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Identifying and Supporting Spatial Intelligence in Young Children

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Teaching and research interests

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ABSTRACT

Intelligence is a concept related to behaviours that are valued in a social and cultural context. Since the establishment of formalised education for Westernised industrial society, education has focussed on the development of literacy and numeracy skills and has acknowledged those areas as important in formal education. Intelligence, hence, has been valued in those who are highly literate and numerate. However, a careful analysis of highly creative people in the area of mathematics and science, and recognition of the impact of technology in an Information Age suggests that other behaviours broadly identified as spatial intelligence are significant areas of human capability. Spatial intelligence has been highlighted in recent years though the work of Howard Gardner. However, interpretations of this work have tended to emphasise the role of spatial intelligence in artistic domains and ignored the seminal contribution that spatial intelligence plays in mathematical and scientific domains. The paper explores spatial intelligence in the sciences from a variety of perspectives including a neuropsychological perspective and uses Gardner's developmental trajectory of intelligence to explore how to facilitate the development of spatial intelligence. We challenge practitioners to examine their practices in educational settings and reflect on the extent to which they provide opportunities for children to demonstrate and develop their spatial intelligence.

Introduction

Over time, the concept of intelligence has changed to suit the needs of a society. In prehistoric times, intelligent humans might have been those who had the abilities to forage for food, to hunt or to predict natural events on the basis of star movements. Elders, themselves highly competent at these tasks, fostered these skills in the youth. In contemporary society, where globalisation and technology are changing the way we live, new perceptions of intelligence and new definitions of what is intelligence are important concerns for modern educators. Spatial intelligence represents a set of behaviours that have at different times been deemed important but have in contemporary education been neglected. Changes in society particularly related to computer technology - a visually oriented medium - have challenged us to revisit the significance of spatial intelligence. This paper highlights the significance of spatial intelligence especially in the domain of mathematics and science, which underpins technology. We explore the development of spatial intelligence through the framework of Gardner's (1997) developmental trajectory of intelligence and seek to challenge practitioners to focus on development of spatial intelligence as a valued and essential capability for the new millennium.

Intelligence

Intelligence has been a concept that thinkers have grappled with since Antiquity (e.g., Sternberg, 1990). Generally viewed, intelligence represents some cognitive attribute associated with the capability to learn. Intelligence enables people to operate on environmental cues to build understanding and respond to their situations. It is the power, speed and capacity to overcome ignorance and be "goal responsive" (Goldman, 1986). Formal testing to distinguish among people on the basis of some intellectual skill featured in both Western and Eastern traditions. For example, Civil service examinations prevailed in the Chinese empire for 3000 years (DuBois, 1966) and testing was endemic in Greek education. In the late 19th century and beginning of the 20th century, a tradition of identification of individual differences was initiated by Francis Galton in the United Kingdom and subsequently by James Cattell in the US (Anastasi, 1968). These people used a range of tests involving sensory discrimination, and reaction time as measures of intellectual function. Francis Binet, specifically to identify “subnormal” children for the French Ministry of Public Instruction, adopted tests of judgment, comprehension and reasoning as measures of intelligence with results expressed as mental age. Lewis Terman adapted Binet’s tests in the US and reported performance as a ratio of mental age and chronological age which was defined as an intelligence quota or IQ. Aptitude tests that measured a range of aptitudes as “factors” of a general intelligence were developed in the 1930s (e.g., Eliot, 1987). Thus, for much of the 20th century coincident with the expansion of formal education, intelligence was closely associated with measurement of general performance on formal school-related tasks. This tradition of viewing intelligence as a single entity has been challenged in more recent times.

Theory of Multiple Intelligences

Gardner’s theory of *Multiple Intelligences* has broadened our view of intelligence (1983, 1993a, 1993b, 1997). Gardner proposes that there are at least eight different and discrete facets of cognition, which can be regarded as relatively autonomous human intelligences. These intelligences are described as logical-mathematical, linguistic, musical, spatial, bodily-kinesthetic, interpersonal, intrapersonal and naturalistic. Gardner’s theory explains the diversity of profiles of intelligences within the normal population and the exaggerated cognitive profiles in the range of special populations, such as the gifted, prodigies, and idiot savants. The educational implications of Gardner’s theory are extensive and include appreciating and recognising the characteristics of the various intelligences, and nurturing the diversity of intelligences of children.

