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How to cite this manuscript

If you make reference to this version of the manuscript, use the following information:

Andersen, L. (2014). Visual-Spatial Ability: Important in STEM, Ignored in Gifted Education.

Published Version Information

Citation: Andersen, L. (2014). Visual-Spatial Ability: Important in STEM, Ignored in Gifted Education. *Roeper Review*, 36(2), 114-121.

Digital Object Identifier (DOI): 10.1080/02783193.2014.884198

Publisher's Link:

<http://www.tandfonline.com/doi/full/10.1080/02783193.2014.884198#.U4hxYx1dXU8>

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Visual-Spatial Ability: Important in STEM, Ignored in Gifted Education

Visual-spatial ability is a multifaceted component of intelligence that has predictive validity for future achievement in STEM occupations. Although identification and development of STEM talent is a national priority, visual-spatial ability is rarely measured and relatively neglected in gifted education. Quantitative and verbal reasoning abilities are favored over non-verbal abilities in talent searches and gifted programs, which causes some high-spatial, gifted students to be overlooked. Creative production in STEM requires visual-spatial ability and this ability must be developed in gifted education. Theories of intelligence and testing have advanced to provide methods for identification of specific cognitive abilities, such as visual-spatial ability. However, for these students to be successful in gifted programs, gifted education services must be modified to accommodate gifted spatial learners and develop spatial talents.

Keywords: cognitive abilities; creative production; gifted education reform; identification of giftedness; intelligence testing; science education; STEM talent development; visual-spatial ability

Interest in the prediction of future accomplishments based on ability assessments has existed for over a century. Historically, visual-spatial ability has been used to determine one's suitability for skilled work, such as technician or mechanic (Eliot & Macfarlane Smith, 1983) while one's suitability for a position that requires a college degree, such as scientist or engineer, has been determined by assessments of quantitative and verbal abilities. However, recent research provides empirical support for the importance of visual-spatial ability in creative productivity in the science, technology, engineering, and mathematics (STEM) domains and in scientific theory development (Trickett & Trafton, 2007; Wai, Lubinski, & Benbow, 2009). Moreover, identification and development of STEM talent has become a national priority (National Science Board, 2010) and research supports that spatial ability is a predictor of success in these fields (Lubinski, 2010). Nevertheless, this ability is rarely measured and is relatively

neglected in the general practice of teaching and learning in the K-12 setting as well as in gifted programs. Talent searches and gifted programs have historically failed to serve students who have high-spatial ability but relatively lower math and verbal ability, resulting in underachievement and underemployment of these talented individuals (Gohm, Humphreys, & Yao, 1998; Mann, 2005). The neglect of spatial abilities in identification procedures for gifted programs, talent development programs, and admissions criteria for university programs is a contributing factor in the national shortage of domestically produced scientists and engineers.

What is Visual-Spatial Ability?

Empirical and theoretical knowledge of visual-spatial ability has progressed considerably over the past three decades. Lohman (1994) defined visual-spatial ability as “the ability to generate, retain, retrieve, and transform well-structured visual images” (p. 254). Lohman’s early work identified several distinct factors within the visual-spatial ability construct. Recently, the work of the contemporary intelligence theorists has been integrated to create a unified model of intelligence, Cattell-Horn-Carroll (CHC) theory (McGrew, 2005). In CHC theory, visual-spatial ability is one of several independent factors that comprise general intelligence. Two of the abilities within this factor are of particular importance to STEM: *visualization* and *imagery* (Trickett & Trafton, 2007). First, visualization is defined as “the ability to apprehend a spatial form, object, or scene and match it with another object, form, or scene with the requirement to rotate it (one or more times) in two or three dimensions” (McGrew, 2005, p. 152). A key component of visualization is three-dimensional mental rotation. Second, imagery is defined as the “ability to mentally encode and/or manipulate an object, idea, event, or impression in the form of an abstract spatial form” (McGrew, 2005, p. 153).

Visualization and imagery are two abilities within the CHC intelligence factor called Visual-Spatial abilities (Gv). In this paper, the terms visualization and imagery will be used as distinct terms, according to the above definitions.

