AN INVESTIGATION OF THE INFLUENCE OF GENDER AND MINDSET ON SPATIAL TRAINING EFFECTS

By

Kara Lynn Constantine

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ABSTRACT

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Spatial visualization skills are important to success in engineering and there have been increased efforts to improve students' spatial skills through training. Sorby and colleagues at Michigan Technological University (MTU) created a spatial visualization course that appears especially promising for improving engineering students' spatial visualization skills (Sorby & Baartmans, 2000). Preliminary evidence suggests that participation in this course is related to higher rates of retention and performance in subsequent engineering and mathematics courses (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013). The curriculum may be especially promising for women who, on average, score lower on spatial ability measures when the tasks involve some degree of mental rotation (Voyer, Voyer, & Bryden, 1995). However, the developers of the curriculum completed much of the research and it is unclear whether the effects transfer to increased performance on standardized measures of complex problem solving, another skill in which women sometimes struggle (Halpern et al., 2007). The current study examines whether a spatial visualization course that uses Sorby and Baartmans's (2000) curriculum is related to increased spatial visualization and math computation scores over time. A secondary aim of the study was to determine whether individuals' mindset (i.e., the extent to which individuals think abilities are malleable) was related to whether they chose to take the course and whether mindset differed by gender. Results suggest that individuals in the intervention group showed significantly higher growth in their spatial visualization skills over time, and improved their raw scores on the Purdue Spatial Visualizations Test: Rotations

(*PSVT:R*; Guay, 1976) by approximately nine correct problems. The intervention group's standard scores on the Math Computation subtest of the *Wide Range Achievement Test-Fourth Edition (WRAT4*; Wilkinson & Robertson, 2006) did not significantly change over time. On average, all individuals in the study displayed comparable mindset scores, irrespective of intervention group and gender. Future directions are also discussed including how using supplemental outcome measures may help to determine whether the intervention leads to transfer effects on novel measures of mental rotation and complex problem solving.

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CHAPTER 1

INTRODUCTION

Women remain underrepresented in the science, technology, engineering, and math (STEM) workforce despite efforts to increase their presence (Beede et al., 2011; Hill, Corbett, & St. Rose, 2010). Similarly, women are less likely to pursue an undergraduate degree in STEM, especially in the field of engineering (Beede et al., 2011; Hill et al., 2010). It is imperative to increase the number of females in STEM fields (Hill et al., 2010). Many STEM professionals are at or nearing retirement age and so women can help fill this loss (Nelson & Brammer, 2010). Scientists and engineers are involved in solving major national and international problems, and so it is important that women are involved in these efforts to represent the female demographic (Nelson & Brammer, 2010). Similarly, engineers help design commonly used products and architecture and so it is vital that these projects consider female consumers (Hill et al., 2010). Women in STEM fields also earn more than women in non-STEM occupations and so increasing the number of women in STEM might help to decrease the gender wage gap (Beede et al., 2011).

The etiology of gender differences in STEM is still highly debated and researchers have argued for both environmental and biological sources (Ceci & Williams, 2010). Evidence suggests that the genders differ in occupational choices and interests (Ceci & Williams, 2010; Su, Rounds, & Armstrong, 2009), and STEM self-efficacy (Bandura, 1997; Pajares, 2005; Zimmerman, 2000; Zeldin & Pajares, 2000). Moreover, women might be thwarted from pursuing STEM fields due to gender stereotypes (Cheryan, Plaut, Davies, & Steele, 2009; DiDonato & Strough, 2013; Diekman, Brown, Johnson, & Clark, 2010) and characteristics of the STEM environment (Hewlett et al., 2008). Others have posited that gender differences in specific skills—particularly spatial and mathematical ability—might result in females' underrepresentation in STEM (Ceci & Williams, 2010).

Males consistently outperform females on spatial tasks that involve some degree of mental rotation (Geiser, Lehmann & Eid, 2008; Maeda & Yoon, 2013; Masters & Sanders, 1993; Voyer, Voyer, & Bryden, 1995) and tend to perform higher on mathematics tests that involve complex problem solving skills (Corbett, Hill, & St. Rose, 2008; Halpern et al., 2007). Mental rotation skills are not only related to mathematical ability, but might help explain gender differences on college-level mathematical achievement tests (Casey, Nuttall, Pezaris, & Benbow, 1995; Casey, Pezaris, & Nuttall, 1992; Casey, Pezaris, & Nuttall, 1997). Evidence also suggests that mental rotation skills and mathematical ability are both related to pursuing and succeeding in engineering (Budny, LeBold, & Bjedov, 1998; Honken & Ralston, 2013; Shea, Lubinski, & Benbow, 2001; Uttal & Cohen, 2012; Van Dyken, Benson, & Gerard, 2015; Wai, Lubinski, & Benbow, 2009; Webb, Lubinski, & Benbow, 2007; Yoon, Imbrie, & Reed, 2014). Thus, increasing females' mental rotation skills might help to attract and retain females in the engineering field, as well as decrease gender differences in complex mathematical problem solving.

Research suggests that spatial skills can be improved through spatial training (Uttal et al., 2013). Specifically, there has been considerable effort to increase undergraduate students' mental rotation skills in the field of engineering (Hsi, Linn, & Bell, 1997; Onyancha, Derov, & Kinsey, 2009; Sorby & Baartmans, 2000; Gerson, Sorby, Wysocki, & Baartmans, 2001). Sorby and colleagues created a spatial visualization course that seems especially promising for undergraduate engineering students since it demonstrates consistent spatial visualization gains (Sorby & Baartmans, 2000). Evidence also suggests that among students initially identified as having low spatial skills, those who participate in the course perform better in later engineering courses (Sorby, 2009; Sorby & Baartmans, 2000) and are more likely to be retained in engineering (Sorby, 2009; Sorby & Baartmans, 2000; Sorby, Casey, Veurink, & Dulaney, 2013). However, women and men tend to make comparable gains through this training, which maintains the gender gap in spatial visualization skills (Sorby & Baartmans, 2000; Sorby, 2009; Sorby, Casey, Veurink, & Dulaney, 2013; Walton et al., 2015).

It is also unclear whether spatial training gains generalize to mathematical performance, although two studies have found promising spatial training transfer effects to mathematics in young children (Cheng & Mix, 2011; Cheng & Mix, 2014). Sorby and colleagues have also found preliminary evidence that spatial gains predict subsequent mathematics grades (Sorby, 2009; Sorby et al., 2013; Sorby & Veurink, 2010b); however, the researchers did not use an empirically sensitive measure of mathematical ability. Use of a standardized mathematical measure is especially important when investigating gender effects since the male advantage is often seen on mathematical tests involving complex problem solving (Halpern et al., 2007; Corbett et al., 2008) but not in mathematical course work (Hill et al., 2010). Moreover, previous studies did not account for the degree to which students believe they can actually change their cognitive skills which, given societal gender expectations (Cheryan et al., 2009; Diekman et al., 2010; DiDonato & Strough, 2013) may influence performance.

Evidence suggests that student's beliefs about the malleability of their intellectual ability (i.e., mindsets) influence persistence and effort during challenging tasks (Dweck, 2000). These beliefs have been linked to mathematical and science achievement in adolescence and early adulthood (Blackwell, Trzesniewski, & Dweck, 2007; Grant & Dweck, 2003). Moreover, studies have found that students who believe that their intellectual ability is malleable rather than fixed demonstrate more improvements in mathematics and spatial ability (Blackwell et al., 2007; Dar-

Nimrod & Heine, 2006; Good, Aronson, & Inzlicht, 2003; Moé, Meneghetti, & Cadinu, 2009; Moé & Pazzaglia, 2010). Preliminary evidence has also found that students' mindsets are related to gender differences in mathematics and science achievement as well as to persistence in STEM fields (Dweck, 2007; Dweck, 2008b; Grant & Dweck, 2003; Good, Rattan, & Dweck, 2007). Believing that ability is malleable might help buffer women from negative gender stereotypes about mathematics and spatial ability (Good et al., 2007; Good, Rattan, & Dweck, 2012).

The main purpose of the current study was to examine whether students' gender was related to changes in their spatial and mathematical ability following a comprehensive spatial visualization course. The sample included freshmen students who declared their major as engineering and had been identified as having initially low spatial visualization skills. College readiness was controlled to examine the influence of gender on spatial training outcomes since standardized college readiness assessments are especially predictive of freshmen year college performance (Coyle & Pillow, 2008) and are related to general cognitive ability (Coyle & Pillow, 2008; Koenig, Frey, & Detterman, 2008). A secondary aim of the study was to investigate whether students' gender predicted the degree to which they believed their cognitive skills were malleable and in turn whether students' mindsets predicted whether they chose to enroll in the spatial visualization course. The study was exploratory in nature since few studies have examined the transfer of spatial training gains to mathematics (Mix & Cheng, 2012) and no study had used a standardized measure of mathematical ability in college-age students. Moreover, previous studies had not examined the influence of students' mindsets on participating in the spatial visualization course. More specifically, the current study investigated the following questions:

1. Are intervention group membership and gender related to spatial visualization score

changes over time?

2. Do time and gender predict changes in the math computation scores of the intervention group?

3. Do males and females significantly differ in mindset?

4. Do the intervention and control groups significantly differ in mindset?

CHAPTER 2

LITERATURE REVIEW

Women comprise nearly half of the workforce in the United States; however, they account for just 24 percent of workers in the science, technology, engineering, and math (STEM) fields (Beede et al., 2011). Despite efforts to attract and retain females, a disproportionately low number of women pursue undergraduate degrees in STEM, especially in the field of engineering (Beede et al., 2011; Hill et al., 2010). In the United States, females represented only 18.6% of students enrolled in undergraduate engineering programs in 2011 (NSF, 2011) and earned a mere 19.1% of engineering bachelor's degrees in 2012 (NSF, 2012). Even more alarming, only about 26 percent of women—versus 40 percent of men—who earn degrees in STEM fields actually work in STEM occupations (Beede et al., 2011).

