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The malleability of spatial ability under treatment of a FIRST LEGO League-based robotics unit

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THE MALLEABILITY OF SPATIAL ABILITY UNDER TREATMENT OF A FIRST LEGO LEAGUE-BASED ROBOTICS UNIT

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To my wife, Krystal,

for her understanding and support.

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Abstract

Spatial ability is important to science, technology, engineering, and math (STEM) success, but spatial talents are rarely developed in schools. Likewise, the gifted may become STEM innovators, but they are rarely provided with pedagogy appropriate to develop their abilities in schools. A stratified random sample of volunteer participants (n=75) ages 9-14 was drawn from 16 public school districts' gifted programs, including as many females (n=28) and children from groups traditionally underrepresented in gifted programs (n=18) as available. Participants were randomly divided into an experimental (n=38) and a control group (n=37) for an intervention study. All participants took the *CogAT (form 6) Verbal Battery* and the *Project TALENT Spatial Ability Assessments*. The experimental group participated in a simulation of the FIRST LEGO League (FLL) competition for 20 hours total over five consecutive days. All participants took the spatial measure another time. Experimental males evidenced significant and meaningful gains in measured spatial ability (Cohen's $d = 0.87$). Females did not evidence significant gains in measured spatial ability. This may be due to sampling error, gender differences in prior experience with LEGO, or differences in facets of spatial ability in the treatment or measurements. Further research studies with larger samples of females, other treatments and measurement tools, and longer treatment periods are recommended. The literature review revealed that FLL is beneficial for STEM engagement in both genders and its use in schools is recommended. The present study provides additional evidence for FLL's usefulness in increasing the number of individuals in the STEM pipeline.

Keywords: spatial, gifted, talent, robotics, FIRST LEGO League, science

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Chapter 1

"For tomorrow belongs to the people who prepare for it today"

–African proverb

Problem Overview

The fields of science, technology, engineering, and math (STEM) are of vital importance. There is a shortage of capable people graduating from institutions of higher education in STEM fields. Gifted students, particularly the spatially gifted, are especially able to excel in STEM fields. Although much of the research detailed in Chapter 2 suggests that spatial ability is improvable through treatment, there is a severe lack of both STEM educational opportunity and appropriately challenging gifted programming in schools, particularly for the spatially gifted. One potential way to provide a challenging educational experience for the gifted is through academic competition. The For Inspiration and Recognition in Science and Technology (FIRST) LEGO League (FLL) is an academic competition involving many aspects of STEM fields that holds promise for challenging the spatially gifted. Questions about the ability of FLL to improve spatial ability remain to be answered through research.

Spatially Gifted Children and the Need for STEM Education

In the past decade, several national reports have called for increased STEM education, including suggestions for earlier intervention, foci on the most able children, and renewed interest in the importance of spatial ability for STEM innovation. In particular, The National Science Board (2010) details the lack of STEM preparation in schools and outlines an agenda for action in their report, *Preparing the next generation of STEM innovators*. The report notes that, while many others have made recommendations focusing on raising overall performance of America's students, few have "focused on raising the ceiling of achievement for our Nation's most talented and motivated students" (p. 4). The National Science Board further outlines key issues, including the importance of early intervention and that spatial ability is rarely measured or developed in children. Cited in the report, The Business Roundtable (2005) suggests that the problems cannot wait to be addressed:

> One of the pillars of American economic prosperity—our scientific and technological superiority—is beginning to atrophy even as other nations are developing their own human capital. If we wait for a dramatic event—a 21^{st}-century version of Sputnik—it will be too late. There may be no attack, no moment of epiphany, no catastrophe that will suddenly demonstrate the threat. Rather, there will be a slow withering, a gradual decline, a widening gap between a complacent America and countries with the drive, commitment and vision to take our place. (p. 5)

In another national report, *Rising above the gathering storm* (2007), the National Academy of Sciences (NAS), the National Academy of Engineering, and the Institute of Medicine elucidate that point in terms of the future prosperity of the United States:

> Although the U. S. economy is doing well today, current trends in each of those criteria indicate that the United States may not fare as well in the future without government intervention. This nation must prepare with great urgency to preserve its strategic and economic security. Because other nations have, and probably will continue to have, the competitive advantage of a low wage structure, the United

> States must compete by optimizing its knowledge-based resources, particularly in science and technology … (p. 4)

This report notes that STEM, particularly the technological advancements that it encompasses, have driven the U. S. economy for the past several decades. The authors conclude that the highest priority must be to improve K-12 science education. The National Research Council (2007) reflects that, while standards-based reform has been underway for more than 15 years, improvements in U.S. science education have been lackluster, especially in comparison with other countries. They argue that, "At no time in history has improving science education been more important than it is today" (p. 1). The need to improve science education is great, but part of the solution may lie outside the traditional classroom.

The National Academy of Education (NAEd) white paper, *World-class science and mathematics* (2009), affirms this, suggesting that STEM education is vital for the security and economy of the U.S. Despite this well-known importance, the U.S. has yet to make a concerted effort in schools to provide quality STEM education in the Post-Cold War Era. In the book, *Taking Science to School* (2007), the National Research Council (NRC) analyzed the available data and concluded that the United States is seriously behind in science education. This lack of STEM focus is seen in higher education and the job market, which has an ever-increasing need for highly-educated people capable of filling the openings (Shea, Lubinski, & Benbow, 2001; Snow, 1999; Webb, Lubinski, & Benbow, 2007). While employers expect to hire 2.5 million STEM workers between 2004 and 2014 (Terrell, 2007), there is a national shortage of students graduating from institutions of higher education with degrees in many important STEM fields (American Competitiveness Initiative, 2006).

Given the demand for highly-educated people in STEM fields coupled with the fact that they earned about 70% more than the U. S. average in 2005 (Terrell, 2007), it may be surprising that too few people choose to pursue STEM fields in higher education. The reason can be found long before higher education begins. Students who do not prepare well during their K-12 education will likely have a tougher time getting into and succeeding in STEM university programs. As elementary and middle school coursework, particularly in mathematics and science, often decides where students begin their coursework in high school and therefore what level they can complete before entering higher education, more effort must be made to encourage and engage elementary and middle school students in STEM fields. In particular, strong efforts should be made to encourage students who demonstrate the potential to excel in STEM fields to pursue STEM opportunities to the fullest extent during their K-12 education. Even then, the opportunities are altogether too rare.

The lack of STEM opportunities for children in schools is demonstrated particularly well in the science education literature. The NAEd (2009) recommends that science instruction begins by kindergarten, but, according to the NRC (2007), a major part of the problem with U.S. readiness in science is a lack of quality science education in the elementary years. They suggest that young children have a much higher capacity for scientific thought than has commonly been believed under Piaget's early developmental model (NRC, 2007). Moreover, when science instruction is delayed, students may be handicapped in understanding science concepts in later years. In particular, Novak's

(2005) longitudinal studies demonstrated the importance of teaching science concepts before secondary school. He found that children taught science concepts in second grade continued to outperform students who did not receive science instruction until sixth grade throughout high school. Not only did the students with earlier instruction learn more, but they were wrong about less. Novak also found that students receiving earlier instruction had fewer misconceptions about science in the twelfth grade than those whose instruction was delayed.

Teacher preparation is also lacking in science. The NAEd (2009) recommends that teacher training and research on science instruction needs to improve; however, elementary teachers frequently lack the knowledge needed to each science effectively (NRC, 2007; VanTassel-Baska & Stambaugh, 2007). This problem goes hand-in-hand with a lack of research funding and dispersal of the research information that has already been conducted. A meta-analysis of effective science teaching strategies failed to locate many studies concerning elementary science instruction where control groups were used (Schroeder, Scott, Tolson, Huang, & Lee, 2007). Only 61 of nearly 400 studies identified were deemed appropriate for meta-analysis, and only 16 of those 61 studies were conducted with K-8 students. However, while individual studies were not reported on separately by grade level and science intervention, the mean effect size of the K-8 studies of various science education strategies was .68. That is, science education at the elementary level is a meaningful endeavor in terms of student achievement and failing to provide it represents a significant failure to develop STEM talent in young students. The ultimate effect of this paucity of elementary science education on the number of students graduating in STEM fields is not known. Given the research on the importance of early science education, it should not be underestimated.

The Gifted and STEM Fields

While opportunities for STEM education need to be increased and improved, the students most able to succeed in STEM fields suffer the greatest neglect in schools. Gifted students have unique needs, both academically and affectively. They differ significantly in one or more academic areas from their age-peers and need specialized curriculum, faster pacing, and appropriately trained faculty to meet their academic needs (Clarenbach, 2007; Colangelo, Assouline, & Gross 2004; Coleman & Cross, 2005; Davis & Rimm, 1998; Neihart, 2007; Rogers, 2007; Smith 2005; VanTassel-Baska, 2003). The gifted face neglect under current federal laws and gifted education is gravely underfunded (VanTassel-Baska, 2006). At the federal level, only two cents out every $100 spent by the U.S. Department of Education goes to serve gifted and talented students (NAGC, 2009). As the gifted lack the protections other children with special needs are granted under the Individuals with Disabilities Education Act (IDEA) (1990, 2004), they are legally disregarded from the mandate that every child should have an appropriate education.

A Nation Deceived (Colangelo, Assouline, & Gross, 2004) and Rogers' (2007) meta-analysis of accelerative and grouping management strategies each report overwhelming bodies of research suggesting that gifted students need to be challenged in order to continue to make achievement gains and to have positive social-emotional outcomes. In classrooms with a focus on minimum-competency as defined in NCLB (2001), gifted students have few opportunities to be challenged. As federal funding for states is contingent on below average ability students passing basic skills tests, gifted students, whose achievement is disregarded under NCLB, often find their programs under attack. This is particularly damning as value-added assessment analyses have shown that the top 25% of students show the most decline when their needs are not met (Sanders & Horn, 1998). With estimates of gifted students' underachieving ranging from 10-50% (McCoach & Siegle, 2008) and forming 20% or more of high school dropouts (Kim, 2008; Rimm, 1997), providing appropriately challenging education is critically important. Less than half of gifted underachievers finish four years of college (McCoach & Siegle, 2008). The national talent development process for helping the most able students to become highly productive scientists, innovators, and engineers is bleeding potential.

Conclusion and Problem Statement

STEM fields are of vital importance to society. STEM fields provide innovations that enhance our lives. In order to address the shortage of STEM graduates, we must address K-12 education. The National Science Board (2010), the Business Roundtable (2005), the National Academy of Sciences (2007), the National Research Council (2007), and the National Academy of Education (2009) have called for increased and improved STEM education. In particular, as spatially gifted students have great potential within STEM fields, we must ensure that they have the opportunity to develop their talents. Talent development of spatial gifts within STEM fields should not be delayed until high school or university studies; we should encourage the talent development of young children. Detailed in Chapter 2, LEGO robotics, such as is used in the FLL academic competition, is a spatially-focused activity aimed at elementary and middle school children. It is potentially a practical means of talent development for spatially gifted children. A curriculum unit simulating the FLL competition may help to improve students' spatial abilities, furthering their talent development toward becoming tomorrow's innovators. At present, this group rarely has its needs fulfilled in schools. By recognizing spatially gifted children and then providing them with appropriate challenge in their talent area, the future pool of students pursuing STEM fields will likely increase. Research is now needed to help determine appropriate interventions for developing the talent of spatially gifted children. Research on interventions, such as treatment with an FLL-based robotics unit, must be conducted in order to determine if and to what extent improvement on measures of spatial ability is made under treatment.

Chapter 2

I saw the angel in the marble and carved until I set him free.

-Michelangelo

Theoretical Framework

Spatial ability is a construct that characterizes a human difference in "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1993). As this definition suggests, spatial ability has multiple facets and can be further ramified into sub-abilities each focused on different aspects of image processing: generation, storage, retrieval, and transformation (Lohman, 1993). More specifically, spatial ability represents "ability in manipulating visual patterns, as indicated by level of difficulty and complexity in visual stimulus material that can be handled successfully, without regard to the speed of task solution" (Carroll, 1993, p. 362). Spatial ability can be seen as dichotomous with verbal abilities (Lohman, 1993) or trichotomous with verbal and mathematical abilities (Wai, et al., 2009).

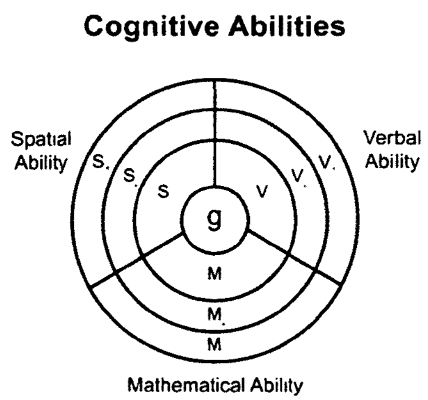
The spatial construct was in the literature for at least 100 years before Gardner's (1983) *Frames of Mind* popularized it along with other domains of ability (which he terms "intelligences") for a mainstream audience. Galton (1880) became the first to suggest that understanding spatial ability as a human difference may be important to education when he put forth that learners who utilize visualization might benefit from different instructional strategies than more verbally-centered learners. Contemporary research continues to support Galton's suggestion of learning differences for the spatially-able, including that the spatially-able are more often creative (Liben, 2009), more likely to be introverted (Lohman, 1993), more likely to have hobbies (Humphreys, Lubinski, & Yao, 1993), and possibly more likely to have reading disabilities (Lohman, 1994; Mann, 2006). They are also considerably more likely to become engineers, artists, and physical scientists (Flannagan, 1979; Humphreys, et al., 1993; Wai, et al., 2009).

Two theoretical models underpin the understanding of the construct of spatial ability as it is used in this study, Carroll's Cognitive Abilities (1993) and Gagné's (2008) DMGT 2.0. The first model has been adapted by Wai, et al. (2009) from Carroll's Cognitive Abilities and the Cattell-Horn-Carroll three stratum theory of cognitive abilities as a simple radex that displays three abilities: spatial, verbal, and mathematical. These abilities radiate from general intelligence or *g*. General intelligence is a natural, largely in-born set of mental traits (Carroll, 1993; Jensen 1984). The second model differentiates gifts and talents. This is important as the words are often used synonymously, but will be differentiated here. The term "gifted" is used throughout this study to refer to children and adolescents who score within the top 10 percent on an intelligence test or who have otherwise qualified for a school district's gifted program (e.g., such as through performance measures). The term "talent" is used throughout the study to mean a learned and practiced set of skills. The term "ability" is used throughout the study to mean the manifested, combined intelligence and talent that can be measured with instruments. Talents are often the extension of giftedness. For example, a gifted child may develop into a talented physicist, if she has appropriate educational experiences to develop that innate intelligence into the talents needed.

Carroll's Cognitive Abilities

Spatial ability has long been considered a facet of *g*. Spatial ability has been included in measures of intelligence from the first Stanford-Binet test, which included spatial items (Terman, 1916), to Project Talent in the 1960s (Wai, et al., 2009), to many ability tests today (e.g., portions of the UNIT, Stanford-Binet, Naglieri, and the Weschler). Wai, et al. (2009) suggest this radex (Figure 1) of cognitive abilities based on Carroll's model (1993) as a theoretical model for understanding the three intelligences predictive of school and career success. General intelligence, or *g*, is depicted at the center to represent the commonality of the intelligences. The researchers use the radex to depict tests of various levels of complexity, with items at Level One being the simplest and Level Three being the more complex (e.g., S3 represents a complex

Figure 1. *Radex of Cognitive Abilities Based on Carroll's Model*



spatial item). One may also consider giftedness on a radex, with individuals having various strengths and weaknesses in and among spatial, verbal, and mathematical abilities with ranges of giftedness within and among the specific abilities represented in the radex.

Most importantly, the radex centers on *g*. Jensen (1984) notes the high correlation between disparate instruments meant to measure separate abilities, knowledge, and skills. According to Jensen's (1984) analyses of hundreds of thousands of individual government workers' scores on batteries of tests and their predictive validity for job performance, the common factor is *g* and represents "common processes of the brain, not common items of knowledge, skill, or learned behavior" (p. 98). Therefore, manifested spatial ability, like all other abilities, is in large part explained by *g*. In his study of specific aptitude tests' overall validity for predicting job performance, Jensen (1984) found that *g* generally accounts for all of the significantly predicted variance. However, he also found that in some cases, including jobs that require spatial ability, the overall validity for predicting job performance is significantly improved by tests of spatial visualization in addition to measures of *g*. Humphries, Lubinski, and Yao (1993) suggest that while the level of ability is related to *g*, the patterns of educational and occupational choices are related to group factors such as spatial ability. Carroll (1994) theorizes that, while more than half of various tests can be explained by *g*, the rest of the variance is explained by a few lower order factors including spatial ability. Jensen's (1984) analysis places this variance explained by *g* somewhat higher at .65. Therefore, this study assumes that instruments used to measure spatial ability include both an individual's *g* and their developed talent in the spatial domain.

It appears to be very popular among teachers and the media to make the argument that life outcomes such as educational attainment and occupational choices are primarily based on environmental influences, especially socio-economic status. However, correlations between socio-economic status and educational, occupational, and even pastime outcomes are only moderate to trivial in comparison to the relationship of those outcomes and ability (Humprehys, et al., 1993).

It should also be noted here that Lohman (1993) provides an alternative explanation to the relationship between *g* and spatial ability:

> Indeed, one can turn Spearman's conclusion around and with equal conviction conclude that measures of G are by and large unreliable measures of the ability to generate and coordinate different types of mental models in working memory. (p. 2)

Lohman allows that hierarchical factor analyses support that complex spatial tasks are primarily measures of *g*, but he notes that they are also measures of task-specific ability and spatial ability that covary with other spatial tasks. Lohman argues that, when the spatial tasks are simpler and timed, however, they show lower *g* loading and higher spatial loading.

Regardless, as *g* cannot be improved, a positive change in a measurement of an individual's spatial ability will be assumed to be the development of talent (and error). Specifically, this study will assume that improvement on the spatial composite over the course of treatment with a LEGO robotics unit (described in Chapter 3) represents the development of talent in a gifted group of participants.