Visual-spatial ability in science. A student who has superior visual-spatial ability is able to create mental representations of complex ideas and then mentally manipulate those representations, which is a skill that is needed for creative productivity and theory development in the STEM domains (Trickett & Trafton, 2007). For example, imagery abilities are used when a scientific theory that is initially presented in words or as an equation is mentally transformed into an abstract spatial representation, such as a graph or model. The process of scientific investigation often involves reconciling a theory-based spatial model with a competing data-based spatial model. Trafton, Trickett, and Mintz (2005) observed that scientists often use visualization to mentally manipulate models and modify theories when confronted with disconfirming data. Therefore, the visualization and imagery components of visual-spatial ability are necessary when theories or models are developed through scientific investigation. Personal visual-spatial abilities are likely to have been considered by students who have chosen STEM careers. Indeed, students who have superior visual-spatial abilities become engineers or physical scientists at much higher rates than those with who do not have such abilities (Wai et al., 2009). The importance of visualization and imagery in the process of doing science points to a need to identify and develop visual-spatial abilities in students who may become future scientists.

Visual-spatial ability and gifted education. Visual-spatial ability is important for STEM, however, many popular assessments do not measure it. The most common ability assessments measure fluid intelligence (Gf) in the verbal, non-verbal (figural), and quantitative domains (Lohman, Gambrell, & Lakin, 2008). Generally, students who

have high visual-spatial ability also have strong abilities to reason figurally, and this is one reason for the common variance between Gf and Gv. If a student who has superior visual-spatial ability also has superior verbal and quantitative abilities, this student is very likely to be identified as gifted and gain access to talent development services.

However, many gifted children do not have uniformly high abilities across all cognitive domains (Lohman et al., 2008). It is much more likely to observe unevenness in ability profiles, and students who have superior visual-spatial abilities may present this ability in combination with relative deficits in verbal and quantitative reasoning abilities. A student with such a profile is not likely to be identified as gifted and is more likely to underachieve (Gohm et al., 1998).

Implications for gifted program identification models. How can spatial ability be identified? Ability profiling using intelligence test subscale scores (WISC and block design subscale) has been recommended by some researchers (eg. Silverman, 2002). However, this method is unreliable because of individual subscale score reliability issues (McCoach, Kehle, Bray, & Siegle, 2001). Considering the potentially depressed full-scale IQ scores of high-spatial children obtained from traditional IQ tests, assessments of spatial ability could provide improved identification of students with high-spatial intelligence for gifted programs. Certain components of visual-spatial ability are measurable using modern intelligence batteries. The recent development of a uniform cross-battery approach allows school psychologists to select the subtests from these batteries that can provide reliable measures of visual-spatial abilities that can help in the identification of spatially gifted students (Flanagan, Alfonso, & Ortiz, 2012).

Comparison of spatial tests and nonverbal tests. The use of nonverbal measures of intelligence may facilitate greater identification of high-spatial students with verbal deficits because these tests measure intellectual ability independently of verbal ability

(Bracken & McCallum, 1998), however, a nonverbal intelligence test is not a spatial ability test. Some nonverbal tasks may test spatial ability, but most nonverbal tasks test fluid intelligence rather than visual-spatial ability. For example, nonverbal tasks ask students to make inferences, deductions and extrapolations from figural stimuli, whereas spatial tasks involve the ability to maintain and manipulate two- or three- dimensional images. In other words, nonverbal tasks are designed to assess reasoning abilities (fluid intelligence or Gf), whereas spatial ability tasks are designed to assess orientation, visualization, and rotation abilities (visual-spatial ability or Gv). Thus, spatial ability tasks are qualitatively different than nonverbal intelligence tasks because they are designed to measure separate, independent constructs.

The Naglieri Nonverbal Achievement Test (NNAT; Naglieri, 1997) and the Universal Nonverbal Intelligence Test (UNIT; Bracken & McCallum, 1998) are examples of nonverbal intelligence tests that are commonly used with children. The Differential Aptitude Test (DAT; Bennett, Seashore, & Wesman, 1974) is an example of a spatial ability test that can be used as early as eighth grade. Eliot and Macfarlane-Smith (1983) cite the removal of all verbal instruction from the timed portion of the test (to ensure that verbal ability issues do not confound the measurement of spatial ability) and ensuring that the items cannot be solved using verbal reasoning as difficulties in the design of valid assessments of spatial ability. The NNAT and UNIT do not contain verbal instructions, however, these tests do not attempt to assess all spatial intelligence factors. The UNIT has six subscales and three of these are related to spatial ability: cube design, spatial memory, and mazes (Bracken & McCallum, 1998). The UNIT may be useful for identifying children with high-spatial ability.