Benefits of Increasing Representation of Women in STEM

It is important to increase the number of women in STEM fields because it will help "maximize innovation, creativity, and competitiveness" (Hill et al., 2010, p. 3). A large portion of science and engineering professionals in the United States are also reaching retirement age and so encouraging more females to pursue STEM careers might assuage this loss (Nelson & Brammer, 2010). Scientists and engineers are involved in finding solutions for complex national and global challenges (e.g., environmental issues, the energy crisis, national security concerns) (Nelson & Brammer, 2010). It is imperative to include women in these efforts so that solutions are representative of the United States' "values, culture, and interest" (Nelson and Brammer, 2010, p. 2). Moreover, engineers help design products and architecture that people use every day and so it is vital to involve women when designing these projects to ensure that they are representative of female consumers (Hill et al., 2010). Excluding women from these efforts might even result in dire consequences. For example, a group of predominately male engineers configured the first automotive airbags to adult male bodies, which resulted in the death of many women and children (Margolis & Fisher, 2002).

Encouraging women to pursue STEM careers is also an economic issue. The gender pay gap has decreased since congress passed the Equal Pay Act in 1963, but has stabilized in recent years (AAUW, 2015). In 2014, women working full time in the United States earned 79 percent of what men were paid (AAUW, 2015). Although women in STEM still earn less than their male counterparts by approximately 14 percent, this gender wage gap is smaller than the 21 percent difference in non-STEM occupations (Beede et al., 2011). Within STEM fields, engineering has the smallest gender wage gap with females earning seven percent less than males. Moreover, women in STEM occupations make 33 percent more than women in non-STEM careers (Beede et al., 2011). Thus, it is important to understand the underlying mechanisms that influence gender dimorphism in STEM in order to improve efforts to attract and retain more women in STEM fields, especially engineering.

Gender Differences in STEM

Researchers have provided many possible biological and social explanations for the underrepresentation of women in STEM fields (Ceci & Williams, 2010; Hill et al., 2010). Research suggests that there are gender disparities in occupational choices and interests (Ceci & Williams, 2010; Su et al., 2009). On average, women report less interest in engineering, science, and mathematics (Su et al., 2009). Research also suggests that females often have lower self-efficacy (i.e., the belief that they can complete the actions necessary to attain a goal) in STEM related outcomes (Bandura, 1997; Pajares, 2005; Zeldin & Pajares, 2000; Zimmerman, 2000). Even when women and men have comparably high mathematical ability, women are less likely to pursue STEM fields (Ceci & Williams, 2010; Lubinski & Benbow, 2006; Wang, Eccles, & Kenny, 2013). One possible explanation for this finding is that women with high mathematical ability are more likely than their male counterparts to also have high verbal ability (Park, Lubinski, & Benbow, 2008; Wang, Eccles, & Kenny, 2013). Mathematically precocious individuals are less likely to pursue STEM careers if they also have high verbal abilities, possibly because they have a wider range of occupational choices (Wang et al., 2013).

Women might also be deterred from pursuing STEM careers due to stereotypes about gender roles and abilities. Research suggests that men and women typically prefer careers that are traditionally associated with their respective genders (Cheryan et al., 2009; DiDonato & Strough, 2013; Diekman et al., 2010). DiDonato and Strough (2013) surveyed 264 college students on their attitudes about occupations for themselves and others. They found that both genders viewed women holding more stereotypically masculine occupations as more socially acceptable than men holding stereotypically feminine occupations; however, the women reported that more feminine careers were still more appropriate for themselves. In fact, the characteristics of STEM work environments themselves may maintain gender-dimorphic attitudes among both women and men by being disproportionally favorable to men.

Characteristics of STEM settings. STEM environments often have characteristics that are unsupportive to women and intensify their feelings of isolation (Hewlett et al., 2008). Many women in STEM continue to experience gender discrimination in access to resources and hear derogatory comments about their gender, which further isolates female workers and lowers job satisfaction (Hewlett et al., 2008; Settles, Cortina, Buchanan, & Miner, 2012). Women are also frequently excluded from recreational activities (e.g., golf, bar, after hours at the lab) where many work decisions are made (Hewlett et al., 2008). Women often have to work harder than men in STEM fields to show their competence, especially since stereotypes suggest that men naturally excel in these occupations (Heilman, Wallen, Fuchs, & Tamkins, 2004). More disheartening, when women do succeed in stereotypically masculine jobs, they are often rated as less likeable and more hostile, which negatively influences their opportunities for advancement (Heilman et al., 2004).

Many STEM fields are also associated with characteristics that are inconsistent with traditionally female gender roles (Cheryan et al., 2009; Diekman et al., 2010). On average, women report preferences for working with people, while men report preferences for working with inanimate things (Su et al., 2009). Moreover, women are more likely to place value on careers that clearly benefit others (Diekman et al., 2010; Hewlett et al., 2008; Konrad, Ritchie, Lieb, & Corrigall, 2000). In contrast, STEM fields are often stereotyped as being socially alienating and as having more of an emphasis on machinery and technology than on helping others (Diekman et al., 2010). Women also report feeling dissimilar to and less belonging with people that embody STEM stereotypes (Cheryan et al., 2009). Women are often thwarted from STEM careers because of extreme work pressures (e.g., long work hours, working across multiple time zones), especially because women are still more likely to have caregiving responsibilities for their children and/or elders (Hewlett et al., 2008).

Women are more likely to pursue STEM fields when they see that women are represented in the setting (Murphy, Steele, & Gross, 2007; Sekaquaptewa & Thompson, 2003). Although the number of females pursuing higher education in engineering has increased over time, women are still drastically underrepresented among full professors in engineering programs (Nelson & Brammer, 2010). Therefore, female students in engineering often lack female faculty mentors (Nelson & Brammer, 2010). Research suggests that female role models can help increase women's positive attitudes and identification with STEM, self-efficacy in STEM, and intent to pursue STEM fields (Lockwood, 2006; Stout, Dasgupta, Hunsinger, & McManus, 2011). Others have suggested that the gender of STEM role models might be less important than the degree to which role models personify STEM stereotypes (Cheryan, Siy, Vichayapai, Drury, & Kim, 2011).

In summary, research suggests that many societal factors influence women's underrepresentation in STEM fields including occupational choices and interests (Ceci & Williams, 2010; Su et al., 2009), STEM self-efficacy (Bandura, 1997; Pajares, 2005; Zeldin & Pajares, 2000; Zimmerman, 2000), STEM gender stereotypes (Cheryan et al., 2009; DiDonato & Strough, 2013; Diekman et al., 2010), and characteristics of the STEM environment (Hewlett et al., 2008). However, it is likely that a combination of cultural and biological factors result in differences in the skills required for success in STEM fields (Halpern et al., 2007). Gender differences in spatial and mathematical ability are two sets of related skills that might help to explain gender dimorphism in STEM (Ceci & Williams, 2010).

Spatial Skills

Importance of spatial skills in engineering. Research suggests that spatial skills are related to success in STEM fields (Shea et al., 2001; Uttal & Cohen, 2012; Wai et al., 2009; Webb et al., 2007). Shea and colleagues (2001) followed 563 (n=393 male) precocious adolescents who were identified as scoring within the top 0.5% for their age on the Scholastic Assessment Test (SAT). After 20 years of follow up data, the researchers found that high spatial skills at age 13 predicted preferences for math and science high school courses, as well as the likelihood to earn college degrees in STEM and be employed in STEM careers even after controlling for mathematical and verbal reasoning. Similarly, Webb et al. (2007) studied 1,060 adolescents within the top 3% in ability and found that spatial ability accounted for 3% unique variance over SAT performance and educational-occupational preference questionnaires when predicting high school course preferences, STEM leisure activities, and anticipated college major and future occupation. Those with higher spatial ability at age 13 were more likely to pursue STEM related activities, studies, and occupations. Wai and colleagues (2009) replicated these findings but used nationally representative longitudinal data from Project Talent to help determine the importance of spatial skills in STEM domains. Project Talent was a longitudinal study that started in the year 1960 and followed over 400,000 high school students through adulthood. The researchers found that spatial skills predicted level of educational attainment in STEM and entry into STEM occupations after controlling for mathematical and verbal ability.

Engineering students and practitioners have especially high mental rotation skills compared to other professions (Johnson O' Connor Research Foundation, 2004). More specifically, studies have shown that there is a relation between spatial visualization skills and succeeding and persisting in engineering graphics and design courses even after controlling for mathematical and verbal reasoning (Field, 2007; Gimmestad, 1990; Hsi et al., 1997; Kinsey, Towle, O'Brien, & Bauer, 2008; Koch & Sanders, 2011; Sorby & Baartmans, 2000). Gimmestad (1990) examined 11 variables related to performance in engineering graphics courses and found that spatial skill was the most significant predictor of success. Hamlin, Boersma, and Sorby (2006) also found that spatial skills were related to proficiency in learning to use computer-aided design software.