Gagné's Developmental Model of Giftedness and Talent 2.0

Through a functionalist lens, variations in spatial abilities are seen by psychologists as individual differences in domains of ability and can be measured well, if imperfectly, with instruments. Gagné (2008) not only considers an individual's intelligence (which he terms "natural abilities"), but also considers the process by which individuals develop talents based on their intelligence through increasingly difficult educational experiences. High ability in one or more domains of ability is advantageous to success within fields requiring that ability or abilities if those abilities are developed into talents. For children, the primary arena for talent development is school.

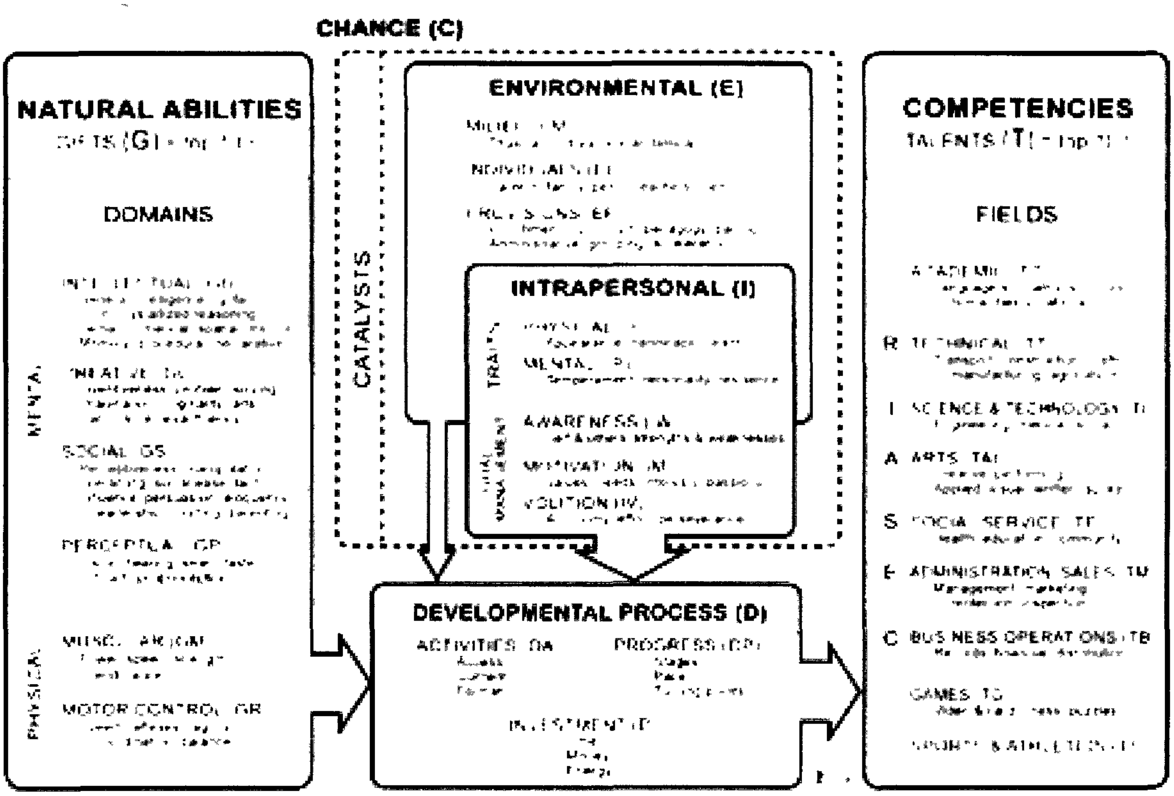
Most importantly for educators, while genetics are a primary factor in determining intelligence (Herrnstein & Murray, 1994), performance on measures of spatial ability is improvable through treatment (Lim, 2005; Liu, Uttal, Marulis, & Newcombe, 2008; Lohman, 1993; Onyancha, Derov, & Kinsey, 2009; Potter, Van der Merwe, Fridjhon, Kaufman, Delacour, & Mokone, 2009; Sorby, 2005; Urhahne, Nick, & Schanze, 2009; Verner, 2004). Thus, it is possible to serve the spatially gifted in schools by developing their talents through increasingly difficult spatial experiences.

Gagné's (2008) Developmental Model of Giftedness and Talent 2.0 (DMGT) is useful for understanding the development of talents from "natural abilities," also called gifts (see Figure 2). In the DMGT model, "natural abilities" include intellectual, creative, social, perceptual, muscular, and motor control. The former four are mental domains and the latter two are physical. Both general intelligence, or *g*, and spatial ability are considered intellectual domains. Gagné considers those in the top 10% of any "natural ability" domain possibly gifted. In the DMGT, "natural abilities" feed into the developmental process, which includes activities, progress, and investment.

The model considers environmental influences, including milieu, individuals, and provisions. Intrapersonal characteristics also go into the DMGT including physical, mental, awareness, motivation, and volition characteristics. Chance underlies all of these aspects of the model. For example, a child who is spatially gifted may or may not have access to activities that aid her development process. On the other hand, she may be born to a family that has the time and money to invest in her spatial education, may have access to activities such as FLL, and she may be allowed to proceed at a rapid pace suitable to her abilities. She may have access, but not have the motivation for LEGO robotics. Catalysts underlie environmental and intrapersonal aspects. For example, a great mentor may be a catalyst in motivating a child in LEGO robotics or another spatially engaging activity.

While "natural abilities," environmental and intrapersonal aspects, catalysts, and chance all feed into the development process, competencies are the resulting output. Gagné suggests that those individuals performing in the top 10% of a field are to be considered gifted. For the purposes of this study, it is important that giftedness and talent development be understood in their current context in U.S. schools.

Figure 2. Gagné's Developmental Model of Giftedness and Talent 2.0



Giftedness and Talent Development in U.S. Schools

Gifted students have no federal protection as a special needs population in the U.S. Much of gifted programming is left to local funding, with highly varied results (VanTassel-Baska, 2006). Gifted programming is similar to other forms of special education programming in that students are selected because the regular instruction and curricula are not appropriate for their abilities and then provided with instruction and curricula that are appropriate for their abilities. However, many myths exist for gifted education that do not exist for other forms of special education including that gifted programs are elitist, that gifted programs represent inequity, and that gifted students will reach their potential without assistance (Neihart, 2007).

The first myths—elitism and inequity—assume that equity means educating different students at the same level based solely on age, which is not logically sound when considering that other special education practices are not generally considered elitist. Every student is not gifted any more than every student is mentally handicapped; both groups differ significantly from average students and need special programming to help them to reach their potentials. Equity in education means that students should be educated according to their individual needs: Students should receive curricula and instruction on par with their mental abilities, not simply for the average ability at a given age. The third belief, that gifted students will reach their potential without assistance, has a wide body of opposing research showing that gifted students need specialized curriculum, faster pacing, and appropriately trained teachers to achieve their potential and that the failure to do so can lead to depression, underachievement, and unfulfilled potential (Clarenbach, 2007; Colangelo, Assouline, & Gross 2004; Coleman & Cross, 2005; Davis & Rimm, 1998; Neihart, 2007; Rogers, 2007; Smith 2005; VanTassel-Baska, 2003). Clearly, gifted programming cannot be left to chance.

Furthermore, the lack of science content knowledge generally found among elementary teachers may have a particularly negative impact on the gifted. Gifted students often perform two or more years beyond their peers and have substantial knowledge of subjects before class even begins (Neihart, 2007; Rogers, 2007). This means that gifted students can outpace less knowledgeable teachers, becoming bored and likely underachieving (McCoach, & Siegle, 2008). While a delay in science education is likely to leave all students with overall lower science achievement at the end of high school (Novak, 2005), gifted students actually lose more potential learning as they can generally learn more than other students in the same period of time (Neihart, 2007; Rogers, 2007). The gifted are the most neglected special needs group in U.S. schools, and some groups within the gifted population ignored within most schools.

The Spatially Gifted and STEM Fields

Within the neglected gifted population is an even more neglected group, the spatially gifted. While some K-12 schools do work to meet the needs of students with mathematical and verbal giftedness, few do anything for the spatially gifted. Spatial giftedness connotes significantly higher potential for spatial ability than one's age-peers. The National Science Board (2010) suggests that spatially gifted students may not fit traditional views of giftedness. The Board notes because "individuals with spatial abilities are routinely overlooked because spatial ability is rarely measured" that this group is underserved in schools and "an untapped pool of talent critical for our highly technological society" (p. 13).

High spatial ability is necessary in many fields, particularly in the visual and performing arts and in STEM disciplines, including engineering, architecture, computer science, the physical sciences, medicine, and dentistry (Shea, Lubinski, & Benbow, 2001; Snow, 1999; Wai, et al., 2009; Webb, Lubinski, & Benbow, 2007). Students with spatial giftedness are particularly well-suited for STEM careers (Webb, Lubinski, & Benbow, 2007; Wai, et al., 2009) and, like other gifted children, in need of special programming to meet their learning needs (Rogers, 2007). In fact, spatial ability in childhood is a reliable predictor of a STEM career as an adult (Newcombe, 2009; Shea, Lubinski, & Benbow, 2001; Snow, 1999; Webb, Lubinski, & Benbow, 2007).

Even at schools that offer gifted programming for students with verbal and mathematical gifts, spatial ability is rarely measured for gifted identification and, likewise, the spatially gifted are rarely served in their area of strength in gifted programs (Lohman, 1994; Mann, 2006; Silverman, 2005; Webb, Lubinski, & Benbow, 2007). Most tests in schools, including the state tests required under NCLB of 2001 and the Scholastic Aptitude Test (SAT), emphasize math and reading and few school programs identify students outside of those domains; therefore, students with spatial gifts are often neglected in school curricula and instruction. As about half of those students who are gifted spatially are not equally gifted mathematically, talent searches also fail to identify many spatially gifted students (Webb, Lubinski, & Benbow, 2007). As such, potential STEM talent is rarely recognized, let alone developed, before students have a chance to enter higher education, losing many students to underachievement, as high school dropouts, and to other fields on which K-12 education tends to focus. This lack of challenging programming has consequences for spatially gifted students. According to

Mann (2006), students with spatial gifts tend to be undereducated and underemployed as adults compared to students with similar gifts in mathematical and verbal areas.

Even worse, as many children with spatial gifts have learning disabilities in the language arts, their disabilities can become the focus of their education, leaving their strengths ignored (Lohman, 1994; Mann, 2006; Silverman, 2005). Silverman (2005) has found that many spatially gifted students do poorly on auditory and sequential IQ test items leading to low overall scores despite excellence on visual-spatial items. She has observed that spatially gifted students may struggle with reading, writing, timeliness, and organization, leading to academic failure. This is detrimental as students do better, even in their areas of weakness, when education is focused primarily on their abilities (Grigorenko, Jarvin, & Sternberg, 2002; Sternberg, Grigorenko, & Jarvin, 2000). Moreover, gifted students tend to decline both academically and emotionally when not challenged in their area of strength (Rogers, 2007; VanTassel-Baska, 2007).

Recently, giftedness in the spatial domain has gained some recognition as an area worthy of service in a few after school and summer programs, but students with spatial gifts are still largely neglected during the regular school day and thus are rarely challenged spatially outside of a few weeks in those special programs (Silverman, 2005; Webb, Lubinski, & Benbow, 2007). Traditional gifted programs and talent searches do not even look for students with high spatial ability, relying instead on math and verbal domains or general intelligence only (Webb, Lubinski, & Benbow, 2007).

Rogers' (2007) meta-analysis of the research on gifted students and challenge strongly suggests that gifted students tend to achieve more when provided with increasingly difficult practice in their area of strength on a daily basis. Without education in their area of strength, spatially gifted children are much less likely to develop into spatially talented adults (Lohman, 1994; Mann, 2006; Webb, et al., 2007). Failure to develop the talent of spatially gifted individuals is not only harmful to the individual children, but to society as a whole. What is the societal cost of an undeveloped cure or innovation? In order to maximize STEM innovation, it is imperative that K-12 schools provide programs that aid the talent development of spatially gifted children. Two large, longitudinal studies demonstrate this point.

Longitudinal Studies Involving Spatial Ability and STEM Outcomes

The importance of spatial ability in STEM disciplines has been known since before the launch of Sputnik (Super & Bachrach, 1957), but through the flurry of interest in STEM education that followed that launch to the relative quietude in K-12 STEM education today, spatial ability has been neglected in curriculum and instruction (Webb, et al., 2007). While schools have been indifferent to students' spatial abilities, research has solidified the importance of spatial ability in STEM fields. In particular, the Study of Mathematically Precocious Youth (SMPY), a 50-year longitudinal study of talent search participants, has demonstrated that high spatial ability is predictive of STEM success (Flanagan, 1979; Shea, et al., 2001; Wai, et al, 2009; Webb, et al., 2007).

SMPY is important not only because of its focus on factors of success in STEM fields and because its size and longitudinal reach gives it credence far beyond shorter studies, but also due to its focus on gifted children. Gifted children, as argued above, are a neglected special needs group with incredible unfulfilled potential. Those with high spatial ability are especially capable of STEM innovation. Wai, et al. (2009) recently reported on SMPY and connected it to a previous longitudinal study involving spatial ability, Project Talent. Students were identified for SMPY by scoring in the top 0.5% on the math portion of the SAT when taken early at age 13. These adolescents were then given a composite of spatial assessments which are discussed later in Chapter 3. Starting in the 1970s, SMPY has followed its former participants at 5, 10, and 20 year intervals by collecting biographical, educational, and occupational information. In the 1990s, SMPY researchers also began to collect data with a questionnaire on occupational preferences of adolescents within the top 3% on the SAT. The researchers found that spatial ability accounted for an additional 3% of the variance in STEM leisure activities, college majors, and desired occupations beyond the variance accounted for in the SAT-M, SAT-V, and the occupational questionnaire. While the 3% sample is a broader spectrum of talented adolescents than the 0.5% sample, the authors note that it is still not a random sample of high ability learners, but drawn from highly motivated students interested in participating in challenging programs. This problem was addressed in Project Talent, a longitudinal study of approximately 377,000 randomly selected high school students followed over 11 years after initial assessments.

Principal investigators Flanagan, Tideman, Clemans, and Wise (1960-1974) gave participants verbal, math, and spatial ability tests along with content tests and measures of personality, interests, and attitudes over the course of one week in 1960. The National Archive of Computerized Data on Aging (NACDA) (2010) reports that Project Talent ran from 1957-1974, from shortly after the launch of Sputnik to overlap the start of SMPY. The study was designed to "investigate the personal, educational, and experiential factors that promote or inhibit the development of human talents" (Flanagan, et al., 1960-1974, ¶ 2). The participants were high school freshman, sophomore, junior, and senior students, approximately evenly distributed by grade and gender drawn from over 1000 schools across the U.S. (NACDA, 2010). Researchers followed up with participants at 1, 5, and 11 year intervals, and are now planning a 50 year follow-up (NACDA, 2010). The spatial composite consists of four sections and is described in Chapter 3 of this study.

Wai, et al., (2009) suggested that, if spatial ability data from SMPY, a sample of highly motivated gifted students, aligned with Project Talent, a random sample, that 50 years of longitudinal data among such a large sample would solidify the importance of spatial ability in STEM expertise. Ninety percent of participants in Project Talent who had earned a Ph.D. in a STEM field by the end of the eleven-year follow-up had spatial ability in the top quartile. In fact, 45% of STEM doctorates were awarded to participants in the top 4% of spatial ability. Another important finding from the Project Talent data was that more than half of the participants in the top 1% of spatial ability were not within the top 3% of math and verbal ability, making them prone to exclusion from talent searches as well as from gifted programs where spatial assessments are not employed. These students have little chance of receiving an education appropriate to their abilities. Wai, et al. (2009) call for more research on educational opportunities for the spatially gifted.

Spatial Intelligence: A Broadly Useful Intelligence

Spatial ability is necessary in many STEM fields, including geography, physical science, and computer programming, engineering, robotics (Snow, 1999; Wai, et al., 2009). Therefore, students with significantly higher spatial ability than their age peers are particularly well-suited for STEM careers (Webb, Lubinski, & Benbow, 2007; Wai, et al., 2009), and all gifted students are in need of special programming to meet their learning needs (Rogers, 2007).

This portion of the literature review seeks to examine the breadth of which spatial abilities have so far been explored in STEM educational settings, including geography, physical science, computer programming, engineering, and robotics in order to aid the direction of future research investigating programs and curricula that can provide appropriate challenge for the spatially gifted. Some research suggests that spatial ability manifests developmentally, some research suggests that spatial giftedness is co-morbid with learning disabilities, and some research suggests that spatial ability manifests with significant gender differences. Most importantly, a growing body of research suggests that spatial intelligence is malleable through treatment. If it is, this has important implications for the potential of spatial curricula and programs to increase the pool of STEM talent.

Geography

Within education, geography appears to be the field with the greatest involvement in investigating the role of spatial ability. An ERIC search with the terms "geography" and "spatial" reveals 472 articles. A similar search for "engineer" and "spatial" reveals only eight articles; "robot" and "spatial" offers only three. Within geography, a great deal of research is being conducted on orientation with the use of various computer applications.

Looking at Taiwanese junior high students' small-scale spatial ability, large-scale environmental cognition, and geographical knowledge using Google Earth, Lei, Kao, Lin, and Sun (2009) used available data as indicators of student ability and achievement before the study. Grades in geography were used to assess prior knowledge, spatial ability was measured with mental rotation, and environmental cognition was assessed with sketch maps of the school neighborhood. Students were asked to complete 16 landmark searching tasks in Google Earth with the search feature disabled, thus forcing participants to search for the landmarks based on their knowledge of their school region. The authors found the strongest predictor of success to be the sketch map followed by spatial ability. While the authors did not re-assess students, they suggest that using software such as Google Earth is an engaging tool for children to learn geography and its use in schools should be expanded.

