in using images and pictures, and in allocating their positions in space. Gardner (1993) and Delgado & Prieto (2004) support Newcombe's claim that spatial abilities influence scientific reasoning. This paper addresses the following question: What elements of ACTs, if any, assist in identifying students for STEM-related fields and degrees? Before answering this central question, we first provide a theoretical framework, review literature related to visual-spatial reasoning; visual, metaphoric, and thematic imagination; and describe the five tasks that are used to assess visual-spatial abilities. Now, we turn to a discussion of the theoretical framework of this paper.

Theoretical Framework

This paper is inspired by the research that identified spatial abilities as the talent needed for more students in STEM fields. Newcombe (2010) has argued for spatial abilities as the pillars behind scientific brains like Einstein, Watson, Cricks, and others. Her assertion stems from the scientific demands of spatial abilities in solving problems. For example, Watson and Cricks used a three-dimensional spatial model to reshape their existing flat images of molecules which resulted in their momentous discovery of the structure of DNA (Watson & Crick, 1953). Also, Wai, Lubiski, and Benbow (2009) discovered that 4 % of students who had the highest spatial ability in their adolescent years attained STEM degrees. Moreover, Towle et al. (2005) found a high correlation between self-efficacy and spatial ability among engineering students.

Literature on spatial abilities highly recommends schools foster visuospatial abilities in students (Web et al., 2007). This call builds on earlier ones. For example, Amheim (1969) suggested a systematic training of visual sensitivity for all preservice teachers. Despite these past and recent calls, teacher content knowledge about visual-spatial reasoning is minimal at best and nonexistent at worst. Mathewson (1999) reviewed studies related to the role of imagery and current knowledge of visual-spatial cognition. He found that teacher content knowledge of visual-spatial reasoning was non-existing at that time. Notwithstanding, Newcombe (2010) still calls for visual-spatial abilities to be regarded as an integral part of the curriculum and teaching practice. This paper is an effort to further raise awareness about the crucial role of visual-spatial reasoning in STEM-related fields by focusing on whether ACTs identify students with high visual-spatial abilities.

Visual-spatial Reasoning

In describing visual-spatial thinking, Wachs (2000) cautioned us against conflating looking with seeing, seeing with understanding. We look with our eyes but see with our brains. When we make sense of what we see, then it becomes a vision. However, seeing and understanding are not the same; seeing is not understanding. Wachs considers the sensorimotor stage of Piaget's theory as the foundation of visual intelligence.

> The determining factor for visual intelligence is not what passes through the eye but rather what a person can understand from a particular visual experience and eventually coordinate with other aspects of the body and sense thinking (p.519)"

Spatial ability, such as the ability to correctly visualize three-dimensional objects when they are represented in two dimensions, is an essential skill for science in general and engineers in particular (, Ramadas, 2009; Towle, et al., 2005). In Sword's (2005) words, visual-spatial thinking is mainly in pictures, sound relation with space, and map reading as well as exceptionally long-term memory. Furthermore, visual-spatial thinking is intricate, detailed, and inventive and information is processed instantly just by looking at the picture. Mathewson (1999) analyzed the importance of visual-spatial reasoning and encouraged mastery of images and visualization. In doing so, he elaborated three types of imagery: visual imagination, metaphoric imagination, and thematic imagination. Each of these types is further described next.

The Visual Imagination

"Visualization offers the method of seeing the unseen" (McCormick et al., 1987, p.3). McCormick meant that visualization goes beyond what the physical eye can see. Thus, visual imagery is an abstract process. Distance, size, and limitations of hardware bring to our attention challenges that the physical eye cannot see. Visual imagery comes in and makes use of mental tools to help us pierce through the unseen (Harris, Hirsh-Pasek, & Newcombe, 2013). Examples of such visual imagery include Faraday's visualization of "lines of force" surrounding changed objects and magnetic poles, as well as geoscientists' visualization of the processes that affect the formation of the earth. The ability to use prior experiences and knowledge to figure out the unseen is an important skill. Presmeg (1992) described visual imagery as “a mental construct depicting visual or spatial information” (p.596). The second type is referred to as metaphoric imagination which we turn to next.

The Metaphoric Imagination

> Metaphors allow us to see and feel things that are otherwise passed by unseen and unfelt and thus enrich our experience of the natural world. Through these metaphors, we ultimately become aware of meaning and structure in the intricate complexity of the surrounding world. (Ashkenazi, 2006, p.1)

Analogical reasoning is vital to expanding and using established and vigorous mental schemas (Marshall, 1995). Mathewson (1999) stated that mental comparisons of mental representation nurture higher-order and analogic thinking. For example, the particle model theory that gives the audience the visual picture of vibrating particles in low temperatures brings the unseen idea of particles into the visual world of vibration. With a thorough and deep understanding of the concept, visual models could be easily created.

The Thematic Imagination

The third and final type of imagination is known as thematic. The overarching ideas in the global world of science are the themes that have been developed historically and form the basis of explorations to put in missing pieces as well as extending or restructuring of these ideas (Robertson, Smeets, Lubinski, & Benbow, 2010; Mathewson, 1999). For example, the mathematical idea of the sum of the angles of a triangle which is 180 degrees has been globally used under Euclidean geometry. This theory was later challenged using spheres, and that theoretical research lead to the invention of spherical geometry versus plain geometry. Thus, each STEM subject has its own themes in different categories that form the foundation of each specific field. Dror et al. (1993) elaborated on five tasks that could be used in assessing visual-spatial abilities. The five tasks are mental rotation, motion extrapolation, mental scanning, spatial relations encoding, and recovering visual features. Each of these tasks is described next.