Relationship between nonverbal intelligence measures and academic performance. Lohman (2005) warned against using nonverbal intelligence measures as

selection criteria for gifted programs because verbal/quantitative scores are much better predictors of academic success in a challenging program. However, this predictive ability is related to the compatibility of the verbal nature of instruction in typical K-12 schools with the ability profile of the child. For a high-spatial, low-verbal student, a weaker ability to reason in the verbal symbol system (words) interferes with achievement. In other words, the incompatibility of the symbol system used in traditional school creates learning difficulties for high-spatial, low-verbal students whose reasoning abilities are more effective in the visual-spatial symbol system (Lohman & Lakin, 2009). These difficulties indicate a problem with the delivery of gifted education services that should be addressed through changes in pedagogy. Moreover, effective strategies exist to teach children with the high-spatial, low-verbal profile in gifted programs (Mann, 2006). These children, who possess exceptional reasoning abilities in the non-verbal domain, are as equally deserving of services to develop their talents as other children. Therefore, teachers should be trained in the use of strategies that allow such students to process content through non-verbal modalities.

Potential vs. prior achievement. When considering young children for talent development programs, attention should be focused on potential, rather than prior achievement, to prevent underidentification of children from impoverished backgrounds. Verbal and quantitative ability measures are more dependent on existing knowledge than non-verbal measures, thus these are measures of prior learning (Naglieri, 2001). Therefore, verbal and quantitative ability measures are more like achievement tests than intelligence tests. Naglieri (2001) stated that cognitive ability measures predict achievement if *appropriate instruction* occurs; his analysis of correlations between different intelligence measures and achievement revealed superior correlations between the Differential Ability Scales (DAS) or Cognitive Assessment

System (CAS) and achievement compared to the WISC-III. The DAS and CAS do not have items that are as highly reliant on prior knowledge of arithmetic or vocabulary as the items on the WISC III (Naglieri, 2001). Students who have relative strengths in spatial ability and weaknesses in verbal ability tend to perform better on tests such as the DAS and CAS. The results obtained by Naglieri (2001) show that students with lower language ability, such as high-spatial, low-verbal children are capable of the same levels of academic success as high-verbal children if the instructional context is appropriate for their cognitive ability profile.

Mismatch between cognitive ability and curriculum. The failure of nonverbal intelligence scores to correlate to academic success is more indicative of a mismatch between the cognitive ability of the learner and the teaching strategies or content in school curricula than of differences in intellectual ability. If this mismatch causes a degree of dysfunction in the school environment that prevents academic success, then it may be that high-nonverbal intelligence constitutes a learning disability in the context of traditional education. By federal law, students with learning disabilities are entitled to receive services that accommodate these individual differences; this entitlement implies that changes to pedagogy should be made to accommodate these students. Lohman (2005) argues that selecting students based on nonverbal intelligence test scores would exclude most of the students who would receive the greatest benefit from gifted services. This logic assumes that available space constrains the number of students that can be selected to receive gifted services, and that gifted services are designed solely for students with superior verbal skills. This reasoning is flawed because every student is entitled to a free and appropriate public education that should include gifted programming for students who are intellectually gifted, defined as possessing “an outstanding ability to grapple with complexity” (McCoach et al., 2001, p. 404).

Descriptions of the high-spatial child support spatial ability as representative of this definition of intellectual giftedness (Dixon, 1983; Silverman, 2002). Therefore, gifted services must be adapted to meet the needs of high-spatial learners through a curriculum that emphasizes visual-spatial reasoning and includes appropriate scaffolds to facilitate students' full participation in gifted education programs.