Some research suggests that spatial skills are especially predictive early in students' STEM education, but become less important as students gain expertise in the field (Uttal & Cohen, 2012). Thus low spatial skills might serve as a barrier to advancing in engineering, and some students might not persist to the point when spatial skills are deemphasized (Uttal & Cohen, 2012). This seems especially relevant since research suggests that undergraduate engineering students are most likely to drop out around the third semester (Min, Zhang, Long, Anderson, & Ohland, 2011). Although spatial skills are widely discussed in relation to STEM fields, exactly what they are is more complex than might be expected. Researchers suggest that there are several components and multiple methods for evaluating spatial skills (Hegarty & Waller, 2005).

Defining spatial ability. Linn and Petersen (1985) defined general spatial ability as "skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information" (p. 1482). However, research suggests that spatial ability is not a unitary construct and there is still much debate on what constitutes the spatial subcomponents (Hegarty & Waller, 2005). Linn and Petersen (1985) identified three types of spatial ability in their seminal meta-analysis on gender differences in spatial ability: spatial perception, mental rotation, and spatial visualization.

Spatial perception. Spatial perception tests measure participants' ability to "determine spatial relationships with respect to the orientation of their own bodies, in spite of distracting information" (Linn & Petersen, 1985, p. 1482). An example measure of spatial perception is Piaget's Water-Level Task, which requires participants to determine the horizontal water level when bottles are tilted (Piaget & Inhelder, 1956). The Rod-and-Frame test (Witkin & Asch, 1948), another spatial perception test, asks participants to place a rod vertically when the frame is tilted (Voyer et al., 1995). Spatial perception tests do not require individuals to mentally manipulate stimuli in two- or three-dimensional space; therefore, mental rotation tests are required to capture participants' ability to cognitively transform spatial information.

Mental rotation. Mental rotation tests involve the ability to mentally rotate two- or three-dimensional figures with speed and accuracy (Voyer et al., 1995). Two-dimensional mental rotation tests include the Spatial Relations subtest of the Primary Mental Abilities Test (PMA; Thurstone, 1958) and the Cards Rotation Test (Ekstrom, French, & Harman, 1976), which require participants to mentally rotate figures to find missing pieces or to match shapes, respectively. Many three-dimensional mental rotation tests involve variations of Shepard and Metzler's (1971) MRT, which requires participants to discriminate between geometric shapes to find a figure that matches a target stimulus. The Vandenberg and Kuse (1978) paper-and-pencil version is the most common variation of Shepard and Metzler's MRT. Some tasks require both spatial perception and mental rotation skills and so spatial visualization tests are used to measure more complex spatial abilities.

Spatial visualization. Spatial visualization tests "involve complicated, multistep manipulations of spatially presented information" (Linn & Petersen, 1985, p. 1484). These tasks often involve the same processes that are required for spatial perception and mental rotation tests, but have multiple possible solutions (Linn & Petersen, 1985). Voyer and colleagues (1995) have identified many spatial ability assessments that measure the spatial visualization domain. The Paper Form Board (Likert & Quasha, 1941) requires participants to identify which two-dimensional shape can be made from individual parts. Other tasks require individuals to identify how an object would appear when folded (e.g., Spatial Relations Subtest of the Differential Aptitude Test (Bennett, Seashore, & Wesman, 1973)) or unfolded (e.g., Paper Folding (Elkstrom, French, & Harman, 1976)). The Embedded Figures Test (Witkin, 1950) is another spatial visualization task that asks individuals to find figures that are embedded in complex designs. Other examples include tasks that require participants to use blocks (i.e., Block Design

(Wechsler, 2003)) or paper-and-pencil (i.e., Design Copying (Korkman, Ursulu, & Kemp, 2007)) to create designs that match specific models.

Measuring spatial skills in engineering. It is imperative for researchers to treat spatial ability as a set of skills instead of a unitary construct, especially when trying to measure spatial ability group differences and the relation between spatial skills and other domains (Mix & Cheng, 2012). However, researchers still debate the number of spatial ability dimensions and many engineering researchers divide spatial ability into two overarching skills: spatial visualization and spatial relation/orientation (Maeda & Yoon, 2013). Under these broad categories, mental rotation ability is subsumed under spatial visualization. More recent research theorizes that mental rotation ability and spatial visualization tasks involve the same types of skills (Uttal et al., 2013).

Uttal and colleagues (2012) conducted a meta-analysis on training spatial skills and proposed a five-category definition of spatial ability. They theorized that spatial tasks could be categorized according to two dimensions. The first dimension is whether the task includes intrinsic or extrinsic information. Intrinsic information is "the specification of the parts, and the relation between the parts, that defines a particular object," while extrinsic information "refers to the relation among objects in a group, relative to one another or to an overall framework" (Uttal et al., 2013). The second distinction is whether the task is static (i.e., fixed information) or dynamic (i.e., involves movement). Uttal and colleagues (2013) found that mental rotation and spatial visualization tasks are both intrinsic and dynamic; however, the researchers divided them into separate categories to be consistent with previous research including Linn and Petersen's (1985) three categories.

Research on spatial skills in engineering use a variety of tests to measure spatial visualization skills including the aforementioned Differential Aptitude Test: Spatial Relation (DAT:SR; Bennett, Seashore, & Wesman, 1973), the Mental Rotations Task (*MRT*; Vandenberg & Kuse, 1978)), and the Paper Form Board Test (Likert & Quasha, 1941). The Mental Cutting Test (*MCT*; CEEB, 1939) and the 3-D Cube test (*3DC*; Gittler & Glück, 1998) are also used in the engineering literature. The MCT asks individuals to choose, among five choices, a picture that represents the cross section of a block that is cut by a plane. The 3-D Cube test (3DC) presents participants with a cube with different marking on each side. Participants are asked to choose the rotated version of the cube among six choices.

Although there are many tests that assess spatial visualization skills, the Purdue Spatial Visualizations Test: Rotations (*PSVT:R*; Guay, 1976) is considered the “gold standard” for measuring spatial skill in engineering education and research (Waller & Lourenco, 2010). The PSVT-R is optimal for assessing engineering students’ mental rotation skills since it includes complex figures instead of simple geometric shapes (Yue, 2004; Yoon, 2011). The test requires individuals to study the rotational relation between two identical objects. Participants are then asked to mentally rotate a target stimulus in the same manner as the initial objects and to choose the resulting figure from an array of five choices (Figure 1).

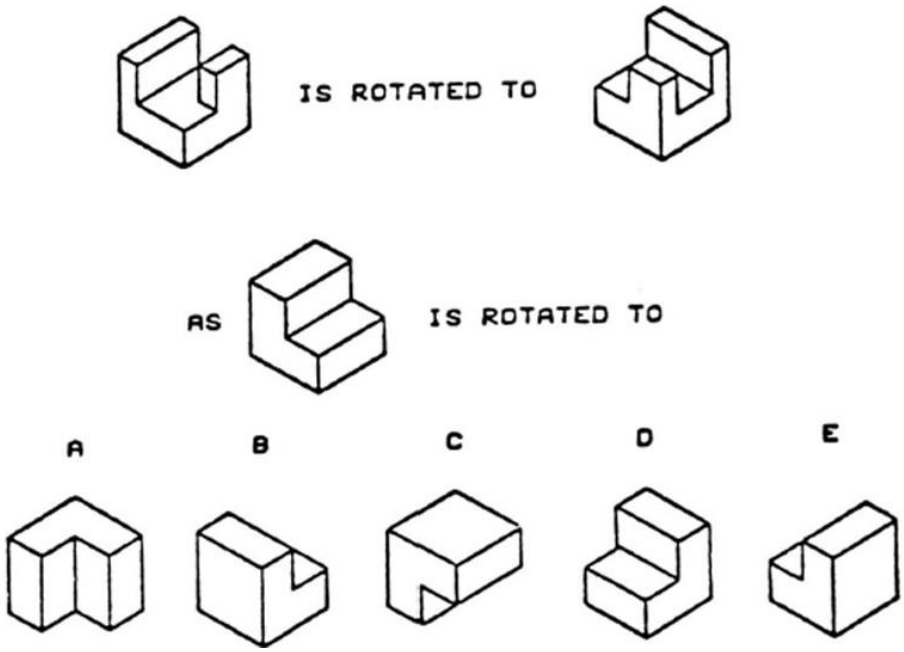

Figure 1 Sample Item From the *PSVT:R* (Guay, 1976)

Thus, spatial ability is a complex construct that comprises several components and multiple measures (Hegarty & Waller, 2005). The next section will examine studies that have defined spatial ability as a unitary measure, as well as studies that have investigated gender differences in individual spatial skills. It is vital to treat spatial ability as a set of skills, especially when examining underlying gender differences in order to see more consistent trends.

Gender and Spatial Ability

There are mixed findings about the relation between gender and spatial ability. Maccoby and Jacklin (1974) published a review of the literature illustrating that spatial gender differences exist in adolescence and adulthood; however, they did not estimate the magnitude of such differences. Hyde (1981) conducted a meta-analysis to quantify the size of the gender differences reported by Maccoby and Jacklin (1974), and found that gender only accounted for 5% of the spatial ability variance. However, Hyde (1981) used a unitary measure of spatial ability, which may have confounded the results.

Linn and Petersen (1985) addressed early research limitations by conducting another meta-analysis with 172 effect sizes that analyzed the subtypes of spatial ability and quantified the magnitude of gender differences. The researchers found that tasks that measured mental rotation produced the largest mean effect size (d = .73, $p < .05$), with the Vandenburg and Kuse (1978) Mental Rotations Test (*MRT*) generating the largest gender differences (d = .94, $p < .05$). The spatial perception tests also showed a significant mean effect at .44 ($p < .05$), but the spatial visualization tests did not detect any gender differences. Voyer and colleagues (1995) also conducted a meta-analysis with 286 effect sizes and replicated Linn and Peterson's (1985) findings. They found that mental rotation tasks produced the largest gender effect sizes favoring males, followed by spatial perception tests. They did not find mean gender differences on spatial visualization tests overall; however, they did find that males outperformed females on spatial visualization tests that included a mental rotation component for example the Paper Form Board (Likert & Quasha, 1941).