Mental Rotation

Mental rotation of an image is the ability to determine if the shapes or objects are alike, or a mirror image of a shape despite orientation (Dror et al., 1993). Shepard and Metzler (1971) provided a mental rotational task that describes the mental rotation activity. Figure 1 presents the two, 3-Dimensional figures which are matched under rotational transformation.

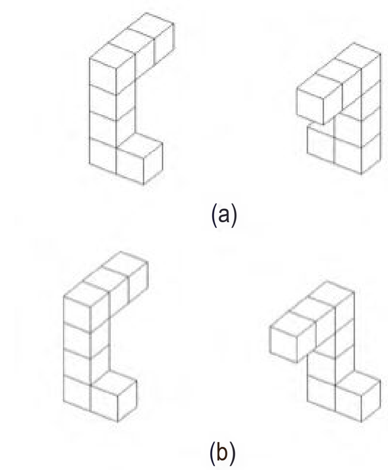

Figure I. (a) Matching and (b) mismatching (mirrorimage) pairs with a 180°rotation.

Motion Extrapolation

Motion Extrapolation is the second task that assists in conceptualizing visual special abilities and assesses the ability to interpret structural features in a scene for tracking and identifying objects moving within the scene. Dror et al. (1993) described it as the ability to track objects in motion in anticipation of their position when it is no longer visible.

Mental Scanning

The third task is image scanning in which the metric properties of mental spatial representation derived from visual experience are evaluated (Chabanne et al., 2004). Chabanne and colleagues stated that image scanning is a process that involves systematic shifting of one’s attention over an object or a scene” (p. 678). The spatial relations component constitutes the fourth task and is discussed next.

Spatial Relations Encoding

The fourth task deals with spatial relations encoding. Humans have two ways of demonstrating spatial relations encoding that originate from the dependency of visual perception on the dorsal and ventral systems of the brain (Jacobs and Kosslyn, 1994). The two systems are in separate places of the brain. The dorsal system preserves location information while the ventral system ignores it. The ventral system of the brain focuses on *categorical spatial relations* like "above, below, left, right and on, off" (Jacob and Kossylin, 1994, p. 362). That is, its role is to assign a relation between two objects to a spatial category (Dror et al., 1993). On the other hand, the dorsal system of the brain focuses on the location, coordination, and representation of information. These representations give specific detail on the metric distance among objects (Jacob and Kossylin, 1994; Dror et al., 1993). The fifth and final task assessing visual-spatial abilities deals with recovering visual features to which we turn next.

Recovering Visual Features

The fifth and final task deals with the ability to observe the ambiguous, hidden image and to convert it into explicit and clear information of the exact image (Dror et al., 1993 and Ohtsuka et al., 1999). Dror et al. (1993) stated that "one often sees objects when they are partially occluded or covered by various kinds of visual noise. For example, an object that might be partially behind a bush, or off in the distance on a foggy day, and so on" (p. 70).

These five tasks are the primary portion of the literature on visual-spatial tasks that we used to determine spatial skills that are essential for STEM-related fields. More specifically, the visual-spatial items included in the ACT test will be examined to see if any of the five tasks are included. Spatial tasks in Mathematics ACT tests and Science tests are evaluated using the table below which was developed by Dror et al. (1993) and Jacob and Kosslyn (1994). Table 1 represents the table used for the analysis of the ACT items.

Table 1

Visual-spatial tasks in ACT tests

	TASK 1	TASK 2	TASK 3	TASK 4	TASK 5
	Mental Rotation Image rotational task.	Motion Extrapolation	Scanning Images	Spatial relations Encoding	Recovering Visual Features
ACT: Science					
ACT: Mathematics					

As Table 1 shows, the five assessment tasks were not represented in any way in the ACT science and mathematics tests. This is reflective of the existing literature which gives more attention to spatial items in mathematics that pertain to thematic imagination. Most items on the ACT focus on mastery of theorems and formulae for problem-solving. There were no opportunities for visual imagination, manipulation, and reasoning. Most items on the geometry section of the ACT deal with the static, two-dimensional space and as such do not demand any use of visual imagination.

Science reasoning tests from the ACT did not include visual imagination and instead focused on the recall of ideas covered in physics and the interpretation of graphs. Both mathematics and science reasoning tests items on the ACT did not assess students' visual-spatial abilities.

Conclusion

This paper supports the existing literature related to assessments used in identifying students for STEM fields. Newcombe's (2010) concern of the possibilities of leaving behind able students in the STEM fields is confirmed (Web et al., 2007). Literature on visual-spatial skills as pillars for STEM fields has proven that these skills develop with training. However, the ACT tests which lack visual-spatial items also indicate a lack of training of these needed skills, hence they are not tested. This paper advocates the training of visual-spatial abilities as early as possible in schools. Moreover, the paper highlights deficits in the curriculum that address visual-spatial skills and recommends that policymakers and curriculum designers pay attention to this critical area and do their best to integrate visual-spatial skills in schools beginning at the preschool level.

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