Visual-spatial ability and verbal weakness. Concomitant strengths in visual-spatial ability and weaknesses in verbal ability are barriers to talent development because of incompatibilities between symbol systems and reasoning abilities. Students who have strong abilities to reason in visual-spatial symbol systems but relatively weak abilities to reason in words (the verbal symbol system) are disadvantaged in a school where the verbal symbol system is used almost exclusively. In CHC theory, verbal ability is part of the general verbal-crystallized intelligence factor (Gc), and is independent of Gv. Visual-spatial ability represents a person's ability to create and manipulate images, while verbal ability represents the ability to reason using words (Lohman & Lakin, 2009). Thus, verbal and visual-spatial ability are distinct and separate components of intelligence (Lohman, 1994) and students who are have lower verbal ability and high spatial ability may have difficulties in language-heavy gifted programs.

Incompatibility of visual-spatial and verbal systems. In the spatial ability literature there are two different explanations for the academic difficulties of high-spatial students. First, Silverman (2002) contrasted the learning styles of visual-spatial learners and verbal-sequential learners. Students who are gifted in the visual-spatial realms are those who learn holistically through observation, think in images, and take more time to put thoughts into words. Verbal-sequential learners listen well, follow directions well, and learn in a step-by-step manner progressing from the simple to the

more complex. The child with visual-spatial strengths and verbal weaknesses has difficulty learning this way. High-spatial children tend to think visually and learn from whole to part. Unfortunately, typical school instruction is organized from part to whole, is transmitted largely by the spoken word, and is assessed based on students' written responses. Each of these norms place verbal-sequential learners in a position of relative advantage compared to visual-spatial learners.

On the other hand, Lohman and Lakin (2009) explained that the ability dimensions of fluid intelligence (Gf), verbal-crystallized intelligence (Gc), and general spatial-visualization (Gv) abilities commonly interact with instructional methods. In other words, when instructional methods emphasize a particular symbol system that is different than the symbol system that the student is able to fluently manipulate, that student will not perform as well as he or she would if the two symbol systems (instructional vs. student cognitive) were the same. Thus, the incompatibility of the visual-spatial and the verbal symbol and reasoning systems can create learning difficulties for many high-spatial ability students who have relative deficits in verbal skills. However, students with high-spatial ability typically demonstrate superior non-verbal reasoning skills. Nonetheless, Lohman (2005) recommended against identification of these students for gifted programs using non-verbal intelligence scores because although these students have high Gf, the reasoning that students must use to perform in gifted programs is in a symbol system (verbal) that precludes success for students with high non-verbal reasoning skills alone. However, actions based on this recommendation may result in the sacrifice of the potential STEM talent of high-spatial students who are denied gifted education services. Perhaps it would be better to change the modality of instruction to better meet the needs of the student than to sacrifice potential talent.

To maximize student potential, the talents in every student must be recognized and strategically developed. The National Association for Gifted Children (NAGC) standards state that teachers should “enable students to identify their preferred approaches to learning, accommodate these preferences, and expand them” (NAGC, 2010, p. 1). However, the predominant methods used in traditional gifted programs do not facilitate this for high-spatial students. Typical instruction tends to be entrenched in the verbal symbol system, therefore a high-spatial, low-verbal student cannot fully participate in such a program. When a high-spatial student’s learning strengths are not accommodated, long-term frustration can transform a bright, inquisitive child into an underachiever (Gohm et al., 1998). According to Dixon (1983), “the fact the average school has little understanding or appreciation for this type of child has got to be one of the greatest sources of wasted human talent in our society” (p. 73).

High-spatial, low-verbal, low-quantitative students who survive the verbal-sequential, secondary school gauntlet do not fare as well as students with high mathematical or verbal abilities in the college selection process because the admission selection criteria used in selective postsecondary programs discriminates against students with superior spatial abilities. Admissions criteria utilize the SAT or the ACT, neither of which includes a measure of visual-spatial ability. Recent research shows that the SAT and ACT are strongly correlated with general intelligence, but only through the fluid and verbal-crystallized intelligence factors (Gf and Gc; Frey & Detterman, 2005; Koenig, Frey, & Detterman, 2008). Thus, students who are high-spatial and low-verbal generally have lower SAT and ACT scores and are disadvantaged in the selection process.

Neglect of Spatial Ability

The neglect of spatial ability is linked to sociocultural perceptions. Historically, spatial strengths have been associated with industrial job performance and vocational-technical aptitude (Eliot & Macfarlane Smith, 1983; Lohman, 1994) while measures of mathematical and verbal abilities, have been associated with professional careers and attendance at prestigious universities. However, recent research supports superior spatial ability as a predictor of success in science, technology, engineering, and mathematics (STEM) fields, including the physical sciences and computer science (Harle & Towns, 2011; Liben, Kastens, & Christensen, 2011; Wai et al., 2009).