There is evidence that the magnitude of gender differences on many spatial skills tasks is decreasing (Feingold, 1988); however, gender differences on mental rotation tests in favor of males have remained stable over time (Geiser et al., 2008; Masters & Sanders, 1993; Maeda & Yoon, 2013; Voyer et al., 1995). Masters and Sanders (1993) conducted a meta-analysis of 14 studies published between 1975 to 1992 that investigated gender differences on the *MRT* in college students and young adults. They found a large mean weighted effect size (d = .90) for gender favoring males with effect sizes ranging from .69 to 1.27. Geiser and colleagues (2008) tested 1,624 German students (9-23 years old) using a redrawn *MRT* and found moderate to large gender differences favoring males across all ages (d = .52-1.49). Using structural equation analyses, they found that gender accounted for 16.1% of variance in *MRT* scores and that gender differences increased with age. Maeda and Yoon (2013) conducted a meta-analysis with 70 effect sizes from 40 studies to quantify the magnitude of gender differences in mental rotation ability on the *PSVT:R* and found a moderate mean effect size (g = .57). Moreover, Sorby and Veurink (2010a) indicate that gender differences, favoring males, remained stable over fourteen-years of data collection at Michigan Technological University.

Studies have also shown that gender differences on mental rotation tasks are influenced by task characteristics (Miller & Halpern, 2014). For example, gender differences favoring males are larger when the task uses three-dimensional instead of two-dimensional shapes (Linn & Petersen, 1985; Voyer et al., 1995) and when tests are administered with time constraints (Maeda & Yoon, 2013; Voyer, 2011). Monahan, Harke, & Shelley (2008) also found that the male advantage on The Revised Vandenberg and Kuse *MRT* (Peters, 1995) decreased from a large (d = 1.05) to medium (d = .59) effect size when the test was administered on a computer instead of paper-and-pencil. However, the computerized version was administered to smaller and some single-gender groups, which could have confounded results.

In summary, many researchers have used discrepant definitions of spatial ability. Some studies define spatial ability as a unitary construct while others conceptualize spatial ability as a broad term that can be subdivided into a variety of spatial skills. More recently, researchers have shown that gender dimorphism in spatial skill may be more stable depending on the measures used. Gender differences on spatial tasks involving mental rotation continue to produce the most robust and stable gender dimorphic features (Geiser et al., 2008; Masters & Sanders, 1993; Maeda & Yoon, 2013; Voyer et al., 1995), thus, they may be an important aspect to investigate in relation to gender success in STEM (e.g., engineering) fields.

Etiology of Gender Differences in Spatial Skills

The etiology of gender differences is still highly debated and researchers have argued for both biological and environmental sources. Some suggest that the exposure of sex hormones across development may be linked to differences in spatial skills, especially during the onset of puberty (Halpern et al., 2007). Consistent with this hypothesis is that sexual orientation and digit ratios (2D:4D) have been associated with spatial skill performance, which researchers suggest may be related to early prenatal hormone exposure (Collaer, Reimers, & Manning, 2007; Manning, 2002; Peters, Manning, & Reimers, 2007; Puts, McDaniel, Jordan, & Breedlove, 2008). Other possible biological influences include: handedness (Casey et al., 1992) and brain function lateralization (Butler et al., 2006; Semrud-Clikeman, Fine, Bledsoe, & Zhu, 2012).

Environmental factors may also influence gender dimorphism in spatial ability. Boys are often socialized toward playing different games (e.g., construction games, mathematically oriented games, video games) and recreational activities (e.g., exploration activities, sports) that use and develop spatial skills (Baenninger & Newcombe, 1989). Similarly, researchers have found a relation between female's self-rated masculinity and spatial ability (Newcombe & Dubas, 1992). Gender equality and economic development have also been associated with larger sex differences on spatial tasks, although this relation still remains unclear (Lippa, Collaer, Peters, 2010). Newcombe, Mathason, and Terlecki (2002) emphasize that it is more important to determine if gender differences can be diminished especially since spatial skills are related to mathematical ability, which is another skill underlying STEM success.

Mathematics and Engineering

Importance of mathematics in engineering. Research suggests that there is a relation between mathematics grades and success in engineering, computing, and design courses (Field, 2007). Robinson (2003) found that students who took advanced mathematics and science courses in high school were more likely to pursue and succeed in engineering in college. Similarly, Moses and colleagues (2011) found that calculus readiness and high school grade point average (GPA) predicted retention in first-year engineering students. Studies have also shown that successes in undergraduate mathematics courses are related to success and persistence in engineering (Budny et al., 1998; Honken & Ralston, 2013; Van Dyken et al., 2015; Yoon et al., 2014). Furthermore, Budny and colleagues (1998) found that students often leave engineering because of difficulty in mathematics courses.

Mathematics gender differences. There are mixed findings regarding the relation between gender and mathematics, and there is evidence that the gender gap fluctuates developmentally, chronologically, and nationally. Hyde, Fennema, and Lamon (1990) conducted a meta-analysis of 100 studies with 254 independent effect sizes. They found that girls showed a slight advantage over boys in computational ability during elementary and early adolescence, while boys consistently showed an advantage during high school, especially in relation to problem solving. Gender differences in problem solving favoring males first emerged in high school (d = 0.29) and increased in college (d = 0.32). Hedges and Nowell (1995) examined data from six national surveys that spanned 32 years and found a small mean difference in mathematical ability favoring males (d = .16), with effect sizes ranging from d = 0.03 to 0.26.

More recently, Hyde and colleagues (2008) examined state assessment data for 10 states and over seven million students between second and eleventh grade. They did not find significant gender differences in mathematics across grades although the assessments did not test complex problem-solving skills and the results were just based on state tests that were meant to satisfy No Child Left Behind legislation. Similarly, Lindberg and colleagues (2010) used meta-analysis techniques to investigate 242 studies between 1990 and 2007 and did not find overall mean gender differences in mathematics (d = 0.05). However, they did find a small male advantage in mathematical ability in high school (ds = +0.23) and college-aged students (ds = +0.18) (Lindberg et al., 2010). There was also a small male advantage (d = 0.16) on problems that measured complex problem solving in high school. The researchers also analyzed four large national datasets and found negligible effect sizes ranging between d = -0.15 and 0.22 (Lindberg et al., 2010). Overall, these results suggest that a small male advantage in mathematics ability is more consistently found in high school and college-aged students, especially when mathematical tests involve complex problem solving.

Researchers have found similar results when examining gender differences in high-stakes mathematics tests like the SAT and ACT (Halpern et al., 2007; Corbett, Hill, & St. Rose, 2008). These tests continue to exhibit a small male advantage on the mathematics section, which include more novel questions that rely on problem solving skills (Halpern et al., 2007; Corbett et al., 2008). Although small, gender differences in problem solving are especially important since it is a critical skill in mathematics-intensive fields, including engineering (Hyde et al., 1990). Despite these gender differences in problem solving, females are earning comparable mathematics credits in high school (Hill et al., 2010) and slightly higher mathematics course grades than their male counterparts in high school and college (Bridgeman & Wendler, 1991; Voyer & Voyer, 2014). However, on average, males report higher confidence in their mathematical ability even when their performance is comparable to females (Lundeberg, Fox, & Punćcohaŕ, 1994).

There is evidence that the relation between math and gender varies internationally (Else-Quest, Hyde, and Linn, 2010; Guiso, Monte, Sapienza, & Zingales, 2008). Else-Quest et al.

(2010) used meta-analysis to investigate mathematical gender differences across 69 nations. They found that mean effect sizes were small (*d* < 0.15), but that national effect sizes varied from male to female advantage (*ds* = -0.42 to 0.40). Similarly, Guiso and colleagues (2008) analyzed international data and found that on average males scored 2% higher than females on mathematics; however, there was considerable variability between countries and gender differences were negligible when the researchers accounted for economic, political, and educational opportunities for women, as well as reports of well-being.

Gender differences in mathematical variance and ability distribution. Some researchers suggest that males' mathematical skills are more variable than females (Halpern et al., 2007; Hedges & Nowell, 1995; Hyde, Fennema, & Lamon, 1990; Hyde et al., 2008). Many researchers use the variance ratio (VR) to analyze gender differences in variances. This statistic is computed by taking the ratio of male to female variance. Values over 1.0 indicate more male variability (Lindberg et al., 2010). Hedges and Nowell (1995) reported that VRs ranged between 1.05 and 1.25 on mathematics tests. Similarly, Hyde and colleagues (2008) reported VRs between 1.11 and 1.21. Conversely, Lindberg et al. (2010) found nearly equal gender variances through their meta-analysis (VR = 1.08) and variances ranged from 0.88 to 1.34 after they analyzed data from four national databases of adolescents in the United States. Some have suggested that gender differences in mathematical variance might help account for the disproportionate number of mathematically gifted males.