In contemporary society, technology has taken over many of the menial tasks that were valued in former times. Speed in mathematical computation, word processing, electronic communication, and the availability of information, all achieved through technology, have transformed society. The skills and attributes now valued are different from those that dominated previous eras, which compels us as educators to examine what we deem important in formal education. In a technologically oriented society, spatial intelligence is of particular importance.

Spatial Intelligence

Spatial intelligence, which also has been referred to as spatial ability, involves the manipulation of information presented in a visual, diagrammatic or symbolic form in contrast to verbal, language based modality (Lohman, Pellegrino, Alderton, & Regian, 1987). Spatial intelligence may manifest as a particular aptitude for thinking and communicating spatially. For example, Einstein (1949), the most renowned scientist of the 20th century highlighted his thinking processes in the following reflection:

> The words or the language, as they are written and spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be voluntarily reproduced or combined. The above mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously in a secondary stage, when the above mentioned associative play is sufficiently established and can be reproduced at will. (p. 147)

Spatial intelligence can be inferred from the ability to invoke and use particular representations and reasoning. In addition to imagery, as identified by Einstein, spatial representations include diagrams, drawings, maps, and models. Reasoning with spatial representations differs substantively from the sequential reasoning used with linguistic representations, such as text and involves cognitive interaction with spatial information to solve problems (Rogers, 1995). Spatial intelligence includes an ability to perceive and represent the visual-spatial world accurately and to form and manipulate mental images (Gardner, 1983). Although traditional IQ tests may be a valid measure of linguistic or logico-mathematical intelligence, they are not a valid measure of spatial intelligence. However, there are numerous tests of spatial intelligence that measure discrete components associated with spatial representation and spatial reasoning (Lohman, et al., 1987). These components include spatial perception, spatial visualisation and mental rotation.

Prior to Gardner's work, spatial intelligence was recognised and measured from factor analysis of performances on aptitude tests (McGee, 1979). Spatial ability was valued in careers involving the need to interpret spatial information. For example, for many years tests of spatial ability were used extensively to predict aptitude towards careers involving aviation, engineering or technical drawing. Spatial intelligence is also recognised among nomadic peoples (Hutchins, 1983; Kearins, 1986) and has been described as an important attribute among hunter-gatherers (Berry, 1976).

Neuropsychological evidence also highlights the significance of spatial intelligence. Luria (1973) demonstrated neurological associations between brain structures and information processing. In particular, he demonstrated that lesions to the left parietal-occipital region cause gross impairment of simultaneous (spatial) synthesis of information. In his terms, simultaneous processing is characterised by a facility towards the manipulation of spatial sensory data in contrast to successive synthesis, which involves the manipulation of information arranged sequentially. The capacity to process information simultaneously is correlated with measures of field independence and with a range of achievements in problem solving, mathematics achievement and reading comprehension (Das & Verhargen, 1986; Harris & Wachs, 1986; Watters & English, 1995; Woodley, 1993). Additionally, Languis and Miller (1992) have demonstrated that brain processing patterns as measured by electroencephalographic (EEG) techniques, correlate with performance in higher order cognitive tasks in a manner consistent with Luria's theory.

Spatial Intelligence and Mathematics and Science

In recent times, spatial intelligence has been commonly associated with art, perhaps because Gardner (e.g., 1993b) used Picasso as an exemplary spatial creator, however there are also many examples of outstanding mathematicians and scientists with high spatial ability, in addition to Einstein (MacFarlane-Smith, 1964). Indeed, some like Leonardo daVinci expressed their spatial intelligence in both the artistic and scientific domains. Indeed, spatial intelligence has long been implicated in mathematics and science achievement at school (Siemonkowski & MacKnight, 1971). Many studies have suggested a correlation between high spatial intelligence and achievement in mathematics (Clements, 1981; Fennema & Tartre, 1985; Guay & McDaniel, 1977, Krutetskii, 1976). Similarly, in science, students with high spatial intelligence have tended to perform better in tasks requiring problem solving and mental manipulation of two-dimensional objects or symbolic representations (Carter, Larussa, & Bodner, 1987; Gabel & Bunce, 1994; Pribyl & Bodner, 1987). Spatial visualisation skills are also acknowledged to be of importance in biology (Lord, 1987) and astronomy (Ault, 1994). Interestingly, there seems to be a two-way interaction between spatial ability and participation in physics. A study by Pallrand and Seeber (1984) showed that spatial abilities affected students' decisions to study college physics and that these abilities improved in those students who did study physics. Graphic user interfaces in computers capitalises on spatial intelligence to use information technology effectively.