Interestingly, it appears that the potential predictive power of spatial ability is ignored by talent search organizations because of the prevailing perception of superiority that is associated with long-standing measures of academic potential (that do not assess spatial ability), such as the SAT (P. Olszewski-Kubilius, personal communication, March 1, 2011). The net effect of this neglect of spatial ability is that students with exceptional spatial strengths who have relatively lower verbal or mathematical abilities are not identified as gifted and do not receive gifted education services (Mann, 2005).

Potential of High-Spatial Students is Lost

A student with high-spatial abilities and lower mathematics or verbal abilities is not likely to reach his or her potential in the traditional school context, for several reasons. First, mathematical and verbal abilities have been the measures of choice to assess intelligence for decades and are widely recognized as predictive of academic success, while spatial ability has only recently been associated with academic success in STEM disciplines. Thus, spatial ability is not measured by many achievement tests, such as the SAT and ACT, and may go unrecognized. Second, cognitive ability profiles are not

uniformly high for most students and are the most uneven for high-ability students (Lohman, 2005; Lohman et al., 2008). Students with high-spatial ability often have relative deficits in verbal ability (Mann, 2006; Silverman, 2002) resulting in full-scale IQ measurements that are below cutoffs for gifted programs. Third, traditional school curricula favor the high-verbal learner and do not optimize learning experiences for the high-spatial learner. Fourth, the combination of verbal deficits and incompatible curricula lead to underachievement. Thus, many spatially talented students are not identified as gifted (Mann, 2005) and not achieving commensurate with individual intellectual ability (Gohm et al., 1998). As a nation, we are overlooking potential STEM talent because talent is identified based on verbal and mathematical abilities while spatial ability is ignored. Therefore, it is the position of this paper that spatial ability should be assessed, considered when selecting students for gifted programs and when differentiating instruction, and be acknowledged in curriculum designs that facilitate learning using students' preferred symbol systems.

Importance of Spatial Ability for STEM

Historically, spatial ability assessments have been used to predict: (1) job performance in industrial jobs such as engineering, science, drafting or designing; and (2) successful completion of vocational-technical training (Eliot & Macfarlane Smith, 1983).

However, spatial ability can be applied in more abstract ways, such as in creating and manipulating mental models to test scientific hypotheses (Trickett & Trafton, 2007).

These applications of spatial ability imply a fundamental connection between spatial ability and creativity (Lohman, 1994). Furthermore, visual images or mental models have given birth to many important scientific theories and discoveries. Anecdotal examples of visualization in scientific theory development are numerous (Shepard,

1988). For example, Shepard describes Einstein's famous thought experiments, such as visualizing what it would be like to ride a beam of light and other visual experiments. These visualizations enabled him to develop the theory of special relativity. Similarly, Friederich Kekulé was led to discover the ring structure of benzene by a vision of a snake seizing its own tail (Shepard, 1988). Examples of the importance of visualization to scientific theory development have also been found in recent studies. For example, contemporary, mixed-method studies of scientists engaged in data analysis and hypothesis testing revealed extensive use of visualization and imagery abilities to construct mental models and make complex comparisons of these internal models to external models (Trickett & Trafton, 2007; Trafton et al., 2005). Modern scientists need visual-spatial abilities to reconcile visual displays of real-world data with scientific models; data and models are transformed in their minds to find possible solutions. Thus, visual-spatial abilities are important for the STEM disciplines because many problems are solved through the creation of novel visualizations or mental model manipulation.