Research suggests that males are overrepresented within the highest levels of the mathematical ability distribution (Benbow & Stanley, 1980; Benbow & Stanley, 1983; Lohman & Laskin, 2009; Strand, Deary, & Smith, 2006; Wai, Cacchio, Putallaz, & Makel, 2010). Strand and colleagues (2006) examined data from a nationally representative sample in the United

Kingdom of over 320,000 students between 11 and 12 years old. Of students who scored within the top 4% (i.e., 9^{th} stanine) on the mathematical portion of the Cognitive Abilities Test (CAT), 60% were males. Lohman and Laskin (2009) replicated these findings by examining nationally representative data (n = 318,599) from the 1984, 1992, and 2000 standardizations of the United States version of the CAT. Data from the Study of Mathematically Precocious Youth (SMPY) provide further evidence of an overrepresentation of males who are mathematically gifted adolescents (Benbow & Stanley, 1980; Benbow & Stanley, 1983; Brody & Mills, 2005). Benbow and Stanley (1980) analyzed data from 9,927 adolescents who were identified as being intellectually talented and found that males outperformed females on the SAT-M (d = 0.40). The researchers replicated these findings in 1983 with another 40,000 intellectually talented adolescents (Benbow & Stanley, 1983). They also found that of students scoring at the top 0.01% on the SAT-M (scores of 700 or more) the male-female ratio was 13:1 (Benbow & Stanley, 1983). Wai and colleagues (2010) extended these findings by examining 1,173,350 SAT test scores from 1981 to 2010 and 440,369 ACT test scores from 1990 to 2010 of seventh grade students who were identified as intellectually talented. They found that the male-female ratio for students scoring within the top 0.01% on the SAT-M has declined to approximately 4:1, but has remained relatively stable since 1990s. The gender ratio was slightly smaller on the ACT-M with a most recent estimate of 2.6:1. Although the ratio has decreased over time, the gender discrepancy is still important since the mathematically gifted are more likely to pursue and succeed in STEM fields (Lubinski & Benbow, 2006). The next sections will investigate how improving students' spatial skills might translate into a higher representation of females at the highest levels of mathematical ability.

The Relation Between Mental Rotation and Mathematical Skills

Research suggests that spatial ability tasks involving mental rotation are related to mathematical ability overall and specific mathematical content areas in adolescence and early adult populations. Rohde and Thompson (2007) examined the relation between academic achievement and cognitive skills, including spatial ability in undergraduate students. They created a composite spatial test by incorporating questions from the Spatial Relations Test of the Differential Aptitude Test (DAT; Bennett et al., 1947), the Cards Rotation Test (Ekstrom, French, & Harman, 1976), and the Paper Form Board Task (Likert & Quasha, 1941). All of these tasks include some degree of two-dimensional mental rotation. They found that spatial ability significantly predicted SAT-M scores. Tolar, Lederberg, & Fletcher (2009) examined the relation between computational fluency, spatial ability, working memory, and mathematical achievement using structural equation modeling with undergraduate students. They created a *3D Spatial Visualization* variable with The Revised Vandenberg and Kuse Mental Rotations Test (Peters, 1995) and the Space Relations Subtests of the DAT (Bennett et al., 1947). They found that 3D Spatial Visualization was related to SAT-M scores controlling for algebra education level.

Other studies have investigated the relation between spatial ability tasks involving mental rotation and specific mathematical content areas in adolescence and early adult populations. Evidence suggests there is relation between mental rotation skills and performance in geometry (Battista, 1990; Delgado & Prieto, 2004; Kyttälä & Lehto, 2008; Sherman, 1979; Weckbacher & Okamoto, 2014). Sherman (1979) found that students' ninth grade spatial visualization scores on the Space Relations Test of the DAT, which involves mental rotation, predicted geometry grades for females and both genders combined at 10th grade. The scores did not predict geometry grades for males when examined independently; however, results could have been confounded since the researchers investigated a smaller, more homogenous subsample for this analysis and used geometry grades instead of a standardized measure of geometry skills. Battista's (1990) study also indicated that high school students' mental rotation scores were associated with their geometry ability and with which geometry problem-solving strategies they employed. Delgado and Prieto (2004) analyzed data from 455 participants (median age of 13 years) and found that mental rotation scores on the Revised Vandenberg and Kuse Mental Rotation Test (Peters, 1995) added unique variance (2%) when predicting performance on geometry and word problems. Similarly, Weckbacher and Okamoto (2014) found a significant relation between *MRT* (Vandenberg & Kuse, 1978) scores and geometry grades ($r(111) = .24$, $p < .05$) and on a standardized geometry measure ($r(111) = .26$, $p < .01$) in high school.

Research also suggests a relation between mental rotation skills and problem solving skills in middle and high school (Hegarty & Kozhevnikov, 1999; Sherman, 1979). Sherman (1979) found that spatial visualization scores predicted 12th grade girls' mathematical problem-solving scores but males were not tested. Hegarty and Kozhevnikov (1999) found that mental rotation scores on the Space subtest of Primary Mental Abilities Test (PMA; Thurstone, 1958) were significantly and moderately related to mathematical problem solving ability (M = 12 years, 1 month) ($r(31) = .52$, $p < .01$). Studies have also found a relation between mental rotation skills and word problems (Delgado & Prieto, 2004; Kyttälä & Lehto, 2008) and arithmetic in adolescence and early adulthood (Geary, Saults, Fan Liu, & Hoard, 2000; Kyttälä & Lehto, 2008; Reuhkala, 2001). Moreover, Tolar and colleagues' (2009) study provides preliminary evidence that spatial ability involving mental rotation was related to algebra achievement controlling for algebra education level in undergraduate students. However, they did not replicate this finding in further analyses with a subsample of the participants.

In summary, evidence suggests that there is a relation between mental rotation skills and mathematics ability in adolescence and early adulthood (Rohde & Thompson, 2007; Tolar, et al., 2009). This relation seems especially strong for specific mathematical areas including: geometry (Battista, 1990; Delgado & Prieto, 2004; Kyttälä & Lehto, 2008; Sherman, 1979; Weckbacher & Okamoto, 2014) and problem solving (Hegarty & Kozhevnikov, 1999; Sherman, 1979). Mental rotation skills have also been linked to performance on word problems (Delgado & Prieto, 2004; Kyttälä & Lehto, 2008), arithmetic (Geary et al., 2000; Kyttälä & Lehto, 2008; Reuhkala, 2001), and algebra (Tolar et al., 2009). These results suggest that it is important to consider mental rotation skills when examining differences in mathematical performance; however, these studies did not investigate whether mental rotation skills were related to mathematical gender differences.

The Relation Between Mental Rotation Skills, Mathematical Ability, and Gender

Evidence suggests that mental rotation skills might help explain gender differences in mathematical ability (Casey et al., 1992). Casey and colleagues (1992) studied the relation between mental rotation skills, gender, and mathematical achievement in 240 adolescent students. Their results indicated that mental rotation skills predicted mathematical achievement and contributed 3% unique variance over scholastic aptitude and verbal achievement for all boys, non-right handed girls, and right handed girls with non-right handed relatives. However, mental rotation skills did not significantly predict mathematical achievement for right-handed girls who had all right-handed relatives. The results suggest that the relation between spatial skills and mathematics ability might be influenced by brain organization. Females are more likely to use verbal, analytical approaches when solving problems, especially when they are right handed with all right-handed relatives. Non-right handed girls and right-handed girls with non-right handed relatives might especially benefit from more exposure to spatial experiences and spatial training since they often display less left-hemisphere dominance (Casey et al., 1992).

Studies have also found that mental rotation skills mediate the relation between mathematical ability and gender (Casey et al., 1995; Casey et al., 1997). Casey and colleagues (1995) found that for females, mental rotation skills predicted SAT-M scores for undergraduate students, mathematically talented adolescents (M = 13.38), and low- and high-ability college-bound 10th grade students controlling for verbal skills. For males, mental rotation skills only predicted mathematical performance for the low- and high-ability college bound students. Males outperformed females in mental rotation skills and SAT-M scores for the undergraduate, talented, and high-ability college bound group, but not the low-ability college bound group. However, gender differences on the SAT-M in the undergraduate and high-ability college-bound students were eliminated when mental rotation skills were controlled. Similarly, Casey et al. (1997) completed a path analysis with high-ability college-bound 10th grade students and found that the relation between gender and SAT-M scores were mediated by mental rotation skills (64%) and math self-confidence (36%). These results suggest that mental rotation skills are especially important to consider when examining gender differences in mathematics. Moreover, improving females' mental rotation skills might help attenuate or eliminate mathematical gender differences.

Spatial Training

Research suggests that spatial visualization skills can be improved through spatial training (Uttal et al., 2013), which might help to close the gender gap in spatial ability, mathematics, and STEM fields. Uttal et al. (2013) conducted a meta-analysis of 206 spatial training studies with 1,038 effects and found a moderate average effect size for training relative to control (g = .47).

Some researchers have been able to significantly improve participants' spatial visualization skills by training the specific spatial task through repeated administrations (Alington, Leaf, & Monaghan, 1992; Lohman & Nichols, 1990; Saccuzzo, Craig, Johnson, & Larson, 1996; Terlecki, Newcombe, & Little, 2008; Wright, Thompson, Ganis, Newcombe, & Kosslyn, 2008) Similarly, Wiedenbauer, Schmid, and Jansen-Osmann (2007) used a training protocol where participants (M = 22.2 years) were instructed to manually rotate virtual geometric block structures to match target stimuli via a joystick. They found that the mean response time for the experimental group was significantly lower than the control group (d = .66). Evidence also suggests that spatial visualization skills can be significantly improved using video/computer games (Cherney, 2008; Cherney, Bersted, & Smetter, 2014; De Lisi & Cammarano, 1996; Feng, Spence, & Pratt, 2007; Okagaki & Frensch, 1994; Terlecki et al., 2008). For example, Terlecki and colleagues (2008) trained undergraduates by either having them complete repeated testing on the *MRT* or play a videogame across 12 weeks. They reported that both conditions led to improvements in *MRT* scores. Videogame training showed a larger rate of growth initially, but there was no difference between conditions at posttest.