Lim (2005) studied how adolescents construct meaning about their local environment using computer graphics, photo-realistic panoramas, and paper maps. The author used a pre- and post-assessed set of two intervention activities. The first had students in pairs using cell phone text and picture messages to navigate unfamiliar territory. The second required the students to take pictures of objects in their neighborhood that represented geographic themes taught in class.

Both females and males made significant gains in rotation and orientation of perspectives, but males consistently outperformed females in all categories. The author suggests that field trips, such as those in this study, are an apt way to improve orientation, an aspect of spatial ability.

These orientation studies are similar to programming LEGO robots to navigate a LEGO table through the use of computer software. Likely, high spatial ability is key to success in these activities, as children must visualize how they want their robot to make precise moves while programming before the robot can move. The above studies' primary importance in regards to this study is in showing that spatial ability is a predictor of success and that spatial ability is malleable.

Physical sciences

The physical sciences require spatial ability to visualize what cannot be seen, among other uses. For example, a chemist may need to visualize a molecule to predict how it will react with other molecules and a physicist may need to visualize how particles will move when they collide. Few studies regarding spatial ability within the physical sciences have strong relevance to this study, but the following study is suggestive of the malleable nature of spatial ability and thus supports the research hypothesis of this study.

Urhahne, Nick, and Schanze (2009) reported on three studies of student chemistry learning about carbon structures using two-dimensional models on paper compared with student learning using three-dimensional models on a computer. Two studies involved college freshman and found no difference in their learning between the two models. However, the third study involved sixteen-year-olds and found a significant advantage to using the three-dimensional computer simulation. The authors believe that this is due to the college freshman having already experience learning from the two-dimensional model whereas most of the sixteen-year-olds were learning this level of chemistry for the first time. Of particular interest here, the authors found a positive relationship between spatial ability and conceptual understanding. This replicates findings from similar research in the sciences (e.g., Piburn, Reynolds, McAuiffe, Leedy, & Birk, 2005; Yang, Andre, & Greenbowe, 2003).

As with the studies in geography, Urhahne, et al. (2009) also suggest that spatial ability is malleable in its finding that college freshmen do better on a 3-D activity when compared to sixteen-year-olds who lacked prior experience with the models. While this may be related to age, studies with younger children discussed later in this chapter suggest otherwise.

Computer Programming

Computer programming has obvious similarities to LEGO robotics in that LEGO robots require students to write programs for them to run. The asynchronous nature of computer programming requires spatial ability in order to visualize the desired outcome even though programs must often be written in small increments before the program, such as a game, can be fully run.

Hong, Cheng, Hwang, Lee, and Chang (2009) created and tested a form for assessing educational video games. Spatial ability was included as one facet amongst mentality change, emotional fulfillment, knowledge enhancement, thinking skill development, interpersonal skills, and bodily coordination. In regards to spatial ability, the authors considered three possible ways in which learning video games should include spatial features: 1) to develop players' spatial navigation skills, 2) to develop players' ability to perceive objects from different angles, and 3) develop the ability to identify the original shape of an object that has been turned into a different shape. The assessment has been field tested and the authors suggest that more testing is now warranted to refine the instrument. While this instrument is still in development, the three suggested features for spatial learning are all required in the use of LEGO robotics. Thus, the proposed study is concomitant with Hong, et al.'s (2009) proposed spatial features.

Engineering

Along with computer programming, engineering is the most directly connected field to LEGO robotics aside from robotics itself, which can be considered a subfield of engineering. The following studies are drawn from the engineering education literature because of their specific focus on spatial ability.

Noting that spatial ability is related to achievement in engineering courses and that some research suggests that spatial ability can be improved with training (e.g., Sorby, 2005), mechanical engineering professors Onyancha, Derov, and Kinsey (2009) set out to compare freshman engineering student spatial ability improvement through targeted training in specific spatial skills compared with participation in a computer-aided design (CAD) course already shown to increase spatial ability (Sorby, 2005). The authors found that both the CAD course and the targeted training improved students' spatial abilities to similar levels, but that the targeted training did so in the least amount of time. However, combining both did not further improve students' spatial ability. While this study showed an improvement in spatial ability, it begs the question: How much can spatial ability be improved? While beyond the scope of this study, future research studies could be derived from this question.

Potter, Van der Merwe, Fridjhon, Kaufman, Delacour, and Mokone (2009) used 20 years of data collected regarding engineering students' spatial ability and pass rates in an engineering graphics course as well as on student spatial improvement by participation in the course. The authors found that spatial ability is an important influence on academic performance and that it can be increased through intervention, corroborating Wai, et al.'s (2009) longitudinal findings with a less select group. High imagery instruction is recommended as an intervention before participation in the engineering graphics course. Unfortunately, the article does not explain the details of how high imagery instruction was utilized.

Computer programming and engineering design software have obvious connections to robotics, especially in the need for spatial ability to manipulate visual images before they come to fruition. Robotics adds the key element of the tangible device which must be designed, engineered, and programmed.

Robotics

A great deal of work involving robotics has been conducted, some of which includes spatial ability. In some instances, literature not including spatial ability but including engineering has been included because of the strong connections between spatial ability and engineering, a field where talent can be developed from spatial ability.

Geeter, Golder, and Nordin (2002) wrote about their experience helping to found new teams in Iowa as part of an Iowa University of Science and Technology project to encourage children and adolescents to pursue engineering. The researchers found that middle school students competing in FLL gained a better understanding of engineering; improved creative thinking, critical thinking, and problem-solving skills; and increased self-confidence levels, interest, and involvement in science and math. They note that many of these skills will be important regardless of what career path students take. The authors also concluded that the biggest challenge was finding dedicated adults to coach the teams.

Verner (2004) used a platform similar to LEGO robotics in it programming called Robocell. However, Robocell is dissimilar in that it is not student constructed, but an arm that students manipulate through five joints. Students write programs to have the arm do various manipulations, including to solve a Soma puzzle (seven unique shapes that form a cube when correctly assembled). Verner looked specifically at middle and high school student gains in spatial perception, mental rotation, and visualization. Verner notes the relevance of spatial ability and robotics use in the classroom:

> Designing robot manipulations involves spatial perception, spatial reasoning and visualization skills. Different spatial representations of the robot and the environment are required to perform analysis of robot movements, their visual verification and physical manipulation of objects in the robot workspace. The designer ''thinks with a robot,''[that is, the designer] uses it as a frame of reference for the performance of spatial operations. (p. 218)

The pre- and post-course assessment consisted of 12 pencil and paper tasks, but no further information is provided. After treatment, 128 middle school students improved from an average of 46.5% correct on the pre-assessment to 62.4%. Broken into the subsets considered, perception and visualization gains were found to be significant while gains in mental rotation were not found to be significant. The author suggests that the lack of gains in mental rotations may be due to the course focus, but participants also scored very highly on the pre-assessment. It could also be that the instrument allowed for too little range or that the participants largely had prior experience with mental rotation. A similar study with 31 high school students by the author reported in the same article found similar results, albeit with a different instrument. In this case, rotation and visualization were significantly improved, but perception was not. Again, the students had very high pre-assessment scores in this area, suggesting that the test did not allow for a span of abilities. While the article has some weaknesses, it adds to the understanding of spatial ability as malleable under treatment.

Petre and Price (2004) conducted a qualitative study based on several robotics competitions, including FLL competitions, and determined that robotics works effectively as an engaging vehicle to guide children toward an effective understanding of programming and engineering principles, and that this learning was generalizeable to other programming and engineering situations. The authors conducted semi-structured interviews with coaches and team members at robotics competitions in the Seattle area. Key themes that emerged included students' desires to complete the tasks ("It's like a video game… You want to have it done"), the open-endedness of competition ("you can always improve it"), and the social context ("It's interesting meeting new people and showing how good you can be"). While this study is not in the gifted literature, nor even mentions giftedness outside of a citation on problem-based learning from *Gifted Child Quarterly*, each of these themes relates to gifted students, especially the need for challenging and open-ended tasks (Coleman & Cross, 2005; Davis & Rimm, 1998) and the benefits of working with ability peers (Coleman & Cross, 2005; Neihart, 2007; Rogers, 2007). This study suggests that a quantitative study of pre-post gains in science content may yield positive results. While the study does not focus on spatial ability, the connection to engineering, science, and computer programming lend themselves to the conclusion that spatial intelligence may likewise be improved through this robotics competition.

Swartz (2007) conducted a qualitative study that also included a Likert scaled survey with twelve 11 and 12-year olds in a remedial class using LEGO robotics to learn about their own learning styles. The survey asked students about their learning styles. The students then participated in a LEGO robotics unit and wrote blogs reflecting on their experiences. Finally, the students took the survey again. Swartz (2007) found that students felt that they learned more about their own learning needs and improved in geometry, physics, and problem-solving. She suggests that the constructivist approach is facilitated in a classroom utilizing LEGO robotics and noted that some students who struggled in a teacher-centered classroom naturally moved into leadership roles in a student-centered environment.

Wang, LaCombe, and Rogers (2004) used LEGO robotics in undergraduate sophomore and junior-level coursework, including such concepts as data acquisition, numerical methods, dynamics, statics, motor performance, fluid dynamics, feedback control, and strength of materials. The authors found several benefits to using LEGO robotics over traditional means of teaching, including data collection, graphical programming required no prior knowledge, students could conduct their research at home, it seemed like play and thus increased time on task, and students had more freedom to design experiments on their own. While this study is aimed at college students, other studies with younger student suggest a great breadth of ages with which LEGO robotics can be used in STEM education.

Williams, Ma, Prejean, Ford, and Lai (2007) conducted a mixed-methods study of LEGO robotics use effect on scientific inquiry and physics content. The authors chose to conduct this study because of their perceived lack of empirical evidence supporting LEGO robotics use in the regular classrooms despite the success of FIRST LEGO League. The authors suggest that content gains will convince more schools to include robotics in their programs. The authors gave a pre-assessment to 21 middle school students participating in a summer program (however, the study included only three girls). The assessment included both questions about Newton's laws of motion and about scientific inquiry. Among other qualitative data sources, the authors also interviewed seven of the ten adult facilitators and interpreted the results in an ethnographic aspect of the study. They found statistically significant improvement in physics content knowledge, but not in scientific inquiry. The qualitative data helped to make sense of the findings. Although a problem-solving method was introduced and a wealth of interview discussion focused on scientific inquiry compared to a relative paucity on physics, students primarily used trial and error to solve problems. The authors believe that this accounts for the lack of progress in scientific inquiry. For the specific purposes of this study, physics may be considered more important as it more directly relates to spatial ability.

The use of robotics as a learning tool has many potential benefits, demonstrated in the research detailed above. Physics content knowledge, breadth of usefulness among many ages, facilitates engineering and computer programming learning, creative thinking, critical thinking and problem-solving, self-confidence, and, most importantly, spatial ability improvement. Still, further research is needed to demonstrate LEGO robotics specific improvements in spatial ability among children and adolescents, using a commonly-accepted valid and reliable instrument, as detailed in Chapter 3. Other factors, including age, gender, and disability are also at play and may influence children's evidence of spatial abilities.

Spatial Ability and Age

Age is possibly related to spatial ability, but exactly how remains unclear. Often, as is detailed in the studies below, it is difficult to separate age and prior experience. Age is particularly important to this proposed study's inclusion of participants between the ages of 9 and 14. Many of the studies detailed earlier involve participants in high school and college. If participants in the proposed study do not improve as predicted, age could be a possible explanation.

Learmonth, Newcombe, Sheridan, & Jones (2008) conducted a reorientation study with 20 three-year-olds, 20 five-year-olds, and 16 six-year-olds designed to determine the age where children use geometry and other features to reorient themselves. Children were taken to a rectangular room where all four walls were identical except for the color of one wall and that two walls were longer than the other two walls. Children were asked to hide a toy in one of four identical boxes, each in a different corner so that none was immediately in front of the colored wall. The children were then spun around with their eyes closed. They were then asked to locate the toy. Six-year olds were correct 74% of the time, while five and three-year-olds were only correct 50% and 36% of the time respectively. A second experiment was conducted with identical methodology except that the space was made larger and the toy was hidden in the box in front of the colored wall. Three-year-olds still chose randomly while five and six-year-olds were both generally successful. The third experiment involved three, four, and five-year-olds. Six-year-olds were not needed as it was determined that five-year-olds performed approximately as well in the first study. In this case, children were told not to step over a taped outline in the center of the room. The experimenter then hid the toy while each child watched.

Children were then disoriented and asked where the toy was located. Three-year-olds chose the opposite corner about as often as they chose the correct corner. Four and five-year-olds chose the correct box the majority of the time. The authors point to change over time to suggest that reorientation is a developmental process. While this study is not particularly related to the proposed study, it investigated among the youngest children of the available studies. The finding that four-year-olds were able to reorient as well as older children suggests that the youngest participants in the proposed study will be able to perform ably in orienting their robot.

In a study involving participants within the age range of the proposed study, Uttal, Fisher, and Taylor (2006) consider three ways by which people obtain spatial information including maps, verbal descriptions, and actual navigation in the environment. Two experiments were conducted. The first involved eight and ten-year-olds as well as adult college students. Each was given either a verbal description or a map of a six room layout (each room containing a different animal) to study. Participants were then asked to construct the environment with cardboard cutouts. Those provided with the map did significantly better than those provided with the verbal description. Ten-year-olds performed similarly to adults, while eight-year-olds performed less well as they generally failed to arrange the rooms into a single large rectangle. The second experiment followed up on the first, involving only eight-year-olds. The participants were shown the shape of the complete layout along with having the verbal description. Their results then more closely resembled the older children's and adults' success. The authors debate whether eight-year-olds are simply not able to form a six room mental model or if they simply have trouble with the difference between left and right. This study suggests that at least the majority of participants in the proposed study should have developed suitable spatial ability to be able to participate ably.

In a study that differentiated between seven and nine-year-olds, Lange-Kuttner (2009) examined children's replications of figural drawings with spatial axes, denoting changes in size as well as children's free drawings of their friends from varying angles were examined for proportion between four age groups: seven, nine, eleven, and seventeen. Students were randomly selected from four convenient schools in the United Kingdom. While maintaining a large sample (N=297), the study suffered from high rates of attrition apparently because of the length of the instrument (25 drawings). This may have caused a non-random selection for participants who had greater persistence, higher drawing ability, or more interest in drawing than the general population. The study found that seven-year-olds made some attempts to adjust by size in parts of the picture, but nine-year-olds were found to be significantly better at adjusting size accurately for the entire picture. Eleven and seventeen-year-olds were found to be similar. The author concludes that a sense of proportion is developmental and generally occurs between seven and nine-years of age, confirming that by age 9 students should have well-developed spatial ability. In a similar study, De Bruyn and Davis (2005) drew on literature from the 1970s and 80s to determine that drawing is a good indicator of children's spatial coding development. With small samples of four (N=13), five (N=15), six (N=15), and seven-year-olds (N=15), the authors provided a simple drawing task to draw a line across a page with differing background patterns of short lines either vertical or at an angle to determine the effect on the differing age groups, predicting that the angled lines in the background would disrupt the task and the vertical lines would make the task easier. The authors found that the vertical pattern was no benefit to the younger children who were disrupted by the background pattern, but that seven-year-olds' drawings were similar to adults in that they performed well regardless of the background pattern. The authors conclude that seven represents a typical milestone for children in their spatial coding development.

In a final age-related study, Verhaegh, Resing, Jacobs, and Fontijn (2009) compared children's success with physical and virtual visual-spatial puzzles. A group of 26 randomly chosen five to seven-year-olds were randomly assigned to either a group that received a randomly-chosen physical puzzle first, followed by a randomly-chosen virtual puzzle or to a group that receive their puzzles in the opposite order. The authors found that regardless of the presentation order and age, children solved the physical puzzle faster. The participants were also observed to engage in obvious problem-solving behavior more often with the physical puzzle. This supported their hypothesis that a tangible puzzle is more appropriate for young children. The authors speculate that the computer interface requires other skills, unrelated to the task at hand, causing lengthier times for solving the virtual puzzles. This study suggested that children may have more difficulty programming the robot than physically building and manipulating it.

While far from conclusive about the age at which children can be predicted to correctly perform basic spatial tasks, the majority of the research presented suggests that it will not be a concern in children older than 8. As the proposed study involves participants ages 9 to 14, age is not predicted to be a factor in the ability to perform the basic spatial tasks required to participate in LEGO robotics. Future research may need to focus specifically on a possible relationship between spatial improvement under treatment of LEGO robotics and age, but the research presented does not suggest that one exists. However, given the evidenced developmental nature of spatial ability, it is likely that older students will perform better in learning new spatial material, such as designing, building, and programming LEGO robots.

Spatial Ability and Disabilities

While abilities generally correlate, high spatial ability does not correlate as well with math and verbal abilities as well as math and language correlate with each other. Wai, et al. (2009) found that the spatial composite used in Project Talent correlates with math only at .61 and language only at .59 while math and language correlate with each other at .76 in a sample of 100,000 high school freshmen. Therefore, it is somewhat less likely that those gifted in the spatial domain are also gifted in math or language than it is that those gifted in language are also gifted in math. In fact, some research suggests that students with spatial gifts may be more prone to certain other exceptionalities, including learning disabilities and underachievement. Spatial ability may also be negatively impacted by attention deficit hyperactivity disorder (ADHD) and anxiety disorders.

The Gohm, Humphries, and Yao (1998) study can be considered the most important one regarding deficits among the spatially gifted, given its focus on comparing spatially gifted students with mathematically gifted students and its size. Drawing about 1000 participants from the Project Talent data base who were seniors in high school in 1960, the researchers made two, approximately even groups in number and by gender: one in which the participants were in the top 1 percent of their gender in spatial ability and one in which the participants were in the top 1 percent of their gender in mathematical ability. Those who overlapped were eliminated, producing a final N of approximately 1700, split into the four groups by ability and gender. While the students all had high general ability and were all assumed to have strong chances of academic and career success, those with higher spatial ability did not perform as well in high school and college and went on to take lower paid occupations. The researchers suggest that college admissions officials, focused on math and verbal abilities, and guidance counselors, intent on tracking spatially able students into technical schools, may both contribute to the problem. They suggest that the educational system must provide supports so that the spatially able are able to fully develop their talents; otherwise, the loss of talent to society will remain great.