Critical Need to Identify STEM Talent

Science, technology, engineering, and mathematics (STEM) are critical to our economic security and continued world leadership in research and development (Adams et al., 2007). The world is increasingly dependent on eminent producers in the STEM disciplines to find solutions to critical global issues and to create the innovative technologies that have become an expectation of high-technology standards of living. A primary concern of gifted education is identifying the best methods to develop potential into eminence (Subotnik, Olszewski-Kubilius, & Worrell, 2011). Successful STEM talent development requires early identification of potential followed by strategic

programs that can develop potential into talent. Early STEM talent needs to be incubated in K-8 programs, actively cultivated in secondary schools, allowed to flourish in undergraduate programs, and groomed to eminence in postgraduate education. The need to identify and develop STEM talent in the US is well documented (National Science Board, 2010), and research has revealed commonalities in the talent development trajectories among people who have become creatively productive in STEM domains (Lubinski & Benbow, 2006; Wai, Lubinski, Benbow, & Steiger, 2010). However, new methods are needed to identify STEM potential in high-spatial, low-verbal students.

Identification of STEM Potential

How to best identify students with potential STEM talent remains an issue of debate. Over-reliance on traditional measures of verbal and mathematical ability, or full-scale IQ, results in underidentification of high-spatial, low-verbal students. Furthermore, the low ceiling of the SAT mathematics (SAT-M) test precludes discrimination among high levels of mathematics ability (Lubinski & Benbow, 2006). This inadequate ceiling of the SAT-M, combined with emphasis on verbal measures of ability dramatically decreases the probability of selecting high-spatial, high-math, low-verbal children for gifted programs and highly competitive undergraduate STEM programs. For example, examination of the top 1% of spatially gifted students in project TALENT showed that 70% of those students would not have been selected by talent search procedures that only consider mathematical and verbal ability in cutoff scores (Wai et al., 2009). Ironically, the high overall SAT scores required for admission into elite colleges may prevent students with high-spatial abilities from entering STEM programs and may preferentially select students (high-verbal, high-math, low-spatial)

who are less well suited for engineering. For example, at the University of California at Berkeley, the fact that 25% of students in their first engineering graphics course earned D's or F's was attributed to weak spatial ability (Hsi, Linn, & Bell, 1997). Furthermore, students with severely tilted profiles may have impairments in the verbal domain that hamper success in school (Gohm et al., 1998) and lead to underachievement. Therefore, the configuration of ability profiles in individuals may be more important than the individual values of each specific ability measure.

Ability constellations. Recent research on the ability profiles of participants in project TALENT has associated unique, domain-specific ability constellations of mathematical, spatial, verbal, and composite ability scores with specific academic domains (Wai et al., 2009; Webb, Lubinski, & Benbow, 2007). Longitudinal studies have supported the predictive validity of this constellation of abilities for completion of doctoral, master or bachelor degrees in STEM disciplines (Wai et al., 2009). The typical ability constellation for students who earn STEM degrees consists of a high SAT-M, a lower SAT-V, and a spatial ability score between the two; this constellation distinguished students who had earned degrees in mathematics, computer science, physical science, and engineering from students who had earned degrees in other disciplines. This ability pattern was consistent across STEM disciplines (mathematics, computer science, physical sciences and engineering) and degrees (bachelors, masters, doctorate). This finding invites further investigation into the use of ability constellations in matching students with careers that align with individual talents and interests (Wai et al., 2009).

Unmet Psychological Needs and Underachievement

Humphreys, Lubinski, and Yao (1993) found that high-spatial/mathematical students

tended to be disproportionately undereducated compared to their peers of similar general intellectual ability and disproportionately represented in careers that required only a high school diploma. In effect, the verbal-mathematical focus of traditional school is such a mismatch for the cognitive ability profiles of some high-spatial ability students that many of these students underachieve. The concomitant deficits in verbal fluency, spelling, and grammar that may be associated with high-spatial ability require accommodations in school. However, typical accommodations used with students who have verbal deficits may not be appropriate for the high-spatial child. In school, the high-spatial child may struggle with tasks that rely on rote memorization while excelling at activities that require higher order thinking and creative problem solving (Mann, 2006).