In the early childhood years, the foundation for science and mathematics is built through play. Mitchell and Burton (1984) argue that the use of construction toys "further the development of spatial ability" and may afford opportunities for children to value and exploit their spatial skills. The importance of play in facilitating the development of high achievement in science cannot be underestimated. The renowned physicist Feynman acknowledged his early experiences with tinkering as establishing a long term involvement in play and modelling to which he attributed to his success in achieving the Nobel prize (Gleick, 1992). Others have also argued for the importance of play in the foundations of becoming a scientist (Wasserman, 1992).

The Developmental Trajectory of Intelligence

In tandem with his theory of Multiple Intelligences, Gardner (1993a). proposes that there is a natural four-stage *developmental trajectory* for each intelligence.

Stage 1 is a *raw patterning ability* associated with a particular intelligence. For example, Gardner argues that the foundation of musical intelligence involves the recognition of tonal differences, while the foundation of spatial intelligence is the appreciation of three-dimensional space. As this stage precedes substantial cultural and educational influences, it primarily reveals an individual's genetic profile in relation to a particular intelligence

Stage 2 involves the use of a *symbol system* that provides an initial insight into a particular domain. Children are introduced to a variety of symbol systems through their culture and prior to the commencement of formal education. For example, songs can provide an introduction to the domain of music. However, drawings can provide an insight into several domains, for example, art (Gardner, 1993b), mathematics (Tufte, 1983), and science (Baigrie, 1996).

Stage 3 is the use of a *notational system* applicable to a particular domain. For example, mastery of musical notation is typically required for optimal understanding of music. Similarly, knowledge of diagrams is important for mastery of mathematics (Eisenberg & Dryfus, 1986). According to Gardner (1993a), the notational system — a second order symbol system — is typically mastered through formal education.

Stage 4 is the expression of an intelligence in adolescence and adulthood through *vocational and avocational pursuits*. For example, a student who is interested in music may become a professional musician or simply pursue an interest in music through concert attendance. Careers that capitalise on spatial intelligence include architecture, mathematics and science.

Gardner (1993a) suggests that while all individuals have core abilities in each intelligence, across the population, individuals will range from those "at promise" to those "at risk" in particular intelligences. He argues that while it is not necessary for all individuals within a community to perform highly in particular intelligences, there is a need to identify those "at promise" in order to advance knowledge in a particular domain. Gardner also argues for early intervention of those "at risk" who are failing tasks associated with particular intelligences. In mathematics, the provision for those at risk generally only occurs for some notational tasks associated with logico-mathematical intelligence with the view that the general populace needs to be numerate (Steen, 1997).

We now consider the development of spatial intelligence.

The Development of Spatial Ability Across the Lifespan

Gardner's (1993a) developmental trajectory of intelligence provides an insight into the four-stage development of spatial intelligence across the lifespan. These stages will be exemplified with reference to the behaviour and performance of people who have been acknowledged as having high spatial ability. These people comprise a now adolescent student, Michelle, whom we have been monitoring for a number of years, and of eminent mathematicians and scientists renowned for their high spatial ability.

Michelle is currently an adolescent. At age seven, we ascertained that Michelle had a high simultaneous synthesis score, and consistently demonstrated high spatial intelligence. Her high score was not unexpected, as she had demonstrated her facility with spatially oriented activities since infancy. Michelle's history and subsequent behaviour and performance provide examples of each stage in Gardner's developmental trajectory as shown on Table 1.