A smaller, qualitative study found similar themes. Noting that students with spatial giftedness only rarely have the opportunity to focus on their area of strength in traditional, American high schools, Mann (2006) conducted a qualitative study to determine effective teaching strategies for twice-exceptional students who are spatially gifted. Mann noted that many common teaching strategies are ineffective in teaching such twice-exceptional students, including "rote memorization, forced oral reading, text-based instruction, and use of teacher-directed activities" (p. 113). She advocated that teachers use higher level thinking through the use of inductive learning strategies, a holistic approach, and interdisciplinary units along with "accommodations such as graphic organizers, spell checkers, word processors, mnemonics, tape recorders, speech-to-text software, and audio-recorded literature and textbooks" (p. 113). Mann used purposeful selection of teachers at a school specializing in students with learning disabilities and triangulated classroom observations, school policy statements, and interviews with teachers and an administrator. She found three key themes emerged: an atmosphere of caring, accommodations that were student-oriented, and learning that was student-centered. The latter suggests particular benefits of LEGO robotics use for spatially gifted students with learning disabilities as it lends itself well to constructivist learning.

Chan, et al. (2009) observed 28 closely-matched children, 14 control and 14 diagnosed with ADHD, who ranged in age from eight to fourteen-years. Using a computer to provide distracters and a stimulus coming from either the right or left, children with ADHD were found to perform significantly more quickly than the control children in perceiving the stimulus when it came from the left and there were few distracters (Cohen's d=1.26). However, children with ADHD significantly underperformed the control group when the stimulus came from the center or the right and there were few distracters. When many distracters were visible, all children performed about the same regardless of the direction the stimulus came from or ADHD status. The experimental sample only included two females; the gender ratio of the control group was 8 males to 6 females. This is problematic as boys and girls generally appear to display different characteristics in regards to some ADHD symptoms such as hyperactivity and inattention. The study benefited from showing that the group means differed significantly on five scores of ADHD, but were similar in IQ and achievement.

In their literature review, Mueller, et al. (2009) noted that animal studies primarily involving purposeful brain legions in rodents suggest that anxiety disorders are related to hippocampal dysfunction. However, as the authors remind us, interspecies differences make the research questionable in regards to humans. Recent research using fMRI suggested that anxiety and spatial ability (e.g, Iaria, Chen, Guariglia, Ptito, &

Petrides, 2007) are both reliant on the hippocampus. Thus, the authors set out to investigate spatial navigation in anxiety disorders with 34 children aged 9-14 with anxiety disorders and 35 control children using a water maze computer simulation task. As predicted, the authors found spatial navigation deficits in children with anxiety disorder. However, the children with anxiety disorders tended to improve over repeated trials, eventually performing similarly to the control group. The authors posit that the children with anxiety disorders may have begun using different strategies to improve on the task to compensate for impaired spatial ability. They suggested that future research investigate the strategies children use on such tasks. The authors were surprised that females generally performed almost as well on the spatial tasks as males, based on research on gender differences with spatial abilities. They posited that this may be due to a largely prepubescent sample and suggest that significant gender differences may emerge after puberty.

Many factors play into an individual's spatial ability. Some may be connected to it, including verbal deficits and underachievement. Although the former is very speculative, it is an important area for further research. The latter has very solid evidence from a large, longitudinal study and should be a primary reason for schools to adopt programs that incorporate spatial education into their curriculum and instruction. For institutions of higher education, especially engineering and science-focused universities, including spatial ability in their selection process could be very beneficial to improving the pool of STEM talent graduating. Neglected so far is another major influence on spatial ability: gender.

Spatial Ability and Gender

Explorations of spatial ability have demonstrated significant sex differences. The difference is so acute that Lohman (2005) suggests using this knowledge to determine if a reasoning ability test is also measuring spatial ability:

> The presence of sex differences provides a good way to distinguish between figural tests that measure spatial ability and those that measure reasoning abilities with figural stimuli. Good tests of spatial ability will show effect sizes for sex of .5 SD or more, whereas good nonverbal reasoning tests show no sex differences. (p. 114)

Of course, while this applies in general, there are spatially-able females. Females in the top 20 percent of spatial ability measures tend to be three times more likely to major in physical sciences, mathematics, engineering, and computer science as their high-verbal same-sex peers while males are only twice as likely to major in those subjects as their high verbal-ability same-sex peers (Humpheys et al., 1993). Likewise, females in the top 20 percent in spatial ability are nearly four times as likely to major in art fields as their high-verbal same-sex peers while males are only twice as likely to major in those subjects as their high verbal-ability same-sex peers (Humpheys et al., 1993). Many studies suggest such a gender difference while also suggesting that both sexes can improve on spatial ability with treatment. As spatially-able females are proportionally more likely to go into the above fields, improvement in spatial ability may have an even stronger impact on female outcomes than male outcomes.

Saricaoglu and Arikan (2009) administered the Multiple Intelligence (MI) Inventory for adults, a Likert scale activity preference survey based on Gardner's (1983) theory of multiple intelligences, to 144 Turkish college students and found that students self-identified as preferring spatial activities second only to logical-mathematical activities. The authors make a mistake in calling the inventory an intelligence test as opposed to an interest survey and in referring to students either having an intelligence or not, without consideration for tertiary preferences. Due to these issues, the phrase "preference for spatial activities" will be used here to describe the findings. The study looked at multiple intelligence preference and grammar, writing, and listening in foreign language classes. The authors found no significant gender difference for spatial preference with similar numbers of females and males self-selecting spatial activities as top preference. This finding is interesting as others suggest that males tend to prefer spatial activities more often than females (e.g., Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000), but this may be due to sampling error as this study only sampled college students. It may also be due to differences in methodology: Benbow, et al.'s (2000) research contains longitudinal career data, and this study is based on a single inventory of preference. The authors found a low, but statistically significant, negative correlation between grammar and preference for spatial activities (-0.172), but no significant difference was found with listening or writing activities. Since Mann (2006) notes that spatially gifted students may be prone to reading and writing disabilities, this finding is not surprising although this study does not consider giftedness or learning disabilities specifically.

Spence, Yu, Feng, and Marshman (2009) provided a thorough literature review, suggesting that women generally do not perform as well as men in spatial activities, especially mental rotation. Of particular note in the literature review is a meta-analysis of

113 studies on spatial ability and gender conducted by Liu, Uttal, Marulis, and Newcombe (2008). They found that improvement can be made on spatial tasks with training, with those performing lowest initially making the largest gains after intervention. The meta-analysis also revealed that, while improvement with intervention was made by both sexes, women generally do not perform as well as men before or after intervention. However, noting several studies contrary to the conclusion of the meta-analysis, Spence, et al. (2009) set out to delineate reasons why women perform as well as men in some studies. The authors found that many studies involving computer games as interventions showed a statistically insignificant gap between men and women's spatial abilities. The authors identify four possibilities for gender disparity found in spatial ability research. These are differences in (a) methodology, (b) spatial tasks, (c) training methods, and/or (d) participants' prior experience with spatial activities. The authors do not mention the possibilities of physiological factors, gender-based stereotype threat, or societal gender norms with the activities utilized.

The authors' choice to use a first person shooter video game is vigorously defended as a complex spatial task, requiring players to "attend to multiple objects whose features, presence, and positions change rapidly and continuously" (p. 1098). Ten male-female matched pairs were selected based on similar scores in a spatial attentional task from an original group of 43 college students. The participants then underwent 10 hours of training with the video game before participating in the same spatial attentional task as a post-test. The group mean improved from 44% to 54% in spatial attentional accuracy. The study found no significant differences in spatial attentional accuracy gains between males and females.

Future research will need to determine if the gender differences suggested here are due to biology or cultural influences or both. Most importantly for the proposed study is the finding that girls can make similar gains in spatial ability to boys under treatment.

Academic Competition

Academic competitions hold possibility for infusing spatial challenge into educational settings and are a powerful way to help meet the needs of gifted students both academically and affectively. Ozturk and Debelak (2008a) identified several ways in which academic competitions help meet the needs of gifted learners including using higher order thinking, working on challenging tasks, creating products with unrestricted levels of excellence, and working in groups of ability-peers. Omdal and Richards (2008) found that mentorships, open-ended problems, and autonomous student work were other factors in many academic competitions that were advantageous for gifted children. Beneficial outcomes for gifted learners, depending on the competition, are many-fold and include increased creativity, improved self-concept, aid in talent development, and higher goal-setting (Omdal & Richards, 2008). Ozturk and Debelak (2008b) also identify several affective benefits for gifted learners in academic competitions, including increased motivation, nurturance of a healthy self-concept, coping with subjectivity, and opportunities to meet scholarly role models. As academic competitions attract students with talent within that field and generally have no ceiling for excellence, most provide excellent challenge for the gifted (Omdal & Richards, 2008). As academic competitions are highly motivating (Omdal & Richards, 2008), they may engage students who typically underachieve (McCoach, & Siegle, 2008). Many competitions are widespread and generally have set rules and regulations, thus they can easily be replicated for new teams or individuals, allowing gifted students across the country chances to participate (Coxon, 2009). There are competitions in almost every conceivable field and for all grade levels (Coxon, 2009). Intervention studies involving academic competitions are likely to demonstrate student gains in the processes involved within the competition. The literature on problem-based learning (PBL) is illustrative of this likelihood.

PBL an instructional method in which students are given a real-world, ill-structured problem statement. Students generally work in teams and must determine what they know, what they need to know, and how they plan to find out using resources such as experts and processes such as scientific investigation, critical thinking, and research. The application of these processes is generally hands-on, that is, the students are often conducting experiments. This is not unlike many academic competitions in which teams of students must come up with solutions to various problems. PBL began in medical education. A meta-analysis of PBL (Gijbels, Dochy, Bossche, & Segers, 2005) focused on studies in medical education (notably, the 2010 FLL theme, *Body Forward*, focused on medical technology) found only a small positive effect size overall (.068) when all measured outcomes are considered, but a very large effect size on understanding concepts and principles (.795). The authors conclude that students path toward expertise is accelerated by PBL interventions. Intervention studies involving PBL units in K-12 schools have also demonstrated gains in student learning. For example, VanTassel-Baska and Bass (1998) and VanTassel-Baska, Avery, Hughes, and Little (2000) both examined science units utilizing PBL. Both found significant gains in student learning, particularly of the scientific process. It seems likely that academic competitions will produce similar treatment effects. Competitions involving aspects of spatial ability may likely produce gains in participant's spatial abilities. One of the most likely to be appropriately challenging for spatially gifted children is the FIRST LEGO League competition (FLL).

FIRST LEGO League

Meta-analysis has revealed that enhanced context strategies have the largest effect size of alternative science teaching strategies on student science achievement when compared to student achievement in traditional lecture-based classrooms (Schroeder et al., 2007). The authors define "enhanced context strategies" as presenting material in the context of real-world examples and problems by bringing the real world to students through technology or taking students out of the classroom into the real world through field experiences. Participation in the FLL, an academic competition based on a different real-world science theme each year, fits this definition both through the real-world use of technology as well as through field experiences (Coxon, 2009; 2010; US FIRST, 2009).

FIRST is the foundation For Inspiration and Recognition in Science and Technology. The not-for-profit organization "designs accessible, innovative programs that motivate young people to pursue education and career opportunities in science, technology, engineering, and math, while building self-confidence, knowledge, and life skills" (US FIRST, 2008a). The foundation sponsors the FLL for ages 9 to 14 years discussed in this paper as well as the new JuniorFLL for ages 6 to 9 years and two high school level robotics programs.

FLL is an international competition taking place in more than 40 countries and involving more than 15,000 teams with an approximate total of 150,000 children participating in the 2008/09 competition year (US FIRST, 2008b). Each year, a new real-world science topic is chosen. Recent topics have included nanotechnology, Mars, energy production, and global climate change. In the FLL, students are asked to design, engineer, and program a LEGO robot to perform tasks on a table set-up with LEGO objects related to the year's real-world science theme as well as to complete a research project based on that theme involving field experiences. For example, if the theme was energy use, students may design, engineer, and program a LEGO robot to place a LEGO solar panel on a LEGO house among other challenges, and they may research energy saving measures, complete an energy audit on a local government building, and then present cost-saving recommendations to local government officials (Coxon, 2009).

Teams register over the summer or in the early fall. Qualifying Tournaments (often called "regionals") are usually held in November or December with Championship Tournaments generally scheduled in early December or January. With more than 450 regional qualifying events scheduled in 2008 and more predicted in future years, children across the U.S. have the opportunity to compete. Every student participating in a FLL event walks away with a ribbon, but only a few teams earn trophies and plaques. This level of difficulty can be a great motivator for gifted students to do their best work.

Started in 1998, FLL is relatively new (US FIRST, 2009), thus only a few studies have so far been conducted. However, this early work shows promising potential. FLL has also been found to be highly motivating for children (Geeter, Golder, & Nordin, 2002), and motivation is positively correlated with achievement (McCoach & Siegle, 2003). Participation in FLL will very likely lead to achievement gains in science. The cost and time required are within a range that would be practical for most schools to afford, costing $70 to $100 per student and requiring about three hours or more per week for the competition period (Coxon, 2010). However, more rigorous research is clearly needed to see to what degree student' spatial ability will be improved through participation in FLL to determine its practical value to schools' desiring improvement in science achievement.

As enhanced context has been established as a highly effective strategy for improving student science achievement, specific enhanced contexts that work effectively to raise student science achievement need to be delineated for practical application by schools. Participation in the FLL has been suggested as a potential way to provide appropriate challenge for the spatially gifted (Coxon, 2009).

Many positive academic outcomes have been achieved in gains related to STEM fields through FLL participation, as determined in a study conducted by the Center for Youth and Communities (CYC) at Brandeis University. CYC found that 94% or more of all students participating in FLL had increases in the following areas: interest in science and technology, programming skills, understanding of how science and technology can solve real world problems, problem-solving skills, teamwork skills, and leadership skills (Melchior, Cutter, & Cohen, 2004). In a separate study by CYC, college outcomes have been determined through the FIRST Robotics Competition (FRC), the high school level program. The study found that, when compared to a control group of students with similar backgrounds, FRC participants were 35% more likely to attend college, twice as likely to major in a STEM field, nine times as likely to have an internship during their college freshman year, and twice as likely to perform community service (Melchior, Cohen, Cutter, & Leavitt, 2005). The FRC is a separate program for older students than the FLL, but as it is very similar in the processes undertaken by students and each competition is appropriately challenging to its respective age level, the study sheds light on likely long-term outcomes for FLL participants as well.

There is strong evidence, both from classroom use of robotics (LEGO and otherwise) and from participation in FLL competition, that gifted students, particularly those with high spatial ability, can benefit from the high challenge level. Geeter, Golder, and Nordin (2002) found that middle school students competing in FLL gained a better understanding of engineering; improved creative thinking, critical thinking, and problem-solving skills; and increased self-confidence levels, interest, and involvement in science and math. Students involved in the year's science theme can become active researchers, turning it into a tangible and meaningful inquiry experience that can then be shared with a real world audience (Coxon, 2010). In a similar vein, physics content knowledge was improved in a study of robotics in a middle school summer program (Williams, Ma, Prejean, Ford, & Lai, 2007).

Robotics has been successfully utilized at many levels. For example, robotics may have similar benefits for average and lower performing students as well. In research conducted in a remedial class of eleven and twelve-year-olds, students showed gains in understanding their learning style as well as in problem-solving skills (Swartz, 2007). LEGO robotics' use is not limited to school-aged children; it has also been used at the college level for training engineers.

Michigan Tech has a program for its engineering students to mentor FLL teams, helping to enhance their own students' engineering education while working to increase the future pool of engineering students (Oppliger, 2002). As robotics can be beneficial to lower achieving students and still provide challenge at the university level, it is likely that robotics curriculum and competition would be beneficial for spatially gifted underachievers and spatially gifted students with other exceptionalities such as learning disabilities. Furthermore, it is likely that, as children participating in FLL are actively engaged in STEM fields, they may become more interested in such careers and begin to pursue advanced classes in those subjects earlier (Webb, Lubinski, & Benbow, 2007).

Particularly apropos to this study, robotics has been used specifically for spatial instruction. Verner (2004) has used pre- and post-measures of middle and high school students participating in a robotics curriculum using kinematics, point-to-point motion, rotation of objects, and robotic assembly of spatial puzzles and found significant student progress in the tasks related to spatial ability. This suggests that treatments with spatial tasks can improve spatial ability. This malleability makes such treatments a potentially important means of increasing the population capable of high achievement in STEM fields. Also of special note, there is strong evidence to suggest that spatial training programs in one area are transferable to other spatial tasks (Newcombe, 2009). Transferability of improvement in one spatial task to another suggests that one treatment of a specific spatial challenge could generalize to positive gains in a number of spatial tasks within the wide domain of STEM disciplines.

Conclusion

Spatially gifted children, including those underachieving and those with other exceptionalities, need to be challenged in their talent area. This need is not fulfilled by most school curricula, but robotics curricula and competitions, such as FLL, hold promise for providing for this challenge need. Based on the literature presented here, the academic benefits of providing appropriate challenge for spatially gifted children will likely increase their spatial talents as well as tangentially include higher overall achievement; improved higher order thinking, creative problem solving, and critical thinking; increased content knowledge in spatial fields such as physics; improved process understanding in programming and engineering; and earlier pursuit of advanced coursework in science and math. Affective benefits should be equally numerous, including higher goal setting; improved motivation and self-concept; increased self-confidence levels, interest, and involvement in science and math; decreased depression, stress, and boredom; and opportunity for mentorship with scholarly role models. The benefits extend to society as well. By recognizing spatially gifted children and then providing them with appropriate challenge in their talent area, the future pool of students pursuing STEM fields such as architecture, medicine, dentistry, and engineering will likely increase.