There has also been considerable effort to increase undergraduate engineering students' spatial visualization skills through more comprehensive spatial courses (Gerson et al., 2001; Hsi et al., 1997; Onyancha, Derov, & Kinsey, 2009; Sorby & Baartmans, 2000). Hsi and colleagues (1997) found that spatial skills could be improved through strategy instruction. Students who had low spatial visualization skills at the beginning of the semester were invited to attend a three-hour instructional session on spatial strategies. Students who took the seminar significantly improved their spatial visualization skills (e.g., object rotations, paper folding, pattern matching, cube counting) at posttest. Similarly, Onyancha and colleagues (2009) found that students' spatial visualization scores on a Web-based version of the PSVT (Guay, 1976) improved after four hours of spatial visualization training. The intervention consisted of two different tools: the Physical Model Rotator (PMR) and Alternative View Screen (AVS). The PMR rotates a physical object synchronously with an identical virtual object in CAD software. This allows students to see both the three dimensional object and its two dimensional representation. The AVS software displays two identical objects at different orientations in the CAD software. The objects can then be rotated so that students can view them in different representations.

Sorby and Baartmans first developed a widely used spatial skills training course at Michigan Technological University in 1993 (Sorby & Baartmans, 2000). The course originally included a textbook on spatial visualization, but the researchers developed multimedia software and a workbook to supplement the textbook in 1998. According to the researchers' assessment and training protocol, students are given the Purdue Spatial Visualizations Test: Rotations (*PSVT:R*; Guay, 1976) as part of their incoming freshmen orientation. Those who fail the initial *PSVT:R* by scoring under 60% are offered the spatial visualization course. The original findings for the 1993-1998 cohorts indicated that individuals in the experimental group significantly increased their spatial visualization scores on the *PVRT:R*, *MRT*, and *DAT:SR* at the end of the 10 week course. The researchers and their colleagues also found that students who trained using only multimedia software modules and the supplemental workbook made comparable spatial visualization gains on the *PSVT:R, MRT, DAT:SR, MCT,* and *3DC* as students who also received the traditional lecture (Gerson et al., 2001). The researchers encourage the use of the lecture, however, because it provides students the opportunity to have support from the instructor and more opportunities to ask questions (Gerson et al., 2001). Moreover, individuals who solely received the software (i.e., without the supplemental workbook or lecture) did not show significantly more spatial visualization score gains than individuals receiving no training (Sorby, 2009). This finding suggests that it is especially important for students to physically practice working with and manipulating spatial information.

Researchers have also examined whether the spatial visualization course generalizes to other populations and settings. The benefits of the course have been replicated with non-engineering college students, as well as middle and high school students (Sorby, 2009). Spatial visualization skills were also significantly improved through training when students with low spatial skills volunteered to take the spatial course or were required by their program. However, individuals who volunteered showed more gains (Sorby & Veurink, 2010a). Researchers outside of Michigan Technological University have also found that engineering students with low spatial ability who participate in spatial training that includes the spatial visualization curriculum (Sorby & Wysocki, 2003) show significant gains in spatial skills (Basko & Holliday-Darr, 2010; Walton et al., 2015).

Overall, the literature suggests that spatial visualization skills can be significantly improved through various interventions (Uttal et al., 2013). Sorby and colleagues' spatial visualization course seems especially promising for college engineering students since the training is comprehensive, easily implemented, and shows consistent spatial visualization gains (Sorby & Baartmans, 2000). Spatial training might be particularly helpful for females who are more likely to underperform on mental rotation tasks. The next section will explore whether spatial visualization skill gains vary by gender.

Spatial training and gender. It is still highly debated whether gender moderates the relation between spatial training and spatial visualization gains. Baenninger and Newcombe (1989) conducted a meta-analysis to determine whether spatial training could improve spatial skills and attenuate spatial gender differences. Their results suggest that spatial training lead to significant increases in spatial skill for both genders and at the same rate; therefore, the male advantage in spatial skill remained. These findings were recently replicated in Uttal and colleagues' (2013) meta-analysis of spatial training; however, they noted that most studies gave relatively little training and so more intensive training might reduce the magnitude of gender differences. Many researchers have demonstrated that spatial visualization gender differences can be decreased through various spatial training paradigms.

Studies examining the influence of repeated practice on mental rotation tasks suggest that females improve at a faster rate and that training can attenuate or even eliminate gender differences (Alington et al., 1992; Saccuzzo et al., 1996). Studies also suggest that gender differences in mental rotation tasks can be decreased through playing video/computer games (Cherney, 2008; De Lisi & Cammarano, 1996; Feng et al., 2007). Feng and colleagues (2007) found that females showed significantly more gains than males on a computerized *MRT* (Vandenburg & Kuse, 1978) after playing an action videogame for 10 hours across four weeks. The control group, who completed the training with a non-action game, did not show any improvements. Furthermore, gender differences on the *MRT* were significantly decreased, while gender differences on a spatial attention task were eliminated at posttest. Cherney (2008) trained college (M = 19.1) students for four hours on either a two- or three-dimensional computer game. They found that women trained in either condition showed significant improvement on the MRT (Vandenburg & Kuse, 1978) and the Card Rotations Test (*CRT*), while men only showed significant improvement on the *CRT* controlling for computer experience. Moreover, the women showed significantly larger improvements than the men. The gender effect sizes decreased from d = 1.03 to d = .66 for the *MRT* and from d = .46 to d = .16 on the *CRT* from pretest to posttest;

however, the *CRT* gender differences were not significant at pre- or posttest. More recently, Cherney and colleagues (2014) found that pretest gender differences on The Revised Vandenberg and Kuse Mental Rotation Test (Peters et al., 1995) were eliminated at posttest after participants completed videogame training for one hour, but not for the control group. Women who completed videogame training also displayed a significantly larger increase in *MRT* scores compared to men even when controlling for factors like spatial experiences, confidence, and masculine childhood activities.

Other studies have specifically examined the relation between gender and spatial visualization training in engineering undergraduate students through instruction (Hsi et al., 1997). Hsi and colleagues (1997) provided specific strategy instruction to 153 engineering students with low spatial visualization skills at pretest. They found that pretest gender differences in the ability to generate orthographic projections disappeared at posttest and women made significantly more gains in spatial visualization tasks. They also found that instruction on spatial strategies reduced gender differences in engineering spatial tasks. Others have found that males and females make comparable gains in spatial visualization scores after spatial visualization training, but women with low spatial visualization skills are more likely to be retained in engineering if they participate in spatial training (Sorby, 2009; Sorby & Baartmans, 2000; Sorby, et al., 2013; Walton et al., 2015). Conversely, Miller and Halpern (2013) trained gifted STEM students using Sorby and colleagues' (2003) training materials and did find a significant gender effect. Males significantly outperformed females at pretest on the MCT, MRT, SAT-Mathematics, and on the Lappan Test (Veurink et al., 2009), which measures students' ability to visualize different views of two- and three-dimensional objects. They found that students, irrespective of condition, improved their spatial skills on the *MCT*, *MRT*, Lappan Test, and the

Paper Folding Test; however, students in the training group improved significantly more on the *MCT* and *MRT* measures. Moreover, gender differences were significantly smaller at posttest on the *MCT*, *MRT*, and Lappan tests.

Some researchers have hypothesized that males and females show parallel trajectories through short training, but that males' growth might slow earlier in longer-term interventions since males are more likely to start with higher spatial skills and experiences (Baenninger & Newcombe, 1989). Some studies have found preliminary evidence that spatial skills, spatial experiences, and gender might influence spatial skills growth patterns during training (Terlecki et al., 2008; Uttal et al., 2013). Research suggests that participants who begin with lower spatial skills show significantly larger spatial training effects (g = .68) (Uttal et al., 2013). Terlecki and colleagues (2008) also found support for gender differences in mental rotation growth patterns in undergraduate participants. Women and men with more spatial experiences before training showed a larger rate of improvement on the *MRT* (Vandenburg & Kuse, 1978) at the beginning of treatment; however, the growth rate for men significantly decreased by the end of treatment while the women's growth rate remained stable. Moreover, females with lower spatial experience showed slower growth in *MRT* scores at the beginning of training, but their growth rate significantly increased by the end of training. The scores for men with low spatial experience could not be analyzed because the sample size was too small. Interestingly, 89% of men reported high spatial experiences, while 93% of females reported low spatial experiences.

It appears that women benefit from spatial training; in fact, some studies have found that women show more spatial gains over time than men (Alington et al., 1992; Cherney, 2008; De Lisi & Cammarano, 1996; Feng et al., 2007; Hsi et al., 1997; Miller & Halpern, 2013; Saccuzzo et al., 1996). Conversely, others have found that women and men make comparable gains after training thus maintaining gender dimorphism on spatial tasks (Sorby & Baartmans, 2000; Sorby, 2009; Sorby et al., 2013; Walton et al., 2015). It also appears that the length of training and level of spatial skill at the beginning of training matters (Baenninger & Newcombe, 1989; Terlecki et al., 2008; Uttal et al., 2013). Although we know that women benefit in terms of increasing spatial skills, there is still question as to whether that training transfers to novel spatial tasks, mathematics, and STEM performance.