TABLE I about here

Stage 1: Raw Patterning Ability

Since an early age, Michelle has shown sustained interest in a variety of spatial activities and a penchant for understanding information presented in spatial format. From when Michelle could first hold a pencil, she had scribbled and drawn. Like many young children, Michelle also enjoyed puzzles, and construction activities.

However what distinguished Michelle's performance from the majority of her peers was the early age at which she demonstrated spatial proficiency. For example, at two years of age, she was able to complete puzzles suitable for children three years older. She also had a fascination with graphic road signs and a seemingly innate understanding of their meaning, which she communicated to her parents.

Stage 2: Understanding a symbol system

Michelle's facility for communicating spatial information was clearly demonstrated in her drawings during her early years at elementary school. At age six, Michelle's drawings featured spatial information and displayed spatial intelligence (see Figure 1). Michelle's drawing of a house shows her understanding of how the flights of stairs link the different levels. This "architectural-design" drawing is commonly seen in young children with high interests in mathematics and science. In the house drawing, Michelle's use of a "cut away" technique to represent the relationship between the stairs and the levels of the house, demonstrates her understanding and use of a particular spatial symbol system. This technique reappeared in some of Michelle's other drawings at the same age. For example, Michelle also used a "cut away" technique to reveal how tortoise eggs are hidden underground (see Figure 1). In both drawings, Michelle demonstrated her spatial awareness through her visualisation of unseen objects, and her understanding of a specific spatial technique to depict this unseen information.

Figure 1 about here

Despite Michelle's proficiency in spatial activities, she experienced difficulties with number facts, spelling and handwriting at school. Her discrepancy between performance on spatial activities and traditional school tasks is not surprising. Proficiency in spatial tasks depends on simultaneous processing of information, while traditional school-based tasks draw upon on successive processing of information (Luria, 1973). The asynchronous profiles of intelligence explains why some high ability children may not perform well in routine activities (e.g., Diezmann & Watters, 1996). As high spatial ability is a characteristic of creative thinkers who exhibit extraordinary interest and aptitude in mathematics or science, opportunities should be provided for children such as Michelle to capitalise on their spatial ability. To provide a further understanding of the characteristics and school experiences of the spatially gifted, the lives of eminent mathematicians and scientists are later discussed.

Stage 3: Use of a notational system (a second order symbol system)

At age eight there was evidence in Michelle's drawing of an enhanced awareness of spatial notation. For example, she produced an unusual abstract drawing modelled upon an understanding of an ECG trace, in which she depicted a person being attacked (see Figure 2). Michelle explained that the first line was a trace of the normal heart beat while the peaks in the second line showed the repeated attack on a person and each subsequent line showed a gradual slowing of the heart until the person finally died. The surface details of the fight have been omitted to reveal the ebb of life. Although the context of Michelle's drawing cannot be derived from the drawing, once the decoder is aware of the code, the dynamism of the situation is evident. Michelle's drawing is complex in that it displays links between shapes in physiological patterns that altered over time, thus depicting a cause and effect situation. Her representation of a fight, using medical notation, which she might have seen on television or encountered in reference materials, reveals a sophisticated understanding of spatial notation.

Figure 2 about here

Stage 4: Vocational and avocational pursuits

In early adolescence, Michelle's avocational interests continue to include spatially oriented pursuits, such as two- and three-dimensional representation. For example, she often spends many hours creating intricate and dynamic patterns using computer software paint programs. Although Michelle has yet to make her career choice, there many careers in which she could capitalise on her high spatial intelligence.

High spatial intelligence was influential in the careers and achievements of some eminent scientists and mathematicians (MacFarlane-Smith, 1964). For example, Friedrich Kekulé's insightful solution to the structure of benzene occurred after he visualised rings of snakes "gambolling" before his eyes (Boden, 1990). Kekulé's success was due to the ability to strip away the irrelevant and recognise the essence of the relationships. Seeing the relationships between atoms, snakes and the behaviour of the images is a clear example of "the ability to see two or more objects in relation to oneself or in relation to each other" (Del Grande, 1990, p. 17). As this network of relationships and interactions provides a mental model (Johnson-Laird, 1983), spatial sense extends beyond perception and communication to the conceptual domain (Greeno, 1991).