Chapter 3

Methods

Six directional hypotheses were proposed in this chapter with an intervention involving usage of LEGO NXT robotics. The research design described includes: participants, instruments, and procedures, which include a description of the LEGO NXT robotics kit, coach training and fidelity, the timeline, and ethical safeguards. Further, an explanation of the analyses is provided.

Directional Hypotheses

Chapter 2 synthesized research literature wherein various treatments led to improvements in students' STEM aptitudes (e.g., Newcombe, 2009; Onyancha, Derov, & Kinsey, 2009), including a few studies that specifically considered the improvement of students' spatial ability with treatments involving robotics building, programming, and interaction (e.g., Verner, 2004; Waks & Merdler, 2003). However, given the importance of STEM fields to society as demonstrated in Chapter 1; the connection between STEM fields, spatial ability, and participation in robotics learning demonstrated in Chapter 2; and the lack of STEM and spatial foci in schools demonstrated in Chapter 1, the research base must be expanded to facilitate increased STEM-focused curriculum. In particular, curriculum which provides talent development opportunities for the spatially gifted, such as LEGO robotics curriculum, could prove to be valuable for increasing the pool of young people capable of achieving at high levels in STEM fields. Of particular importance, given the underrepresentation of women in many STEM fields, are the findings that although females tend to have overall lower scores on measures of spatial ability, their gains are similar to males under treatment (e.g., Liu, et al., 2008; Spence, et al., 2009). To move this research agenda forward, this study has investigated whether:

1a) A sample of students participating in an experimental FLL-based LEGO robotics unit will evidence significantly greater pre-post total test gains on a measure of spatial ability than a group of comparison students not participating in the FLL-based LEGO robotics unit.

1b) The effect size associated with the LEGO robotics treatment group's gains will be sufficiently large as to be considered practically meaningful (i.e., Cohen's $d > .30$).

1c) The effect size associated with the comparison group's gains will be sufficiently small as to be considered practically meaningless (i.e., Cohen's $d < .20$).

2) Total test pre-post gain scores on a measure of spatial ability *will not* differ for students in either treatment group as a function of student gender or traditional level of representation in gifted programs.

3a) Total test pre-post gain scores on a measure of spatial ability *will* differ for students in the experimental treatment group as a function of student age, with students in the older age group evidencing greater gain than students in the younger age group.

3b) Total test pre-post gain scores on a measure of spatial ability *will not* differ for students in the comparison treatment group as a function of student age, with students in the older age group evidencing gains equivalent to students in the younger age group.

4) The total sample of experimental treatment students will evidence significantly greater pre-post gains on the:

4a) mechanical reasoning subtest than the three-dimensional spatial visualization subtest;

4b) three-dimensional spatial visualization subtest than the two-dimensional spatial visualization subtest; and

4c) two-dimensional spatial visualization subtest than the abstract reasoning subtest.

5) Students' CogAt total Verbal Scale scores will correlate significantly and positively with the total test scores from the measure of spatial ability for students in both treatment groups.

6) Students' mean CogAt total Verbal Scale will not differ significantly between students in the experimental and comparison treatment groups.

Research Design

Participants

A stratified random sample (Gall, Gall, & Borg, 2007) was drawn from gifted programs from public schools in a Midwestern metropolitan area. To obtain a sample from that population, letters were sent to all identified public school gifted coordinators within 20 miles of the researcher's institution requesting that the included Participant Interest Form be sent home with all identified gifted students between the ages of 9 and 14. There were 29 school districts identified within the range. The letter described LEGO robotics, the nature of the study, and the intervention schedule. The Participant Interest

Form included a detachable form, asking for its return by May 16, 2011 (see Appendix E).

Gifted students were operationally defined as boys and girls identified by their school district as gifted and, as district definitions vary, be ranked at or above the 90th percentile on a standardized measure of ability (i.e., IQ or ability test part score at or above 120). While there is not broad consensus on definitions of giftedness (Sternberg & Davidson, 2005), establishing a cutoff at the 90th percentile was chosen as a sample size to produce distributions with enough variation to examine correlations between intelligence and improvement on the spatial composite over the course of treatment.

The Participant Interest Form included a place for the students' name, age, school district, gender, ethnic background, free and reduced lunch status, and current grade level as well as parent or legal guardians' names, e-mail addresses, and phone numbers. The Participant Interest Form included a statement informing possible participants that only 40 students would be selected for each group (80 students total) using stratified random selection and a statement asking for only gifted students between the ages of 9 and 14. Participant Interest Form forms were requested to be returned by mail or e-mail to the researcher, postmarked or sent via e-mail by May 16, 2011.

Special efforts were made to obtain a sample representative of the population, including students from ethnic and economic groups traditionally underrepresented in gifted programs (e.g., Latino, Black, and low socio-economic status [LSES]). In particular, the researcher discussed the study face-to-face with the gifted coordinator of the region's largest district, which also contains the largest numbers of students who are Black or Latino, as well as those who are of LSES. The researcher asked her to encourage all gifted students to submit a Participant Interest Form, including those from the previously mentioned underrepresented groups. She agreed.

Responses were received from parents or guardians of students in 16 districts. There were 144 Participant Interest Forms returned by mail and e-mail by the deadline. Approximately 15 more Participant Interest Forms were received after the deadline and were discarded. Only two incomplete Participant Interest Forms were received and both were discarded. To select the groups, the forms were sorted into the categories listed in Table 1: age (9-11 and 12-14), gender (male and female), and ethnic background/SES (traditionally represented in gifted programs [high SES, White, Asian] and traditionally underrepresented in gifted programs [LSES, Latino, Black, and all other ethnic groups]). The researcher sought to draw ten students from each group at random, but there were fewer females, older children, and children from groups traditionally underrepresented in gifted programs than desired. The remaining numbers were filled with students from the least represented groups with remaining unselected forms from categories with more than 10 students, as stated in the proposal.

Table 1

Group categories

Treatment	**Comparison**
10 old males, underrepresented	10 young males, underrepresented
10 old females, underrepresented	10 young females, underrepresented
10 old males, represented	10 young females, represented
10 old females, represented	10 young males, represented

Participating students' parents or legal guardians were all contacted by e-mail or phone (when an e-mail address was not provided) to ensure that the students were still willing and able to participate in the study. Depending on participants' selection status, they received one of the three letters found in Appendix F. Two parents of potential participants notified the researcher that their children could no longer participate. Two more students were selected to participate in the study at random from the remaining pool of unselected students. All selected participants were sent a set of forms for checkout procedures, medical needs, and rules for participation (see Appendix D).

After selections, there was representation from 13 school districts. Five selected participants did not complete the study: Two participants failed to appear after confirming their intentions to participate, one did not complete pretesting due to illness, and two did not complete post-testing: one due to illness and one due to a prior engagement. No participants missed more than one day. A total of 75 children participated fully in the study. The final cell count appears in Table 2 and totals for each group are provided in Table 3 and for each self-selected ethnic group in Table 4.

Table 2

Final Group Categories

Treatment (38)	Comparison (37)
7 young females represented	11 young females represented
7 young males represented	12 young males represented
3 old females represented	1 old female represented
15 old males represented	1 old male represented
2 young males underrepresented	7 young males underrepresented
1 old female underrepresented	5 young females underrepresented
3 old males underrepresented	

Table 3

Final Totals by Group Category

Group		Label	N
Treatment Group	1	Experimental	38
	2	Control	37
Representation	1	Represented	57
	2	Underrepresented	18
Age Group	1	Young	51
	2	Old	24
Gender	1	Female	28
	2	Male	47

Table 4

Final Totals by Ethnicity

Ethnicity	Frequency	Percent
Asian	16	21.3
Black	7	9.3
Latino	5	6.7
White	47	62.7
Total	75	100.0

Instruments

Two instruments were used in the study. The *Project TALENT Spatial Ability Assessments* (American Institute for Research, 2011), referred to here as the spatial composite, was used as a pre- and post-assessment of spatial ability. The Cognitive Abilities Test (CogAT) (Lohman & Hagen, 2001) verbal composite was used as a pre-assessment of ability as unrelated to spatial ability as possible as a measure of *g*.

Project TALENT Spatial Composite.

The composite was given to participants and scored according to the guidelines established in the SMPY delineated below. Developed in the early 1960s, the composite has been widely used in research studies, including longitudinal studies that demonstrated correlations between high scores on the composite and measures of STEM success, including STEM occupation and advanced degrees in STEM fields (Flanagan, 1979; Wai et al., 2009). This study used the Project Talent spatial composite as the pre- and post-assessment. The four dimensions of spatial ability assessed by the composite are:

1. Three-dimensional spatial visualization (16 items measuring the ability to visualize two-dimensional figures after they have been folded into three dimensional figures).

2. Two-Dimensional Spatial Visualization (24 items measuring the ability to visualize two-dimensional figures when they were rotated or flipped in a plane).

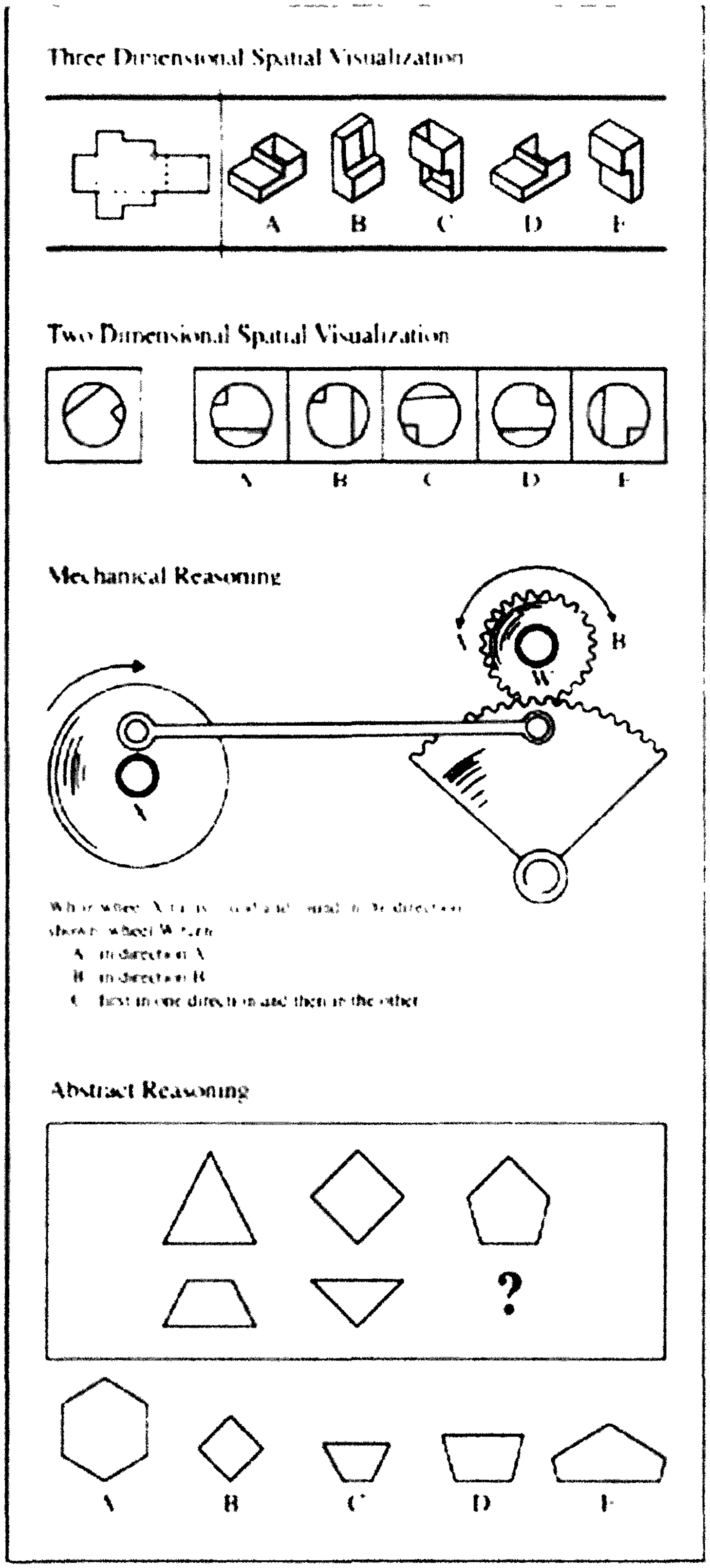
3. Mechanical Reasoning (20 items measuring the ability to deduce relationships between gears, pulleys, and springs as well as knowledge of the effects of basic physical forces, such as gravity).

4. Abstract Reasoning (15 items constituting a nonverbal measure of finding logical relationships in sophisticated figure patterns) (Wai, et al., 2009, p. 822-823).

See Figure 3 for an example of an item from each measure. The measures are weighted to form a composite score to reflect the Scholastic Aptitude Test (SAT) (as SMPY uses the SAT to identify students via a talent search): Spatial Composite = 3.0 * [3-D Spatial Visualization] + 1.0 * [2-D Spatial Visualization] + 1.5 * [Mechanical Reasoning] + 2.0 * [Abstract Reasoning]. These weights were derived by Humphreys (1993) and have been used in several other research studies (e.g., Gohm, et al., 1998; Humphreys, et al., 1993). As the composite is formed from a number of shorter tests, the reliability and construct validity are augmented through aggregation (Lubinski & Humphreys, 1990). The composite ceiling is the maximum number of items correct multiplied by the above weights (132). The composite floor is zero (all items incorrect). No gradient is known to exist within the composite items. The original sample included approximately 400,000 high school students (5 percent of the U.S. high school population in 1960) representing

1300 high schools. Using cross-twin same test correlation with identical twins of the same sex, Humphreys (1991) estimated that the spatial composite has a reliability of .92. Humphreys, et al. (1993) suggests that the composite nature of the test is more valid that any one-dimensional approach to measuring spatial ability and that scores of a composite are therefore less affected by unique variance. Wai, et al. (2009) found that the spatial composite used in Project Talent correlates with the Project Talent math composite at .61 and the language composite at .59 while math and language correlate with each other at .76 in a sample of 100,000 high school freshmen. These are reasonably consistent with Jensen's (1984) finding of .65 as an average correlation between instruments due to *g* loading.

Figure 3. Example Items from Each Spatial Measure



Cognitive Abilities Test.

The CogAT (form six) is a group of tests that can be divided into three batteries: verbal, quantitative, and nonverbal (Lohman & Hagen, 2001). The verbal battery was given to all participants in this study before the intervention. It consists of three subtests: verbal classification, sentence completion, and verbal analogies (Lohman & Hagen, 2001). This verbal battery was used as a general measure of ability unrelated to spatial ability except through *g* loading. The CogAT (form six) was created by Lohman and Hagen (2001) as a revision of a test that was first published in 1954 as the Lorge-Thorndike Intelligence test (Lohman, 2003b). The CogAT (Form Six) was normed in 2001 and 2005 (Lohman & Hagen, 2001). It is a group administered ability test battery standardized with the Iowa Tests of Basic Skills at grades K-9 (Lohman, 2003b). The CogAT and Woodcock-Johnson III are correlated r = .82 (Lohman, 2003a). Of particular importance to the verbal subtest's use in this study, the verbal scale of the Wechsler Intelligence Scale for Children (Third Edition) and the CogAT verbal battery are correlated at r = .87. Both correlations suggest strong concurrent validity of the CogAT with these other widely used measures of intelligence. The verbal battery contains 65 items and takes approximately 51 minutes to administer (Lohman & Hagen, 2001).

Procedures

An experimental intervention study with two groups (treatment and comparison) was conducted. Each group originally consisted of 40 gifted children ages 9 to 14 (the ages allowed in FIRST LEGO League [FLL] competition) and was randomly divided into four subgroups of 10 participants (as 10 is the maximum size allowed for an FLL team). Participants in both groups took a pre-assessment of spatial ability and the CogAT verbal subtest prior to participating in the intervention. For five consecutive days, the treatment subgroups met for four hours per day, for a total of 20 hours of treatment. The research on the national talent search programs suggested that a week of intensive intervention would likely yield large learning gains for gifted students (Swiatek, 2007). During those times, trained coaches guided the participants, in their separate groups, through a section of a curriculum unit based on an FLL competition (see Appendix A). There was one LEGO NXT robotics kit for use by each small group of 3 to 4 participants; 3 robotics kits per group of 10 participants. At the end of the treatment period, both the treatment and the comparison groups took the same measure of spatial ability as the post-assessment. Students in the comparison group were then offered treatment over the next 5 day period.

LEGO NXT kit.

The kit is the primary item needed for the FLL competition described in Chapter 2. Coxon (2009; 2010) gives descriptions of the NXT kit's usage in FLL competitions. The kit is sold commercially and widely available. It contains 437 LEGO pieces, which can be combined to form robots, both stationary and mobile. The center of such a robot is an included computerized brick (hereafter referred to simply as the NXT brick) into which programs written by children in NXT-G code may be downloaded to respond to as many as four sensors and control as many as three motors. The included sensors and motors are connected to the NXT brick via included cables. The sensors include one each for sound, ultrasonic (to detect objects at a distance), and light/color as well as two touch sensors. Rotation sensors are embedded in each motor and the programmer may also utilize a timer and random number generator built into the robot. The three included motors can operate on rotations, degrees, or time at varying levels of power. The motors are generally used to make the robot mobile in conjunction with LEGO wheels or legs built with LEGO bricks or to create arms, cranes, or other mobile attachments to the robot. The included software, which uses a language called NXT-G, can be used by children using drag-and-drop blocks to create logical programs utilizing such computer programming concepts as repeat loops and switches to have the robot complete its tasks by responding to attached sensors with motor movements. With programs, robots can act autonomously to complete tasks (such as the example tasks given in Chapter 2) while operating on a rechargeable battery.

Coach training and fidelity.