Spatial training transfer effects. It is also important to determine to what extent spatial skills training gains transfer to novel spatial skills and tasks (Mix & Cheng, 2012; Uttal et al., 2013). Although some have reported that spatial skill improvements on one task do not transfer to other spatial tasks (Heil, Rösler, Link & Bajric, 1998; National Research Council, 2006; Sims & Mayer, 2002) others have found that gains can be generalized to novel task stimuli (Leone, Taine, & Droulez, 1993), tasks using the same spatial skill (Moreau, 2012; Waller, Knapp, & Hunt, 2001), and tasks using different spatial skills (Meneghetti, Borella, & Pazzaglia, 2015; Terlecki et al., 2008; Wright et al., 2008). Uttal and colleagues' (2013) meta-analysis suggests that spatial training leads to moderate improvements on transfer tasks overall (g = .48). Moreover, spatial training led to moderate improvements in transfer tasks that were similar to the training (g = .51) and transfer tasks that required different skills than the training (g = .55).

Wright and colleagues (2008) trained participants (M = 23.8 years) by having them practice a computerized version of the Shepard and Metzler (1971) mental rotation task or a computerized adaptation of the mental paper folding task (Shepard & Feng, 1972) over 21 days. Overall, they found that both practice groups displayed significantly faster response times and fewer errors during the final practice session compared to the initial session. Although there were larger gains for the practiced tasks, participants showed significant gains (i.e., higher response times and lower number of errors) for the task they did not practice. Both training groups also demonstrated transfer gains to novel stimuli on spatial task they practiced. Moreover, the participants showed significantly larger improvement on the unpracticed spatial task than on a computerized verbal analogies task suggesting that training gains were not solely based on greater familiarity with the computerized testing format. Terlecki et al. (2008) also found that the effects of videogame training transferred to other spatial skills involving some degree of mental rotation. Similarly, Meneghetti and colleagues' (2015) study indicated that participants who received mental rotation training showed significant gains on an object rotation and perspective-taking task. Thus it appears that spatial training effects transfer to new stimuli and other spatial tasks. But more specifically, it is important to understand how spatial training relates to success in the coursework integral to engineering education.

Spatial training transfer to college engineering program success. Research suggests that spatial visualization skills are related to success in STEM fields, especially engineering (Shea et al., 2001; Uttal & Cohen, 2012; Wai et al., 2009; Webb et al., 2007). Therefore, it is important to find spatial skills interventions that will transfer to engineering success. Longitudinal studies have found that engineering students who received spatial visualization training outperformed those in the control group on later graphics courses (Sorby, 2009; Sorby & Baartmans, 2000). Participation in spatial training interventions is also related to retention in the engineering program, especially for women (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013). Spatial visualization training might be particularly useful in helping to improve students' mathematical performance since spatial skills are related to mathematical ability (Mix & Cheng, 2012). Performance in college mathematics courses is related to persistence in engineering and performance in subsequent engineering courses (Baker-Ward, Dietz, & Mohr, 1993; Budny et al., 1998; Felder, Forrest, Honken & Ralston, 2013; Van Dyken et al., 2015; Yoon et al., 2014). Moreover, students often leave engineering due to their lack of competencies in mathematics (Budny et al., 1998). However, it is still unclear whether spatial training gains generalize to mathematical performance.

Even though research suggests a relation between spatial ability and mathematics, there is little research that investigates the transfer effects of spatial training to mathematical outcomes (Mix & Cheng, 2012). Cheng and Mix (2011) used a pretest-training-posttest design with two groups of young children (M = 6.8 years). Children in the experimental group practice a mental rotation task for 40 to 50 minutes, while children in the control group completed crossword puzzles. They found that students in the experimental group significantly outperformed the control group on mathematics tests that included simple addition and subtraction problems and items that tested the students' place value concepts. This finding was especially evident on problems that involved a missing term (e.g., 3 + ___ = 5 or 8 – ___ = 4). The researchers replicated this study and found that children in the experimental group outperformed students on missing-term problems but not number-fact or multidigit calculation problems (Cheng & Mix, 2014). The researchers noted that the mental rotation training might have improved the students' visuospatial working memory capacity or their ability to mentally rotate missing-term problems so that they resembled more conventional equations.

There is also preliminary evidence that spatial training gains might predict subsequent mathematics grades (Sorby, 2009; Sorby et al., 2013; Sorby & Veurink, 2010b), but the research remains inconclusive. Sorby (2009) indicated that those who received spatial skills training performed better in mathematics courses (i.e., pre-calculus and calculus I), although this finding was not consistent across experimental groups. Sorby and colleagues (2013) also found that spatial skills training was significantly related to subsequent calculus grades, but with a small effect size of $d = .20$. Notably, the influence of the spatial training course did not significantly defer between males and females. Sorby and Veurink (2010b) found that students who initially failed the *PSVT:R* and were required to enroll in the spatial skills course had higher Calculus I grades than the students in the control group who just marginally passed the *PSVT:R*, suggesting that the spatial skills course might lead to higher mathematical grades even when it is compulsory.

In contrast, Ferrini-Mundy (1987) specifically examined the influence of spatial training on calculus achievement in 250 college students and did find gender differences. Students who were enrolled in a calculus course were randomly assigned to receive no spatial training, instruction on spatial strategies, or instruction on spatial strategies supplemented by concrete manipulative aids over an eight-week period. Results suggest that the treatment and control groups did not significantly differ at posttest in calculus grades or spatial visualization scores on the *DAT-SR*, but women overall had significantly higher calculus grades irrespective of group membership. Women who received training showed significantly higher scores on a measure of visualization of solids of revolution, which involves solving for the volume of a solid produced by rotating a plane curve around an axis (*VSRSC*). Also, women who solely received instruction on spatial strategies significantly outperformed those who received instruction supplemented by use of concrete manipulative aids on their calculus course grade. Moreover, women who were trained scored higher on the *VSRSC* than women who did not receive training, while men's scores did not differ between treatment groups and control. These findings suggest that spatial training may benefit women in calculus on areas requiring the visualization of solids.

Not all mathematics courses seem to be influenced by training in spatial skills. Miller &

Halpern (2013) found that participants who participated in spatial training had higher final Newtonian physics grades compared to controls, but they did not find significant differences in Differential Equations I, Multi-Variable Calculus I, Chemistry, or Engineering grades. Similarly, Walton and colleagues (2015) did not find a significant difference in mathematics grades between training and control groups. Moreover, math placement scores and pre- and post-test *PSVT-R* skills did not significantly predict mathematics grades.

In summary, preliminary research examining the relation between spatial training and mathematics in college students is inconclusive. Some researchers suggest that students with low spatial skills who participate in spatial training outperform students with comparable spatial skills who do not take the course (Sorby, 2009; Sorby, 2013; Sorby & Veurink, 2010b); however, others have not found a significant relation (Miller & Halpern, 2013; Walton et al., 2015). No study, to this investigator's knowledge, has examined whether spatial training is associated with changes in mathematical performance on a standardized measure of mathematical ability in college-age students. Use of a standardized mathematical measure is especially important when investigating the response to spatial training as a function of gender since females often get comparable or slightly higher grades in mathematics courses than their male counterparts (Bridgeman & Wendler, 1991; Hill et al., 2010; Voyer & Voyer, 2014), while a male advantage is often seen on mathematical tests involving complex problem solving (Halpern et al., 2007; Corbett et al., 2008). Moreover, previous studies did not account for the degree to which students believe they can actually change their cognitive skills, which might have confounded results.

Ability Mindset, Gender, and STEM Learning

Research suggests that students' beliefs about the malleability of intellectual ability influence their motivation to complete challenging tasks (Dweck, 2000). These beliefs can be referred to as mindsets or implicit theories of intelligence (Dweck, 2000; Dweck, 2008a; Dweck & Leggett, 1988). According to this model, individuals who believe that intelligence is more of a fixed trait hold an entity theory (i.e., fixed mindset), while students who believe that intelligence is more malleable and can be cultivated espouse an incremental theory (i.e., growth mindset) (Dweck, 2008a). Individuals with an entity view of intelligence are more likely to give up on tasks where they have to expend effort since they view intelligence as unchangeable, while those with an incremental view of ability are more likely to persist and use more effort in order to overcome difficult tasks (Dweck & Leggett, 1988).

Research suggests that students' mindsets are related to their mathematics and science achievement in adolescence and early adulthood (Blackwell et al., 2007; Grant & Dweck, 2003). Blackwell and colleagues (2007) followed 373 students with comparable mathematical achievement as they transitioned to seventh grade. The researchers found that a growth mindset predicted an upward trajectory in mathematical grades over two years, while a fixed mindset predicted a flat trajectory. Moreover, those with a growth mindset were more likely to be oriented toward learning goals, believe in exerting effort, and display more mastery-oriented reactions to challenges (e.g., exert more effort, try new strategies). Grant and Dweck (2003) also examined the influence of mindset but with college students taking a challenging pre-med organic chemistry course. They found that students who were oriented toward learning goals over validating their own intelligence had higher grades in the course controlling for SAT mathematics scores. Students with a growth mindset were also more likely to recover from an initial poor grade.

Research also suggests that increasing students' growth mindset is related to improvements in mathematics and spatial ability (Blackwell et al., 2007; Dar-Nimrod & Heine, 2006; Good et al., 2003; Moé et al., 2009; Moé & Pazzaglia, 2010). Dar-Nimrod and Heine (2006) found that college women who were told that gender differences in mathematics were experientially based (i.e., growth mindset) scored significantly higher on a mathematics task than those who were told that the differences were genetically based (i.e., fixed mindset). Studies (Blackwell et al., 2007; Good et al., 2003) have also taught middle school students that the brain is malleable and can change through learning experiences. They found that students in the intervention group displayed significantly more mathematics gains over time. Good and colleagues (2003) also found that students who received the mindset intervention scored significantly higher on their next mathematics achievement test compared to controls. Moreover, girls made significantly more gains than boys, which decreased the magnitude of the mathematical gender differences. Similarly, evidence suggests that receiving growth mindset messages influences individuals' performance on mental rotation tasks (Moé & Pazzaglia, 2010) and that women display significantly higher mental rotation skills when they hold growth mindsets for masculine tasks (Moé et al., 2009).