Supporting the Development of Spatial Intelligence

The learning environment and schooling have been shown to play a significant part in developing children's potential (Artman & Cahan, 1993). However, school was a difficult experience for many eminent scientists and mathematicians who possessed high spatial intelligence (MacFarlane-Smith, 1964). For example, Trevithick, the developer of the steam engine and screw propeller, was described as disobedient, obstinate and inattentive at school while Galois annoyed the teachers by being "original and queer", and "argumentative". Several future achievers avoided or had limited schooling. Einstein not only skipped classes because he did not enjoy the instruction at the Swiss Polytechnic, but withdrew from school at 15 because he hated the dull regimentation and unimaginative spirit of school. From biographical sketches of these eminent persons (MacFarlane-Smith, 1964), it is clear that the intellectual processes and abilities of many of these mathematicians and scientists did not conform to educationally acceptable standards. Their high spatial intelligence ultimately provided an advantage but one would speculate it also put them at odds with their teachers and peers because of the lower value placed on spatial intelligence. Clearly these historical figures, despite constraints, achieved outstanding success. But how many others would have been successful had they received support in their early years and throughout their schooling?

Gardner’s four-stage developmental trajectory described earlier provides a useful framework for supporting the development of spatial intelligence across the lifespan, beginning with the early childhood years.

First, parental accounts of children’s *raw patterning ability* associated with spatial intelligence are important to consider. These accounts provide information about “at promise” children who have the potential to advance a spatially oriented domain through their spatial intelligence.

Second, all children’s *understanding of spatial symbol systems* should be developed. The foundational skills needed to create and interpret spatial symbol systems are based on spatial perception. According to Del Grande (1990) these skills are:

1. Eye-motor co-ordination
2. Figure-ground perception
3. Perceptual constancy (an object has invariant properties even though it may look different when viewed from another perspective)
4. Position-in-space perception (the relationship between two objects or an object and an observer eg., the orientation of letters)
5. Perception of spatial relationships (eg., flips, slides, turns)
6. Visual discrimination
7. Visual memory

Given the importance of these skills, various experiences should be planned to provide opportunities for the development of each of these skills. Suitable play experiences include construction with wooden blocks, tinker toys, Lego and similar materials, and design activities involving tangrams, jigsaw puzzles, embedded figure puzzles, mazes and patterns (Mitchell & Burton, 1984). Painting and drawing are widely used avenues for spatial expression. However, mapping activities also provide opportunities for enhancing and expressing spatial intelligence. For example, children can be encouraged to draw their way from home to school, or to sketch the layout of the home, playground or school building.

Because of the perceptual-conceptual interplay in spatial intelligence, appropriate perceptual experiences are necessary to generate representations. Children need opportunities to interact with information presented in a spatial format in order to construct knowledge representations, which are reconstructions of experience, and to engage in spatial reasoning with these representations. Battista (1994) speculates how such spatial sense could be developed in a child who might “perform—first in action, later in imagery—the spatial/kinaesthetic manipulations of combining and separating configurations of objects.” With practice and experience, perceptual input is unnecessary and manipulations occur with “tokens” (Johnson-Laird, 1983). Hence, the extension beyond the perceptual domain to the conceptual domain suggests that thought has a spatial analogy, perhaps complementary to “inner speech” (Vygotsky, 1962).

Third, children’s *use of spatial notational systems* needs explicit attention. For example, research on children’s use of diagrams reveals that they are reluctant to use diagrams (Yancey, Thompson, & Yancey, 1989) and do not see diagrams as a means to a solution in mathematics (Dufoir-Janvier, Bednarz, & Belanger, 1987). Children also need to be able to interpret two-dimensional plans of three-dimensional objects, and to construct three-dimensional objects from a plan (Moses, 1990). Hence, teachers need to explicitly teach children about particular representations, and how to move between two- and three-dimensional representations. There is evidence that students can benefit from spatially-oriented skill development programs in mathematics (Diezmann, 1999) and science (Small & Morton 1983).

Fourth, children should be provided with an insight into the variety of *vocational and avocational pursuits* that are associated with spatial intelligence. Although this stage is not particularly relevant to young children, opportunities may arise to expose children to careers and leisure activities that are of interest. For example, in Michelle's school, origami demonstrations by Japanese visitors stimulated her early interest in paper folding as a leisure activity. Computer simulation games and video games are other examples of spatially oriented activities.