Four coaches led subgroups of 10 participants each through the challenges of a section of the FLL-based unit (see Appendix A). They participated in a three-hour session focused on the FLL-based unit utilized in this study led by the researcher with a foci on appropriate help in student problem solving, reading the FLL *Coaches' handbook* (2010), and complete the NXT-G programming tutorial by programming a robot to follow a black line. Coaches were instructed in proctoring the instruments described above. Each coach was observed for at least one hour in total during implementation of the unit by the researcher to ensure treatment fidelity.

An instrument, the Coach Fidelity Observation Scale (C-FOS) (Coxon, 2011), was developed to monitor coaches' behavior in regards to problem solving (see Appendix B). Coach fidelity in the present study was considered in regards to the following FLL core value as its standard: "We do the work to find solutions with guidance from our coaches and mentors" (FLL, 2008, p. 1). From the coaches' perspectives, this is restated:

> The children do the work. This is their opportunity to learn and grow. The children on my team do all of the programming, research, problem solving, and

> building. Adults can help them find the answers, but cannot give them answers or make decisions. (FLL, 2008, p. 3)

The C-FOS was developed based on these standards of coaching behavior. The programming and building aspects are delineated in terms of problem solving in the scale; the research aspect has been removed as it is not part of the present study. Problem solving is the most fundamental aspect of FLL (Coxon, 2010). Critical thinking and creative thinking are widely considered to be important aspects of problem solving (Davis & Rimm, 1998; Piirto, 2004; Treffinger, Isaksen, & Dorval, 2006). The present study hypothesized that participation in the problem solving aspects of the FLL competition (including creative and critical thinking), which involves demands on participants' spatial thinking in building and programming robots, will increase students' abilities to perform on measures of spatial ability. Therefore, this observation scale was developed to ensure the fidelity of the coaches in regards to appropriate assistance in the participants' problem solving in relation to building and programming. The scale assesses the existence of positive coaching behaviors that encourage participants to use techniques such as brainstorming and evaluation processes to answer their own questions and make their own decisions.

The foundation and organization for the C-FOS is *The William and Mary Classroom Observation Scales, Revised (Part 2) Teacher Observation* (COS-R) (VanTassel-Baska, et al., 2005). However, the C-FOS was significantly reorganized for the present study.

The C-FOS has four scales: programming problem solving, building problem solving, critical thinking strategies, and creative thinking strategies. Each of the four scales has four aspects for a total of 16. Scores for each aspect range from -2 to 2; therefore, total scores on the scale may range from -32 to 32. Scores of eight or more on the total scale were considered appropriate coaching. Scores of seven or less were proposed to warrant analysis between coaches to determine if the coaching differences were associated with significantly different pre-post mean gains on the measure of spatial ability used in the study. Independent samples *t*-tests would be used to investigate possible differences between the four groups' pre- and post-assessment spatial ability gains.

Timeframe.

- April 24, 2011: Letters were sent to all identified area gifted coordinators explaining the study along with the Participant Interest Form to distribute.
- May 16, 2011: Deadline for submission of completed Participant Interest Forms
- May 23, 2011: Selections were carried out as described and letters were sent to all submitters (see Appendix F) asking for those selected to confirm their intention to participate.
- May 31, 2011: Deadline for participant confirmation
- June 9, 2011: Coaches training
- June 13, 2011: Pre-assessment
- June 13-17, 2011: The experimental group underwent treatment
- June 17, 2011: Post-assessment
- June 20-24, 2011: The control group was provided with the treatment
- September 2, 2011: Defense

Ethical safeguards and considerations.

At the onset of the study, children's parents or legal guardians were asked to sign informed consent forms (see Appendix C). Participants' parents or legal guardians were responsible for all transportation to and from the program. Emergency contact information as well as information regarding any medical needs participants was collected from parents or legal guardians at the onset of the study and are kept in a locked office. Names or other identification between individual student data and demographics have been kept confidential by researcher. Reasonable efforts have been made to preserve privacy for the participants. All students had pre-numbered tests for all assessments and student names were never placed on assessments. Student names linked to the test numbers are kept on a password protected computer. Original assessments completed by participants are kept in a locked office. Study results will be reported as group data, and individual scores will not reported. A policy for safely checking students out from the program by parents and legal guardians or their assigned caregivers can be found in Appendix D.

Analyses

To test hypotheses 1a, 2, 3a, and 3b, a 2 (treatment group) x 2 (gender) x 2 (age level) x 2 2 (representation level) between subjects analysis of variance (ANOVA) was proposed to test the differences between the pre- and post-assessment mean gain scores of all participants to determine if a statistically significant growth in spatial ability has been made by the treatment group, if a statistically significantly greater growth has been made by the treatment group than the comparison group, and if a statistically significant difference has occurred between any group's (gender, age, representation) gain in assessed spatial ability (Gall, Gall, & Borg, 2007). Factors (gender, age, and representation) may be eliminated when fewer than ten individuals comprise any one group (see Table 1) due to the very low chance of reaching significance. To run the ANOVA, a column of gain scores (i.e., T2-T1) was manually created.

To test hypotheses 1b and 1c, Cohen's *d* was calculated to determine the overall effect size of the treatment (Gall, Gall, & Borg, 2007). Practical meaningfulness for both treatment groups was considered when an effect size of $d \geq 0.30$ was achieved, based on Cohen's (1988) theoretical model for practical significance. To test hypotheses 4a, 4b, and 4c, three dependent-samples *t*-tests were used to test for differences: one between the mechanical reasoning subtest and the three-dimensional spatial visualization subtest; one between the three-dimensional spatial visualization subtest and the two-dimensional spatial visualization subtest; and one between the two-dimensional spatial visualization subtest and the abstract reasoning subtest.

Finally, Pearson correlations were used to address hypothesis 5. An independent samples *t*-test was used to address hypothesis 6.

This chapter has proposed six directional hypotheses and an intervention study involving usage of LEGO NXT robotics to test them. The research design was described including participants and the instruments; the procedures were delineated including the LEGO NXT robotics kit, coach training and fidelity, a timeline, and ethical safeguards; and an explanation of the analyses. The results can be found in the next chapter.

Chapter 4

The study was conducted as described in Chapter 3. After discussing treatment fidelity, this chapter presents the results and is organized by hypotheses. Hypotheses are paraphrased followed by the analyses conducted and the result.

Treatment Fidelity

All coaches were observed using the C-FOS as described in Chapter 3. As the researcher supervised the study and spent most of each day's four hour time visiting the four classrooms, each classroom was visited for approximately one hour each day. All of the coaches scored between 9 and 11 on the C-FOS, so no further analysis was conducted. Notably, no poor coaching behavior was noticed at any time during the researchers' nearly 5 hours spent in each treatment classroom during the experimental period. This is likely due to the background of the adults volunteering as coaches for the study. Three of the four coaches are state certified teachers of the gifted, three of the four had either FLL or JuniorFLL prior experience, and all participated in the coaches' training. The fourth coach is a computer programmer who has coached FLL teams involving his children for several years.

The potential influence of the coaches, acting in similar capacities as classroom teachers, must not be understated. There is no greater environmental influence in educational settings that teachers (Chetty et al., 2011; Sanders & Horn, 1998). It is possible, despite these efforts to reduce this possibility for treatment fidelity, that coaches did influence the results of the study, including possible differential treatment by gender that led, in whole or in part, to the differences discussed below. This possibility, coupled with the experience of using the C-FOS, have led to suggested improvements to the instrument.

Based on the experience of using the C-FOS in practice, it may be useful for the instrument to be revised in four key ways. First the coaches' scores were all very close. It may be useful to increase the points earned for higher levels to further stratify the scores and allow researchers to differentiate average and good coaches from those who are highly talented.

Second, while negative behaviors were not noted in this study, it is possible for a negative behavior to be zeroed out by a single positive behavior. One can imagine a coach who treats some students with appropriate coaching behavior and others with poor coaching behaviors or often uses appropriate behaviors, but attempts to expedite student problem solving with poor coaching behaviors. This would not be acceptable practice. Therefore, it is recommended that the C-FOS be revised for further use to increase the negative scores for poor coaching behaviors to eliminate this possibility.

Third, as the results of this study varied by gender as discussed below, coach treatment by student differences, including gender and other characteristics with likely differences in teacher treatment such as race and ethnicity (Ford, 1998), should be included on the observation instrument.

Finally, as the C-FOS focuses primarily on aspects related to the curriculum, it may also be useful to consider other features of teaching, perhaps along a constructivist model of positive teaching behaviors such as provided by Brooks and Brooks (1993). These include encouraging autonomy, using academic language, concept development, drawing on students' prior learning, and encouraging appropriate interpersonal communication between students.

Hypotheses 1a, 1b, and 1c

Hypothesis 1a predicted that the experimental group would evidence significantly greater pre-post total test gains on a measure of spatial ability than a group of comparison students. Hypothesis 1b predicted the effect size of the treatment to be sufficiently large as to be considered practically meaningful. Hypothesis 1c predicted the comparison group's scores on pre-post total test gains on a measure of spatial ability to be considered practically meaningless.

Descriptive statistics by group category can be found in Table 1. A 2 (treatment group) x 2 (representation level) x 2 (age level) x 2 (gender) between subjects analysis of variance (ANOVA) was planned to test differences between groups; however, as stated in the proposal, groups with fewer than 10 participants per cell would not be analyzed.

Table 1

Descriptive Statistics by Group Category

Group		Label	Spatial Battery Mean Gain	Standard Deviation
Treatment Group	1	Experimental	6.55	9.380
	2	Control	1.81	7.404
Representation	1	Represented	3.81	9.284
	2	Underrepresented	5.50	6.793
Age Group	1	Young	3.45	9.702
	2	Old	5.83	6.084
Gender	1	Female	3.46	5.232
	2	Male	4.66	10.307

As there were fewer underrepresented students than desired, a 2 (treatment group) x 2 (gender) x 2 (age level) ANOVA was conducted. Results of the ANOVA are presented in Table 2, and reveal no significant main effects for Treatment, Gender, or Age. A significant interaction was found between treatment group and gender ($F_{(1)}$ = 6.85, $p < .05$). None of the other two-way or three-way interactions were significant. Follow-up *t*-tests were conducted on the sole treatment by gender interaction. Males in the treatment group made significantly greater mean gains on the spatial battery than males in the control group: $t_{(45)} = 2.91$, $p < .05$; however, there were no treatment effects among females. Hypothesis 1a is partially supported.

Table 2

Tests of Between-Subjects Effects, Dependent Variable: Spatial Gain

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance
Corrected Model	1296.960[a]	7	185.280	2.851	.012
Intercept	690.477	1	690.477	10.626	.002
TreatmentGroup	15.767	1	15.767	.243	.624
Gender	35.599	1	35.599	.548	.462
AgeGroup	25.778	1	25.778	.397	.531
TreatmentGroup * Gender	445.316	1	445.316	6.853	.011
TreatmentGroup * AgeGroup	86.566	1	86.566	1.332	.253
Gender * AgeGroup	252.050	1	252.050	3.879	.053
TreatmentGroup * Gender * AgeGroup	12.430	1	12.430	.191	.663
Error	4353.627	67	64.980		
Total	6982.000	75			
Corrected Total	5650.587	74			

a. R Squared = .230 (Adjusted R Squared = .149)

Cohen's *d* was calculated to determine the effect size of the treatment on males. The males in the experimental treatment group had a mean gain of 8.15 points on the spatial battery with a standard deviation of 10.41 and the comparison treatment group had a mean gain of -0.05 points with a standard deviation of 8.262. Therefore, Cohen's *d* is 0.87 for the males in the treatment group, a meaningful effect. Both hypotheses 1b and 1c are partially supported.

Hypothesis 2

Hypothesis 2 predicted no significant difference on the same measure as a function of gender or traditional representation status. As mentioned previously, there was a significant interaction for gender, which resulted in significant gains for males but not for females. Analyses on representational status were not run due to low numbers of underrepresented groups. Hypothesis 2 is partially supported.

Hypotheses 3a and 3b

Hypothesis 3a predicted a difference among the experimental group on pre-post total test gains on a measure of spatial ability as a function of student age with older students making significantly greater gains than younger students. Hypothesis 3b predicted no significant difference among the control group as a function of student age. In the ANOVA results shown in Table 2, there were no significant main effects or interactions based on age. Hypothesis 3a is not supported. Hypothesis 3b is supported.

Hypotheses 4a, 4b, and 4c

Hypotheses 4a, 4b, and 4c made predictions of the order that the student gains would be made on each subtest of the spatial composite: That students would evidence significantly greater gains on the mechanical reasoning subtest than the three-dimensional spatial visualization subtest, on the three-dimensional spatial visualization subtest than the two-dimensional spatial visualization subtest, and on the two-dimensional spatial visualization subtest than the abstract reasoning subtest.

Three dependent-samples *t*-tests were conducted to test for differences among the experimental treatment group's gains on the subtests of the spatial battery. Participants in the experimental group did not perform significantly better on the mechanical reasoning subtest than the three-dimensional spatial visualization subtest ($t_{(38)} = -1.142, p > .05$), on the three-dimensional spatial visualization subtest than the two-dimensional spatial visualization subtest ($t_{(38)} = .749, p > .05$), or on the two-dimensional spatial visualization subtest than the abstract reasoning subtest ($t_{(38)} = -.456, p > .05$). Hypotheses 4a, 4b, and

4c are not supported. Mean scores for each subtest can be found in Table 3. Spatial mean gain scores, which were created by subtracting pre-test scores from post-test scores, are weighted as described in chapter 3, while the four subtests presented in the table are unweighted.

Table 3

Mean Gain Scores for the Spatial Battery and Subtests

Treatment Group		Spatial Gain (weighted)	Two Dimensional Gain	Three Dimensional Gain	Mechanical Reasoning Gain	Abstract Reasoning Gain
Experimental	Mean	6.55	.7105	1.0000	.5000	.9737
	N	38	38	38	38	38
	Standard Deviation	9.380	1.75388	1.75530	1.95559	2.76549
Control	Mean	1.81	.3243	.1892	.6757	-.0811
	N	37	37	37	37	37
	Standard Deviation	7.404	2.14805	1.66396	1.78036	2.48751
Total	Mean	4.21	.5200	.6000	.5867	.4533
	N	75	75	75	75	75
	Standard Deviation	8.738	1.95462	1.74759	1.86064	2.66759

Hypothesis 5

Hypothesis 5 predicted that experimental participants' CogAT total Verbal Scale scores would correlate significantly and positively with the total pretest scores from the measure of spatial ability for students in both treatment groups. Pearson correlations were used to address hypothesis 5. The correlation between participants' CogAT total Verbal Scale scores and their spatial composite pretest scores was not significant ($r_{(75)} = .20$, $p >$

.05). However, when three outliers were removed, the correlation became significant ($r_{(75)} = .30$, $p > .05$). As the standard deviation found on the CogAT for the sample was 6.4 as opposed to 15 expected for the population (likely due to the sample of gifted children), the correlation was corrected for restriction. Once corrected, $r = .59$. This is the same as the correlation found between verbal and spatial abilities in Project Talent. Hypothesis 5 is supported.

Hypothesis 6

Hypothesis 6 predicted that students' mean CogAT total Verbal Scale would not differ significantly between the two treatment groups. An independent samples *t*-test was conducted to address hypothesis 6. Students' mean CogAt total Verbal Scale did not differ significantly between students in the experimental and comparison treatment groups ($t_{(73)} = .957$, $p > .05$). Hypothesis 6 is supported.

Conclusion

This chapter presented the results of the study. In summary, significant and meaningful gains were found for the mean gain score on the spatial battery for the males in the treatment group over males in the control group; however, females did not make significant gains. There were no differences based on age. There were too few underrepresented participants to warrant analyses. Gains on the spatial composite's subtests for the experimental group were not ordered as hypothesized. Verbal ability scores significantly correlated to spatial ability pretest scores as predicted. As hypothesized, there was not a significant difference in verbal ability between the treatment and control groups. Chapter 5 will present a discussion to explain the results of this study with the existing theories and research that preceded it.

Chapter 5

This chapter provides an overview of the study's important findings and relates them to pertinent literature reviewed in Chapter 2. Limitations to the study's validity and generalizability are discussed along with recommendations for further research and professional practice with emphasis on increasing the pipeline of young people capable of achieving high levels of success in needed STEM fields.

Important Findings Related to Prior Research

In this section, the important findings are related to relevant prior research studies reviewed in Chapter 2. Important findings regarding spatial ability under treatment with LEGO robotics were found involving gender and age and are discussed below. The unexpected findings regarding the spatial battery subtests are also discussed. Due to the small number of underrepresented participants, analyses were not conducted on traditional representational status; however, the mean gain scores of the experimental portion of this subgroup were very high suggesting that significant and meaningful gain scores may be found if a larger sample was to participate in the treatment.

Gender

Treatment with LEGO robotics among gifted males ages 9-14 produced significant and meaningful mean gain scores on a measure of spatial ability; however, although significant gains for all experimental participants were hypothesized, there were no significant gains for females. This is surprising given that several reviewed studies suggested that although females were likely to perform lower on measures of spatial ability (Lohman, 2005), they were likely to make gains under treatment similar to males (Spence et al., 2009). Based on this, it is **not** surprising that a *t*-test comparing male (*n*=47) mean pre-test scores on the spatial battery (90.68) with female (*n*=28) mean pre-test scores (80.11) showed a significant difference: $t_{(75)} = -2.21, p < .05$, but **it is** surprising that female post-test mean scores did not show improvements. There are several possible reasons as to why this may have occurred.

As discussed in Chapter 2, Spence, et al. (2009) delineated several reasons why females perform as well as males in some studies focused on spatial ability, but not in others. Taking their work into account, potential reasons for the difference between males and females in this study could be participants' prior experience with LEGO based on societal gender norms. A second possibility is sampling error. An alternative set of possibilities are gender differences in the facets of spatial ability that were measured or improved by the treatment.