A teacher's response to the weaknesses of the high-spatial child is likely to be increases in time spent on remediation in areas of weakness, however, this approach is likely to have unintended effects. These effects can include the child reducing effort in school or disengaging from school (Silverman, 2002). A better approach is to allow students to express themselves and look for the quality of the thinking instead of focusing on the quality of the writing (Mann, 2006). In doing so, superior thinking abilities of high-spatial children can be recognized first, then assistance can be provided to improve writing skills. Overly harsh criticism of the form of writing and failure to recognize the quality of the content may cause the high-spatial child to lose the desire to express his or her thoughts in written form. These students thrive on hands-on activities and interdisciplinary approaches to learning. A high-spatial child needs opportunities during the school day to use her or his strengths as well as opportunities to develop in areas of weakness (Mann, 2006). Without recognition of the high-spatial child's intelligence, it is likely that these children will dislike school and avoid higher

education. It is important to help the high-spatial child maintain self-esteem and to recognize his or her own abilities as valuable. Instructional methods need to take the approach of building on strengths. For example, traditional methods for teaching reading, such as phonics-based instruction, do not work well with this population. However, alternative methods for teaching reading exist that work well with high-spatial children (Silverman, 2002). Working from strength and interest can help students stay motivated and engaged. Providing reading materials in areas of interest to the high-spatial child can motivate reading efforts. The high-spatial gifted child may have below average verbal ability, therefore teachers must look for indications of giftedness in all children, even those who may be below average in school subjects or have developmental delays in verbal abilities (Dixon, 1983).

Some of the most brilliant scientists have fit this profile of the high-spatial child. Both Albert Einstein and Isaac Newton struggled in school, but now these men are recognized as the two greatest minds in physics. Each of these men was able to achieve greatness because a mentor recognized superior spatial abilities that were masked by verbal deficits. For Einstein and Newton, individual strengths were developed and amazing talents were revealed. As educators, we need to value individual differences and look for each child's areas of highest ability to prevent wasting the great scientific minds of our future because of our ignorance and neglect of spatial abilities. Exceptional spatial ability is a valuable gift that needs to be opened via identification of potential and development of potential into talent.

The Future of Visual-Spatial Ability

The recent advent of technologies such as Geographic Information Systems (GIS) and other computer visualization tools has set the stage for an era of emphasis on spatio-

temporal thinking (Gould, 1999). *Spatio-temporal thinking* refers to the use of space and time considerations to solve problems. This mode of thinking can be applied to many disciplines. Before the computer age, spatio-temporal analyses were very difficult. A classic example is the method that John Snow used to determine the cause of the 1854 cholera outbreak in England. By mapping the locations of reported deaths, Snow tracked the source of the disease to a public water pump (National Research Council, 2006). For this work, Snow is considered the father of modern epidemiology. However, modern epidemiologists use technologies like GIS to easily create displays of spatio-temporal data instead of plotting by hand.

New computer tools, such as GIS, are ripe for exploitation by high-spatial thinkers. To effectively use these tools, scientists must be able to employ their own visualization and imagery abilities to mentally explore how data can be explained with scientific models, how theories can be modified to explain unexpected observations, or how to generate new theories based on relationships observed in spatial displays of data. Geographic information systems (GIS) are an analytic tool that must be operated by individuals who have expertise in spatial thinking. The National Research Council (2006) emphasized the importance of spatial thinking across all academic domains and in the K-12 setting. However, the typical school curriculum emphasizes verbal-sequential learning and does not develop spatial thinking. An increased emphasis on visual-spatial thinking is needed in gifted programs including opportunities for students to develop and apply visual-spatial abilities such as visualization and imagery.

The failure of the current education system to meet our nation's increasing need for individuals with STEM degrees in the workforce mandates new STEM talent development programs (Atkinson & Mayo, 2011). A key element of such talent development is the identification and development of visual-spatial abilities that are

important to these domains – visualization and imagery. Alternative measures are necessary to identify students with STEM potential and to increase the numbers of students who complete STEM degrees. The use of ability profiles is preferable to full-scale IQ measures to provide information about students' visual-spatial abilities. The problem of identification of STEM talent extends to higher education because admissions decisions to STEM programs based on SAT scores favor students with higher verbal ability over those with high-spatial ability, potentially selecting students who are less suited for STEM disciplines over those that are more suited. Identification models at all levels would benefit from the addition of assessments of spatial ability. Adding spatial ability to the array of available assessments would permit identification of students with high-spatial ability that are likely to be overlooked by existing identification models. Identification of high-spatial ability students is one crucial step toward increasing the number of STEM graduates. Improved identification will help educators and students to recognize the gift of spatial ability, but to open the gift will require a better understanding of the talent development trajectory for spatial ability and the provision of developmentally appropriate experiences to high-spatial learners in schools.

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