Conclusion

In this paper we have argued that teachers at all stages of education need to reflect on their practices and beliefs about spatial intelligence in order to optimise opportunities for children to utilise and develop this intelligence. As the early childhood years provide the foundation for later learning, specific opportunities for the development of spatial intelligence should be provided in early education settings. Current practices in pre-school settings and school settings appear to provide contrasting opportunities for the development of spatial intelligence. Whereas pre-school settings appear to provide multiple and varied opportunities for the development of spatial intelligence, opportunities in more formal school settings seem scant. Just as in the pre-school setting, rich learning experiences that enhance spatial intelligence can be provided in the elementary school "through activities that begin with play" (van Hiele, 1999).

Whereas spatial intelligence has commonly been associated with art, its importance in mathematics and science cannot be underestimated. We suggest there are four key ways to promote the development of spatial intelligence in the sciences. First, the value accorded to spatial intelligence in relation to logico-mathematical and linguistic intelligence needs to be reconsidered by teachers and curriculum developers. Second, all young children require opportunities to develop and express spatial intelligence in informal and formal learning environments. Third, children require instruction in the use of two- and three-dimensional spatial representations within mathematical and scientific contexts. Finally, "at promise" children should be identified and their intelligence nurtured because these children have the potential to contribute new knowledge in mathematics and science for the benefit of society.

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Table 1
Developmental trajectory of intelligence

Four Stages of Developing Intelligence	Examples of Spatial Intelligence
1. Raw patterning ability	A young child’s facility with puzzles.
2. Understanding a symbol system	The use of drawing to depict spatial information.
3. Use of a notational system (a second order symbol system)	The ability to construct and interpret diagrams
4. Vocational and avocational pursuits.	An interest in two- and three-dimensional representation is still evident in early adolescence.

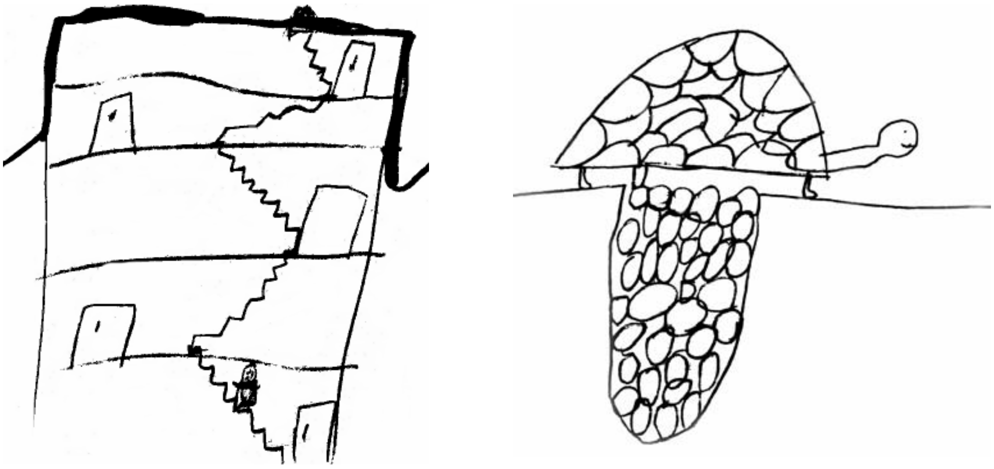

Figure 1. Cut away drawings revealing flights of stairs linking the levels in a house, and tortoise eggs hidden underground.

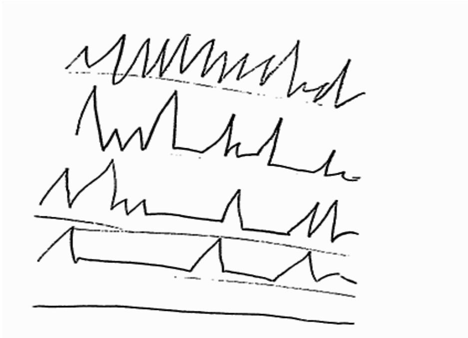

Figure 2. A fight to the death: an ECG trace of a victim of an attack.