All participants were polled during the treatment about their prior LEGO experience. A majority of all participants, males and females, had prior LEGO experience (*n*=66), but only five had FLL experience. This makes it appear unlikely that prior experience led to the differences. However, data was not collected on the amount of time spent playing with LEGO. It is possible that males played with LEGO for more time, until an older age, or both. Such differences could be based on societal gender norms or physiological differences.

Sampling error was a possible cause of the gender differences found in this study. It could be that societal norms led to the small number of females in the sample that perhaps led to sampling error. LEGO appears to be regarded as a male-focused toy and the interest in participating in this study was largely male. Of the 144 on-time and complete Participant Interest Forms returned, only 32 were from females. Of the five participants who did not complete the study, four were females. This appeared to be random, not caused by the treatment. Two participants, a male and a female, never appeared for the study after confirming their intent to participate. Of the remaining three, one was sick during pretesting, one was sick during post-testing, and one attended a citizenship ceremony for her mother during post-testing. Only 28 females fully participated in the study, having all been selected from the pool of 32 female volunteers described in Chapter 3. This was not as random as for males, of whom 48 were selected from 112 male Participant Interest Forms. This could have been a special group of females with an interest in LEGO robotics who may have already reached their spatial potential. This seems unlikely as they performed significantly lower than males on the pretest and begs other explanations.

An alternative set of explanations are gender differences in the facets of spatial ability linked to the treatment, assessed with the instrument, or both. These gender differences could also be physiological, the result of societal gender norms, or a combination of both. While much of the research reviewed in Chapter 2 suggests that females will make gains on measures of spatial ability similar to males under treatment, Liu et al. (2008) concluded their meta-analysis with the overall finding that, while treatments may reduce the gap between male and female performance on measures of spatial ability, a gender gap persists in most studies. Similarly, the significant gender differences that Lohman (2005) has found are suggestive of physiological differences that would likely run across a majority of studies. Given the disparity of findings, more research is clearly needed to understand gender differences in measured spatial ability. However, some possibilities are presented here to benefit future research.

One may speculate that differences in gains of measured spatial ability found in this study are related to gender differences in the facets of spatial ability linked to the treatment, assessed with the instrument, or both. There are many spatial treatments that may result in spatial talent development (Coxon, under review). These treatments include existing geometry, physics, chemistry, and geography courses; the visual arts, including such diverse fields as choreography, sculpture, photography, drawing, and painting; architecture; design, a broad terms which includes fields ranging from home decorating to product development to web design and advertising; activities involving geographic information system (GIS) devices such as geocaching and way finding; computer programming for creating video games and animations or controlling robotics; building with materials including popular building toys such as wooden blocks, LEGO, K'NEX, Lincoln Logs, Erector sets, toothpicks, construction paper, or drinking straws; origami; and electrical activities among many combinations of the above and other possibilities beyond the scope of this paper (Coxon, in preparation). While little research yet exists on various treatments, it is easy to imagine that some treatments will produce greater gains in measured spatial ability for females. Of course, how spatial gains are measured is another influential matter if there are gender differences within discrete aspects of spatial ability.

The instrument used measured four aspects of spatial ability: two dimensional reasoning, three dimensional reasoning, abstract reasoning, and mechanical reasoning. Lohman's (1993) definition includes the processes of generation, storage, retrieval, and transformation. Arguably, the spatial battery used in this study focuses primarily on transformation across three of its subtests:

- the two dimensional subtest requires participants to make mental rotations,
- the three dimensional subtest requires participants to determine which three dimensional object could be created by folding a two dimensional object with fold lines (similar to origami), and
- the mechanical reasoning subtest requires participants to determine the direction of wheels, gears, and other objects in mechanical devices.

The abstract reasoning subtest, which requires participants to complete patterns, is the exception and notably the subtest on which female participants made the greatest gains, albeit nonsignificant. It may be, as described below in the discussion of the subtests, that the abstract reasoning subtest has a higher *g* loading, that the subtest relates more to the generation facet of spatial ability, or both. Notably, although males' pretest scores were significantly higher than females', females' mean pretest score (10.89) were almost identical to males' (10.94) on the abstract reasoning subtest. This suggests that the abstract reasoning subtest may have less gender bias than the other subtests, while the fact that experimental males made significant gains over the male control group while females in both groups made similar, mild gains suggests that the treatment may be less effective for females. However, the abstract reasoning subtest could be useful in measuring gains of females under other treatments. There are also a number of other spatial ability assessments available that could potentially be used to measure gains in intervention studies with other likely spatial treatments, though none is known to have been used in large, longitudinal research as was the spatial battery used in the present study, limiting generalizability.

Research findings published after the present study's literature review was conducted support the possibility of treatment and measurement differences by gender. Tzuriel and Egozi (2010) report on a controlled study of 116 first grade children. The authors found that gender differences on a measure of spatial ability were significantly reduced for the experimental group by including strategies to process visuospatial information as part of the intervention. The authors recommend using virtual reality programs as a means of reducing the gap between males and females. This recommendation for computer technology use is similar to the findings of Spence, et al. (2009) discussed in Chapter 2. These studies suggests that various treatments may produce different results by gender and that computer games and virtual reality may reduce the gap between males and females.

Yilmaz (2010) provides a literature review of the theories and research on gender and various facets of spatial ability, concluding that "various spatial tasks may be differentially sensitive to the effects of experience" (p. 93) as an explanation for changing gender differences. This supports the discussion above related to the present study. However, Yilmaz notes that the literature is often contradictory and that little research has been conducted to determine likely causes.

Sorby (2009) draws connections between engineering and the arts, noting that the earliest engineers began as artists (e.g., Leonardo da Vinci). She notes that males are more likely to use holistic, perceptual strategies while females are more likely to use analytical strategies that consume more time. The author reports on her body of research on spatial ability development among engineering undergraduates and the success courses that directly teach 3-D spatial skills has had on student success and retention in the engineering program, especially for females.

The new studies reviewed here suggest that females will likely benefit from the direct teaching of spatial skills, which the present study did not include. This suggestion should be embedded in future research studies.

Age

Although age accounts for many differences in spatial ability in prior research, it appears that spatial ability develops through early childhood and is similar to adults by age 9. For examples, Uttal et al. (2006) found that 10-year-olds performed similarly to college students on spatial tasks and Lange-Kuttner (2009) found that 9-year-olds performed much better than 7-year-olds and similar to 11 and 17-year-olds. In that light, this study's finding of no differences based on age between a sample of 9-11-year-old children and a sample of 12-14-year-old children is not surprising.

Subtests of the spatial composite

The gains on the spatial composite's subtests were not ordered as hypothesized. Improvements in mean gain scores on the spatial subtests for the experimental group were largest over the control group in the following order: abstract, three-dimensional, two-dimensional, and mechanical. These subtest results are discussed below in their predicted order of mechanical, three-dimensional, two-dimensional, and abstract.

As the mechanical reasoning test has elements that appear to be similar to understanding how to build a working robot (e.g., items asking the direction that gears turn in a picture of a machine), participants were expected to make the greatest gains on it. However, the mechanical reasoning subtest had the most required reading, which may have been difficult for younger children (the composite was originally developed for use with high school students), and was the most obviously dated subtest (e.g., it included questions about steamboats). These issues may have accounted for the fact that gains on the mechanical reasoning subtest were roughly equivalent for both the experimental and control groups.

While the two and three-dimensional reasoning subtests were not ordered as predicted, both were in the middle of the four subtests in terms of gains as expected and participants showed similar gains on them. This is unsurprising as both demand mental rotations and folds similar to visualizing building a LEGO robot.

The abstract reasoning subtest, hypothesized to show the smallest gains under treatment, showed the largest gains. It required participants to complete patterns of shapes. The subtest appears to be the least relevant to building and programming LEGO robots; however, given that participants were selected from gifted programs that use ability tests that select for high *g* it could be that the abstract reasoning subtest had the highest *g*-loading of the spatial subtests. Why males improved on it so much over the course of a LEGO robotics treatment is unknown. It may be that it was the most related to the spatial talent developed through the FLL simulation. As noted earlier, the abstract test may challenge participants in their ability to generate geometric forms for pattern completion, while the other three subtests focus more on the transformation facet of spatial ability.

Groups Traditionally Underrepresented in Gifted Programs

While the small number of underrepresented participants (n=18) was too small to warrant analyses, the mean gain scores of the experimental portion of this subgroup were very high. The experimental subgroup's mean gain score on the spatial battery was 10.5 while the mean gain score for the traditionally represented experimental group was 5.8. This suggests that significant and meaningful gain scores may be found if a larger sample was to participate in a similar treatment. Similar studies with a larger sample of participants from groups traditionally underrepresented in gifted programs are needed to affirm this. This is particularly important for practice as traditionally underrepresented populations generally have the greatest needs and are unlikely to receive services (VanTassel-Baska & Stambaugh, 2007).

Limitations to the Study's Validity and Generalizability

Many precautions were taken to increase the validity and generalizability of this study. The study included a matched control group, controlling the effects of pretest interaction on the results. A verbal ability test showed no significant difference in verbal intelligence between the experimental and control groups, suggesting that the groups were equivalent in intelligence. Furthermore, the corrected correlation between the spatial and verbal batteries was identical to the correlation found in a large, longitudinal study suggesting that the sample was similar to the general population outside of being gifted. The instruments used have strong validity, including the use of the spatial battery in longitudinal research that demonstrated its predictive validity for STEM success. The participants were selected through a stratified-random process and were randomly assigned to coaches. Coaches were observed with an instrument seeking to evaluate appropriate problem-solving facilitation from coaches; they were found to be similar.

Efforts were also made to be inclusive with the sample. More than a quarter of the study's participants were from groups traditionally underrepresented in gifted programs and more than a third were females. Although many precautions were taken to increase validity and generalizability of the present study, several limitations to the study's validity and generalizability exist.

While many of the threats to the study's validity were controlled for, sampling remains the largest threat. It was desirable that half of participants would be from groups traditionally underserved in gifted programs and that half also be females. While there were enough females to run analyses, there were not enough underserved participants to do so with confidence. Further research is needed understand the influence of LEGO robotics on female participants and to measure the impact of LEGO robotics usage on spatial ability with underserved participants.

Another threat to validity is that participants were selected from gifted programs that rely on composite measures of intelligence. As Wai et al. (2007) suggest that 50% or more of spatially-able children are not as high in math and verbal abilities; it is likely that some spatially-able children were missed in favor of children with strengths in math and verbal abilities.

The treatment time of 20 hours within one week was both more intense and much shorter than participants in the FLL competition would likely spend. Increasing the treatment time could produce different effects; potentially significant gains for females who may be less prepared to make gains in a short study because they may tend to play with LEGO less than males. Time spent preparing for an FLL competition varies widely by participating teams, but is estimated to be greater than 40 hours on average over the course of approximately 8 weeks (Coxon, 2010). Research measuring gains in spatial ability of FLL participants is needed.

Finally, the sample was drawn from a population of volunteer gifted children who had some interest in doing LEGO robotics. It is possible that the results could differ with a sample randomly chosen, an important potential line of future research.

Recommendations for Practice and Future Research

Despite the limitations outlined above, the study has important implications for practice and has raised questions for further research. Recommendations for both practice and future research are discussed in this section.

Practice

The STEM pipeline is losing potential long before children reach college and have the opportunity to engage in more spatially-oriented curriculum in engineering and arts programs, among many others. This study sought to illuminate a potential means by which to serve spatially-able students in schools through further developing their spatial talents with a FIRST LEGO League-based unit as a potential means by which to increase the pipeline of individuals capable of achieving high levels of success in STEM fields. The results suggest that the treatment with LEGO robotics meaningfully increases gifted males mean score gains on a measure of spatial ability. As spatial ability is important to STEM success in higher education, career success, and innovations, which are important to our quality of life and economic improvements, this is an important finding that should be incorporated into practice in schools.

LEGO robotics is a means by which schools can challenge gifted males and facilitate their spatial talent-development. That females did not make similar spatial gains suggests that more research is needed to determine why this was the case, but not that LEGO robotics is not potentially good for females as well. Indeed, studies by the CYC described in Chapter 2 suggest that both genders improve in their interest in math and science and are more likely to major in STEM fields in college, among many other positive benefits (Melchior et al., 2004; Melchior et al., 2005).

Moreover, the potential for underrepresented populations to develop spatial talents through FLL is hinted at in the present study with their particularly large gains described earlier. While there is a paucity of young people in the pipeline overall, children within this population are almost absent. The lessened diversity in STEM fields is not only detrimental to the individuals whose potential goes unfulfilled, but to society as a whole. While more research is needed to affirm the large gains found in this studies' small sample of underrepresented participants, when considered alongside the other evidence provided in the literature review for FLL's effectiveness in increasing interest in STEM fields, schools should not delay beginning FLL programs, particularly with these populations.

LEGO robotics can be incorporated during the school year within classes and gifted programs, after school as a club, and during the summer in camp settings. LEGO robotics can also be used by children and adolescents at home, if their families can afford sets. Given the research reviewed on academic competitions in Chapter 2, it seems likely that participation in the FLL competitions may be the most advantageous for spatial talent development among the gifted, primarily because of the level of challenge (Ozturk & Debelak, 2008a), the real world connections (Coxon, 2009), and the enhanced context setting (Schroeder et al., 2007). More research is needed in various settings, especially within classrooms and in the FLL competition.

Further Research

Limitations of the present study have led to some suggestions for further research. In particular, studies looking at LEGO robotics with more females and participants from groups traditionally underrepresented in gifted programs are needed. A study similar to the present one could be run with a greater number of participants from groups traditionally underrepresented in gifted programs, but different methods are needed to test for differences among females. Based on recent research reviewed in Chapter 4, including direct instruction of spatial skills will likely reduce the gap between males and females on measures of spatial ability. Likewise, the use of computer technology such as virtual reality as a treatment may also show diminished differences between males and females. A longer study, as described below, could test the potential for a longer treatment to lead to significant gains. Moreover, a study that compared spatially-able females to females with similar intelligence but relative spatial weakness could test the potential for a difference in the ability to improve spatially between those groups. Perhaps spatially-able females would make significantly greater improvements in spatial talent development. If true, this would be important information to develop the talents of spatially-able females who are much more likely than spatially-able males to go into needed STEM fields (Humpheys et al., 1993). Similarly, it is possible that research comparing spatially-able females with similar males would result differently than the present study. Most importantly, different assessments and different treatments should be utilized to find those most effective in measuring and improving female's spatial abilities.

While this study used a unit than can be considered a set of simulations of the FLL competitions, it was limited to 20 hours of treatment time. Research with FLL participants, who generally spend 40 hours or more working on their robots during the competition season (Coxon, 2010), is needed to determine the effects of this greater treatment time. It may be that the treatment continues to improve participants' spatial ability or that the effect is muted over the course of extended treatment. It is possible that, with more treatment time, females would make significant gains.

While it appears likely that participation in the FLL competition will have the strongest effect on spatial ability, some schools may not have access to the competition, some students may not be emotionally ready for competition, and some parents and educators may have a philosophical belief against competitions. Thus, research is needed within classroom and home settings to determine the effectiveness of various activities and curriculum using robotics on spatial ability improvement in children. There are many potential spatial activities that are not foci of the FLL competition that have potential for spatial talent development including building working simple machines, studying chemistry and physics, and creating useful robotic inventions.

Finally, other factors thought to be important to STEM were revealed in the literature review to be likely related to spatial ability and innovation, especially creativity (Liben, 2009). Creativity could also be measured in a pre- and post-test manner to test for differences. If robotics usage increases measured creativity, this could illuminate another area of talent development that may be improved upon with LEGO robotics. As with spatial ability, creativity is linked to innovation. This is especially pertinent now, as the US economy is dependent on innovations for growth and creativity scores have declined over the past two decades (Bronson & Merryman, 2010). To best enhance the STEM pipeline, it appears that researchers and practitioners will both need to give increased attention to spatial and creative abilities.

Conclusions

In Chapter 1, the case for improved STEM education is made upon both national reports and the existing research evidence of the need for the improved education of the spatially gifted in order to improve the STEM pipeline well before students enter high school and their postsecondary education. Chapter 2 explained the construct and theoretical models on which the present study is based and provided a review of the existing literature on a variety of research studies relevant to the present study. Chapter 3 described the hypotheses and the procedures, instruments, materials, and analyses to be conducted to answer them. Coach fidelity and the results of the study, including outcomes that differed from hypotheses in gender, age, and subtest improvement order, were described in Chapter 4. Chapter 5 discussed the study's important findings, especially those involving gender, age, and subtest improvement order, and offered recommendations for future research and professional practice.

Society depends on innovations to improve quality of life, but the STEM pipeline is bleeding potential. Innovations hold the possibility of helping us live longer, happier lives, improving the economy, and increasing security. The gifted have the potential to become innovators, if provided with appropriate talent development opportunities, including of their spatial abilities. Schools typically offer few opportunities for STEM talent development, often leaving potential future innovators unready and uninterested in pursuing STEM fields. This often occurs before children even have an opportunity to engage in STEM coursework at the high school and postsecondary levels. The results of the study largely support the use of LEGO robotics to increase measured spatial ability among gifted children at the elementary and middle school levels. More research is needed to clarify some questions, especially about gender, but the results suggests that LEGO robotics is beneficial. FLL is one way in which schools may increase and enhance potential future innovators in the STEM pipeline.

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Appendix A

LEGO Robotics Unit

The unit, STEMbotics, was prepared for Prof. VanTassel-Baska's EPPL 612 course (2008), curriculum and instruction for the gifted, at The College of William and Mary. It is available at http://stevecoxon.com. It can be considered a set of simulations of the FLL competition designed around STEM careers.

Appendix B

Coach Fidelity Observation Scale (C-FOS)

Coach: ______________________ Group #: ____ Number of students: ____

-2= Exceptionally intrusive	-1= Somewhat intrusive	0= Not observed	1= Standard met	2= Standard exceeded
The coach evidenced…				
extensive use of answering and/or decision making.	some use of answering or decision making.	Not observed	some use of the standard.	extensive use of the standard.

Programming problem solving standards	**-2**	**-1**	**0**	**1**	**2**
As students encounter challenges in programming, the coach…					
employed brainstorming techniques.					
engaged students in problem identification and definition.					
engaged students in solution finding activities.					
engaged students in comprehensive solution articulation.					

Building problem solving standards	**-2**	**-1**	**0**	**1**	**2**
As students encounter challenges in building, the coach…					
employed brainstorming techniques.					
engaged students in problem identification and definition.					
engaged students in solution finding activities.					
engaged students in comprehensive solution articulation.					

Critical thinking strategies standards	**-2**	**-1**	**0**	**1**	**2**
As students engage in problem solving, the coach…					
encouraged students to judge or evaluate situations, problems, or issues.					
engaged students in comparing and contrasting ideas (e.g., analyze generated ideas).					
provided opportunities for students to generalize from concrete data or information to the abstract.					
encouraged student synthesis or summary of information within or across disciplines.					

Creative thinking strategies standards	**-2**	**-1**	**0**	**1**	**2**
As students engage in problem solving, the coach…					
solicited many diverse thoughts about issues or ideas.					
engaged students in the exploration of diverse points of view to reframe ideas.					
encouraged students to demonstrate open-mindedness and tolerance of imaginative, sometimes playful solutions to problems.					
provided opportunities for students to develop and elaborate on their ideas.					

Total score: ____/32

Appendix C

LEGO Robotics Study Informed Consent Form
Maryville University of St. Louis and The College of William & Mary

The overall purpose of this study entitled "**The malleability of spatial ability under treatment of a FIRST LEGO League-based robotics unit**" conducted by Steve Coxon, assistant professor at Maryville University, and Tracy Cross, Jody and Layton Smith professor at the College of William and Mary, is to determine the impact of LEGO robotics use on gifted children's spatial ability. This study has the potential to benefit gifted and science education; science, technology, engineering, and math (STEM) fields; and quality of life through scientific innovations by identifying a means of increasing the talent pool of young, future innovators capable of performing at high levels in STEM fields. I understand that I will be asked to take both a brief ability test and a spatial ability battery as a pre- and post-test. I understand that I will be asked to participate in a unit involving the use of LEGO robotics. My participation in this study should take a total of about 22 hours (four hours per day for five consecutive days) and about two hours of testing time. I understand that my responses will be confidential and that my name will not be linked with any results of this study except to the researcher. Data will be kept on a password protected computer and reported in academic journals and conference presentations only as group data. I know that I may refuse to answer any question asked and that I may stop participation at any time. I also understand that my participation in the LEGO robotics unit will not be affected by my responses or by my exercising any of my rights. Potential risks resulting from my participation in this project are similar to a typical classroom environment and may include frustration with test items and frustration with problem solving. I am aware that I may report dissatisfactions with any aspect of this experiment to the Chair of the Protection of Human Subjects Committee at the College of William and Mary, Dr. Lee Kirkpatrick, (757) 221-3997 or lakirk@wm.edu, and to the Chair of the Institutional Review Board at Maryville University, Dr. Nancy Williams, (314) 529-947 or nwilliams@maryville.edu. My signature below signifies my voluntary consent to my child's participation in this project, and that I have received a copy of this consent form.

____

Steve Coxon
Assistant professor of gifted education
Director of graduate programs in gifted education
Maryville University

____

Date

Signature of Parent/Guardian giving consent to participate in this study	Print Parent/Guardian Name
Signature of Participating Student giving assent to participate in this study	Print Student Name

College of William and Mary IRB statement:
THIS PROJECT WAS FOUND TO COMPLY WITH THE APPROPRIATE ETHICAL STANDARDS AND WAS EXEMPTED FROM THE NEED FOR FORMAL REVIEW BY THE COLLEGE OF WILLIAM AND MARY PROTECTION OF HUMAN SUBJECTS COMMITTEE (Phone: 757-221-3966) ON [INSERT DATE].
If study subject has any questions in regard to this project, please contact the Principal Researcher directly: (Steve Coxon, 314-529-9567 or scoxon@maryville.edu).

Maryville University IRB statement:
If you have any questions regarding this study, or if any problems arise, you may contact the researcher, Steve Coxon at (314) 529-9567 or scoxon@maryville.edu. You may also ask questions, state concerns regarding your rights as a research subject, or express any feelings of pressure to participate by contacting: Dr. Nancy Williams, Chair of the Institutional Review Board at Maryville University, (314) 529-9471.

Maryville University recognizes its federally mandated responsibility to ensure that research be conducted in an ethical and scholarly manner, respecting the rights and welfare of all the human participants. Any research misconduct including but not limited to fabrication, falsification, or plagiarism in proposing, performing and reviewing research, or in reporting research results, should be reported to Dr. Tammy Gocial, the Research Integrity Officer at Maryville University at (314) 529-6893.

Maryville University investigators, and their colleagues who are conducting research, recognize the importance of your contribution to the research studies which are designed to improve (therapeutic care; educational learning environments). Maryville University investigators and their staffs will make every effort to minimize, control, and treat any complication that may arise as a result of this research.

By signing this form, you are stating that you have read and understand this form and have had an opportunity to ask questions about the research project. You are agreeing to participate in a study based on the information presented to you. You may choose to withdraw at any time without prejudice or penalty. You will receive a copy of this form, which will include the name and phone number of the researcher and the IRB at Maryville University, should you have any questions.

_____ Parent/Guardian initials

Appendix D

Student checkout policy and procedures

Pick-up Form

Participant: ________________________

- To be completed only by a parent or guardian
- A separate form must be completed for each participant (children of the same parent/guardian may be in different rooms for the study)

List below the person(s) allowed to pick up your child from class, including yourself. Your child's teacher will only release your child to the listed individual(s). Anyone picking up your child (including yourself) will need to provide a driver's license (or other government issued photo identification) as proof of identity **each time** you or an authorized person pick up your child. That is, you must show your driver's license every day, no matter how well we know you, no matter how far away you parked, and no matter how excited your child is to see you. For the safety of your children, there will be no exceptions to this policy.

Please write clearly.

You:____________________ ________________________

________________________ ________________________

________________________ ________________________

________________________ ________________________

I understand that only the above individuals will be allowed to pick up my child.

________________________ ________________________ ___/___/____

PRINT Parent/guardian name SIGN Parent/guardian name Date

****

OPTIONAL Waiver for children who are 13 years of age or older at the outset of the study:

"I prefer that my child, who is 13 years of age or older, walk unescorted to a location for pick-up outside of the building. I do not hold responsible Maryville University or the adults involved with this study for his or her welfare."

________________________ ________________________ ___/___/____

PRINT Parent/guardian name SIGN Parent/guardian name Date

LEGO Study Participant Medical Information and Emergency Contact List

Participant: ________________________

- A separate form must be completed for each participant
- Please specify any medical information and/or special needs that we need to be aware of:
- Please list any endangering allergies, such as to medications or nuts, that we need to be aware of:

<u>List emergency contacts in order of first-to-call</u>

1. Name:
   Relationship to participant:
   Legible contact number(s) in order of first-to-call:

2. Name:
   Relationship to participant:
   Legible contact number(s) in order of first-to-call:

3. Name:
   Relationship to participant:
   Legible contact number(s) in order of first-to-call:

4. Name:
   Relationship to participant:
   Legible contact number(s) in order of first-to-call:

________________________	________________________	__/__/___
PRINT Parent/guardian name	SIGN Parent/guardian name	Date

Basic Rules for Participants in the LEGO Study

Participant: ___________________________

1. Do your best on the assessments. This study has the potential to demonstrate a means by which schools can increase the pool of young people capable of succeeding at high levels in science, technology, engineering, and math (STEM) related fields.
2. Please do not bring LEGO pieces from home, nor remove LEGO pieces from Maryville University. Please be careful with the LEGO pieces.
3. You will be working in a team with 2 or 3 other participants to build and program a LEGO robot to accomplish tasks. Work cooperatively and respectfully with your teammates and all other participants.
4. Each group of three teams (9-10 participants) will have a coach to guide and encourage their work. Work cooperatively and respectfully with your coach.
5. Bring snacks, if desired. Please refrain from bringing snacks with nuts, including peanut butter. Food is not provided and the snack machines are not available to participants.
6. Drinking fountains are available. You may bring a water bottle, if desired, but please only bring water (not juice or soda) and please use a bottle with a secure lid.
7. Between drop-off and checkout, stay on the hall of second floor Kernaghan, where the four LEGO Study rooms are located, and use the bathrooms in this area only.
8. Take any needed medications before you come to the study or after you have been checked out from the study. If you need to have an inhaler or other medication on hand during the study, they should be placed in zippered bag or other appropriate container with your name on it. The medication should be given to your coach at the start of each session and picked up at the end of each day.
9. In the event of a participant not following the above rules, the participant may be removed from the study. Depending on the severity of infractions, participants may or may not be given a warning before removal from the study.
10. Internet access may be available on the computers used in the study. If so, students may be allowed by coaches to seek robotics-focused content, if desired. Maryville University and the adults leading the study are not responsible for the content of the Internet. Students seeking inappropriate content will be removed from the study.

___________________________	___________________________	___/___/____
PRINT Parent/guardian name	SIGN Parent/guardian name	Date
___________________________	___________________________	___/___/____
PRINT Participant name	SIGN Participant name	Date

Appendix E

Letters to locate potential participants

April 1, 2011

Maryville University
Gander Hall
650 Maryville University Dr.
St. Louis, MO 63141

Director of gifted programs:

I am writing to inform you about a study involving LEGO robotics that I am conducting on Maryville University campus this summer during the weeks of June 13-17 and 20-24 in hopes that you will share the included form with all identified gifted students in your district between the ages of 9 and 14 (as of Jan. 1, 2011).

The study will help to determine if LEGO robotics usage improves an ability among gifted students that is highly related to success in science, technology, engineering, and math careers, which are the fields most responsible for increasing our quality of life and economic growth.

I am asking that the included form be returned directly to me by parents/guardians of students interested in participating by April 30, 2011. Again, students must have been formally identified as gifted and between the ages of 9 and 14 (as of Jan. 1, 2011). Eighty participants meeting those criteria will be randomly selected from complete, returned forms. I expect more than 80 complete forms to be returned. Returning this form does not guarantee participation.

Participation is free of charge and, with the addition of taking a set of assessments, will be very much like an academic summer program. Parents or other legal guardians of selected participants must sign an informed consent form at the onset of the study. The study involves risks similar to a normal classroom environment, including possible frustration with task difficulty. The study is funded by Maryville University and The College of William and Mary.

Please call (314-529-9567) or e-mail (scoxon@maryville.edu) me if you have any questions.

Sincerely,

Steve Coxon
Assistant professor of gifted education
Director of graduate programs in gifted education
Maryville University

LEGO Robotics Study Participant Interest Form

Who: We are seeking students, ages 9-14 (as of January 1, 2011) who have been identified as intellectually gifted (by their public school district or other qualified professional) to participate in a study using LEGO robotics. Eighty participants meeting those criteria will be randomly selected from complete returned forms. We expect more than 80 complete forms to be returned. Returning this form does not guarantee participation.

What: The study involves participants taking a brief assessment of general intelligence and an assessment of specific ability related to using LEGO robotics (approximately two hours total), participating in a set of LEGO robotics challenges for four hours per day for five consecutive weekday mornings, and then retaking the battery of specific ability. Participation is free and is similar to a summer camp for LEGO robotics with the addition of the above assessments. Results will be reported as group data and not linked to individual participants.

When:
1. All participants will take the brief measure of general intelligence and a battery of specific ability related to using LEGO robotics from 8-10 a.m. on Monday, June 13.
2. Half of selected participants will continue with LEGO robotics from 8 a.m. to 12 p.m. from Monday, June 13 through Friday, June 17.
3. The other half of selected participants will participate with LEGO robotics from 8 a.m. to 12 p.m.
from Monday, June 20 through Friday, June 24.

Where: The study will take place on Maryville University Campus. Details will be sent to selected participants.

You will be contacted in early May regarding selection. Parents or other legal guardians of selected participants must sign an informed consent form at the onset of the study. The study involves risks similar to a normal classroom environment, including possible frustration with task difficulty. The study is funded by Maryville University and The College of William and Mary. If you have questions about the study, please contact the principal investigator, Steve Coxon, assistant professor of gifted education at Maryville University: scoxon@maryville.edu or 314-529-9567.

---Detach and return the lower portion----------------------------

LEGO Robotics Study Participant Interest Form

Student name: ______________________________ Parent/guardian name: ________________
Student birth date: __/__/_____ E-mail*:______________________________
Gender (circle): Female or Male Phone 1: (_____) _______ - ___________
School district: ______________________________ Phone 2*: (_____) _______ - ___________
Ethnicity: ______________________________ * if applicable
Current grade level: ______________________
Does the student qualify to receive free or reduced priced lunch at school (circle): Yes or No

Return this completed lower portion postmarked by April 30, 2011:
Prof. Steve Coxon
Maryville University
650 Maryville University Dr.
St. Louis, MO 63141

Alternatively, you may send all information to scoxon@maryville.edu by April 30, 2011.
Incomplete forms/information cannot be considered for study participation.

Appendix F

Letter to the experimental group

Your child has been randomly selected as a participant in the Maryville LEGO Robotics Study for the week of June 13-17 from 8 a.m. until noon each day.

Please reply to this e-mail to confirm participation by May 30 (one week from today).

There were 142 submitted interest forms for only 80 slots. If your child cannot participate, please let me know as soon as possible so that I may select another participant. If you do not reply by May 30, another participant will be selected on May 31.

Attached, you will find a list of forms to complete. A parent or guardian may either bring them completed on June 13 or blank paper copies will be available for you to complete that morning.

The parent or guardian and the participant will asked to sign the Informed Consent Form for the study at that time. A parent or guardian must be present to sign the Informed Consent Form on June 13 at 8 a.m.

On the first day, participants and their parent or guardian should report to Kernaghan 3121. Parking is fairly easy on Maryville's campus. You may park in any Student or General Parking Spot, such as lots 6 and 7 (see the map, below). Do not park in faculty, handicapped, or otherwise designated space. Here is a printable campus map:
http://www.maryville.edu/documents/pdf/Parking_Map_8_16_10.pdf

Schedule:

June 13: Arrive between 7:30 and 8 a.m. Testing (with participants from both weeks) from 8 until approximately 10 a.m. Students may wish to bring a book in case they finish one or both tests early. Begin robotics from 10 a.m. until noon. Students should be picked up between 11:50 and 12:10 daily. A driver's license matching the attached Pick-Up Form must be shown every day.

June 14-16: Arrive between 7:45 and 8 a.m. Robotics from 8 a.m. until noon.

June 17: Arrive between 7:45 and 8 a.m. Robotics from 8 until 10 a.m. Post-test from 10 until 11 a.m. Family visiting to see student work from 11:15 until 11:45 a.m. 11:45 a.m.-noon Clean up.

Please let me know if you have any questions.

Steve Coxon
http://stevecoxon.com
Assistant professor, Maryville University
Director of Graduate Programs in Gifted Education
http://maryville.edu/academics-ed-gifted-master.htm
Follow me on Twitter @GiftedEdStLouis

Letter to the control group
Your child has been randomly selected as a participant in the Maryville LEGO Robotics Study for the week of June 20-24 from 8 a.m. until noon each day. Initial testing will occur from 8 a.m. until approximately 10 a.m. on June 13. Your child must participate in testing in order to participate in the LEGO robotics.
Please reply to this e-mail to confirm participation by May 30 (one week from today). There were 142 submitted interest forms for only 80 slots. If your child cannot participate, please let me know as soon as possible so that I may select another participant. If you do not reply by May 30, another participant will be selected on May 31.
Attached, you will find a list of forms to complete. A parent or guardian may either bring them completed on June 13 or blank paper copies will be available for you to complete that morning. The parent or guardian and the participant will asked to sign the Informed Consent Form for the study at that time. A parent or guardian must be present to sign the Informed Consent Form on June 13 at 8 a.m.

On the first day, participants and their parent or guardian should report to Kernaghan 3121. Parking is fairly easy on Maryville's campus. You may park in any Student or General Parking Spot, such as lots 6 and 7 (see the map, below). Do not park in faculty, handicapped, or otherwise designated space. Here is a printable campus map:
http://www.maryville.edu/documents/pdf/Parking_Map_8_16_10.pdf

Schedule:

June 13: Arrive between 7:30 and 8 a.m. Testing (with participants from both weeks) from 8 until approximately 10 a.m. Students may wish to bring a book in case they finish one or both tests early. Parents of students participating in the second week may remain on campus; the coffee shop and new dining facilities are enjoyable places to wait for two hours, if desired.

June 20: Arrive between 7:30 and 8 a.m. Test from 8 a.m. until approximately 9:15 a.m. Begin robotics from 10 a.m. until noon. Students should be picked up between 11:50 and 12:10 daily. A driver's license matching the attached Pick-Up Form must be shown every day.

June 21-23: Arrive between 7:45 and 8 a.m. Robotics from 8 a.m. until noon.

June 24: Arrive between 7:45 and 8 a.m. Robotics from 8 until 11 a.m. Family visiting to see student work from 11:15 until 11:45 a.m. 11:45 a.m.-noon Clean up.

Please let me know if you have any questions.

Steve Coxon
http://stevecoxon.com
Assistant professor, Maryville University
Director of Graduate Programs in Gifted Education
http://maryville.edu/academics-ed-gifted-master.htm
Follow me on Twitter @GiftedEdStLouis

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Letter to the unselected group

I regret to inform you that your child was not randomly selected for the LEGO Study at Maryville University this year. There were 142 submitted interest forms for only 80 slots.

I do hope to offer similar programs in the future.

Thank you for your interest.

Steve Coxon
http://stevecoxon.com
Assistant professor, Maryville University
Director of Graduate Programs in Gifted Education
http://maryville.edu/academics-ed-gifted-master.htm
Follow me on Twitter @GiftedEdStLouis