Students' mindsets might help explain gender differences in mathematics and science achievement, as well as persistence in STEM fields (Dweck, 2007; Dweck, 2008b; Grant & Dweck, 2003; Good et al., 2007). Dweck (2007; 2008a) suggests that high-achieving females might be especially likely to hold a fixed mindset. High-achieving girls are often praised for their intelligence (Dweck, 2007; 2008a) and placed in high ability classes (Boaler, 1997). They often internalize the idea of being smart or clever, which might lead to a need to maintain the image of having a high intelligence and difficulty coping with failure (Boaler, 1997). Early studies discovered gender differences with how precocious elementary students coped with confusing material while learning a new task. They found that girls with higher IQ performed more poorly on tasks with confusing material. Males showed the opposite trend and seemed energized by challenging tasks (Licht & Dweck, 1984; Licht, Linden, Brown, & Sexton, 1984; Licht & Shapiro, 1982). Grant and Dweck (2003) found that among college students with a fixed mindset, males significantly outperformed females in final organic chemistry grades; however, among students with a growth mindset, females had slightly higher—albeit not significant—final grades than males. These findings are especially relevant since gender differences in mathematics and mental rotation ability are more prevalent at the higher end of the ability distribution and thus might be partially explained by gender differences in the ability to cope with challenging or confusing tasks (Dweck, 2007). Dweck (2008b) also noted “students tend to have more of a fixed view of math skills than of other intellectual skills” (p. 2).

In summary, student’s mindsets are related to success in science and mathematics achievement in adolescence and early adulthood (Blackwell et al., 2007; Grant & Dweck, 2003). Moreover, research has found that improving students’ growth mindset is related to increases in mathematics and spatial ability (Blackwell et al., 2007; Dar-Nimrod & Heine, 2006; Good et al., 2003; Moé et al., 2009; Moé & Pazzaglia, 2010). Evidence also suggests that differences in mindset might help to explain gender differences in science and mathematics achievement (Dweck, 2007; Dweck, 2008b; Grant & Dweck, 2003; Good et al., 2007). The next section will discuss how gender stereotypes might contribute to women underperforming in mathematics achievement and spatial ability, as well as how espousing a growth mindset might buffer women from the negative influences of gender stereotypes.

Stereotype threat. As previously discussed, women are often deterred from pursuing STEM fields because they are traditionally seen as masculine careers (Cheryan et al., 2009; DiDonato & Strough, 2013; Diekman et al., 2010). Stereotypes also suggest that women's mathematics and spatial skills are inferior to men even though research does not consistently support these assertions (Blanton, Christie, & Dye, 2002; Lindberg et al., 2010). These stereotypes represent fixed mindset beliefs since they state that individuals need to be part of a certain group in order to have biologically bestowed abilities (Dweck, 2008b). According to the theory of stereotype threat, these beliefs are dangerous and might lead to individuals underperforming on tasks where their group is stereotyped as inferior (Steele & Aronson, 1995). When individuals are asked to perform these tasks, they often exhibit increased concern that they will confirm the negative stereotype, which leads to underperformance and a perpetuation of the stereotypes (Steele & Aronson, 1995). Research has found that stereotype threat can influence women's performance on tasks that measure mathematical ability (Danaher & Crandall, 2008; Dar-Nimrod & Heine, 2006; Good, Aronson, & Harder, 2008; Johns, Schmader, & Martens, 2005; Johnson, Barnard-Brak, Saxon, & Johnson, 2012; Kiefer & Sekaquaptewa, 2007; Schmader, 2002; Nguyen & Ryan, 2008; Spencer, Steele, & Quinn, 1999) and spatial skills (Campbell & Collaer, 2009; Heil, Jansen, Quaiser-Pohl, & Neuburger, 2012; Martens, Johns, Greenberg, & Schimel, 2006; McGlone, & Aronson, 2006; Moé, 2012; Wraga, Helt, Jacobs, & Sullivan, 2007).

Espousing a growth mindset might also buffer women from the influence of negative gender stereotypes in mathematics and spatial ability (Good et al., 2007; Good et al., 2012).

Good and colleagues (2007) followed college women as they completed a calculus course in order to examine the relation between mindset, belongingness in mathematics, desire to pursue subsequent mathematics courses, and final mathematics grades. Among those who reported that negative stereotypes about gender and mathematics were present in their course environment, females who held a growth mindset were more likely to report that they belonged in mathematics, intended to take additional mathematics courses, and earned higher grades. Similarly, Good and colleagues (2012) found that women's sense of belonging decreased when they perceived the environment as providing fixed mindset and gender stereotypical messages. Lowered sense of belonging also mediated women's desire to pursue subsequent mathematics courses and their final calculus grades. Women who perceived growth mindset environmental messages, rated their belongingness in mathematics higher even when gender stereotypes were apparent in their environment.

Students with a fixed mindset do well when tasks are easy for them and when they do not encounter challenges; however, research suggests that they might be disadvantaged when facing difficult tasks (Dweck, 2008b). Dweck (2000) notes that among students with fixed mindsets, "challenges are a threat to self-esteem" (p. 2). Individuals with growth mindsets are more likely to exert more effort during challenges and try new strategies (Blackwell et al., 2007). Preliminary evidence also suggests that students with growth mindsets are also more likely to take advantage of opportunities to enhance their deficient skills (Bergen, 1992; Hong, Chiu, Dweck, & Lin, 1998). Thus, mindsets are important to consider when determining how students respond to interventions that try to elevate their underdeveloped skills, especially in highly stereotyped domains like mathematics and spatial ability. However, no studies have examined the relation between students' mindsets and their response to spatial skills interventions.

Current Study

The primary purpose of this quantitative study is to determine whether participation in a comprehensive spatial visualization course and gender are related to higher spatial visualization and math computation scores at the end of treatment. Although studies have consistently found that males and females make comparable gains in spatial visualization skills after participating in the spatial visualization course (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013; Walton et al., 2015), a paucity of research examines the transfer of spatial training gains to mathematics (Mix & Cheng, 2012). Moreover, no study has used a standardized measure of mathematics using a pretest-posttest paradigm when examining spatial training transfer effects with college age participants.

A secondary goal of this study is to determine if gender differences exist in students' mindset and whether mindset scores differ between individuals who take the spatial visualization course and those who choose not to participate. Although this model will be underpowered, the study is not attempting to generalize findings to the larger population, but rather identify possible variables that should be further explored. More specifically, this study will attempt to answer the following questions:

Primary Questions and Hypotheses

Research question 1. Are intervention group membership and gender related to spatial visualization score changes over time?

1a. Does intervention group membership predict the amount of spatial visualization score change from pre- to posttest controlling for college readiness?

Hypothesis 1a. Intervention group membership will predict the amount of spatial visualization score change from pre- to posttest controlling for college readiness.

Rationale. Considerable evidence suggests that spatial visualization scores significantly improve following participation in spatial training that includes the spatial visualization curriculum developed by Sorby and Wysocki (2003) (Basko & Holliday-Darr, 2010; Gerson et al, 2001; Sorby, 2009; Sorby, 2013; Sorby & Baartmans, 2000; Sorby & Veurink, 2010a; Walton et al., 2015). It is therefore hypothesized that participation in the spatial visualization course in the current study will be related to changes in spatial visualization scores over time.

1b. Does gender predict the amount of spatial visualization score change from pre- to posttest controlling for college readiness?

Hypothesis 1b. Gender will predict the amount of spatial visualization score change from pre- to posttest controlling for college readiness.

Rationale. Consistent with previous literature, males will likely have higher spatial visualization across time points since males consistently outperform females on the spatial visualization tests including the PSVT:R (Maeda & Yoon, 2013; Sorby & Veurink, 2010a).

1c. Is there an interaction between intervention group membership and gender when predicting the amount of spatial visualization score change from pre- to posttest controlling for college readiness?

Hypothesis 1c. There will be no significant interaction between intervention group membership and gender when predicting the amount of spatial visualization score change from pre- to posttest controlling for college readiness.

Rationale. The literature examining the relation between gender and spatial training gains is inconclusive, especially with interventions that teach college students spatial strategies and that provide more comprehensive spatial instruction. Some studies have found that spatial training might especially benefit women and that gender differences can be attenuated through spatial instruction (Hsi et al., 1997; Miller & Halpern, 2013). However, it is likely that there will not be a significant interaction between intervention group membership and gender since others have found that women and men make comparable spatial visualization gains when using Sorby and Wysocki's (2003) curriculum (Sorby, 2009; Sorby et al., 2013; Sorby & Baartmans, 2000; Walton et al., 2015).

Research question 2. Do time and gender predict changes in the math computation scores of the intervention group?

2a. Does the intervention group's math computation scores change over time controlling for college readiness?

Hypothesis 2a. The intervention group's math computation score will significantly change over time controlling for college readiness.

Rationale. A paucity of research examines the transfer of spatial skills gains through training to mathematics (Mix & Cheng, 2012). Some researchers suggest that students with low spatial skills who participate in spatial training obtain higher grades in subsequent college mathematics courses than those with comparable spatial skills who do not take the course (Sorby, 2009; Sorby, 2013; Sorby & Veurink, 2010b); however, others have not found a significant relation (Miller & Halpern, 2013; Walton et al., 2015). Cheng and Mix (2011, 2014) found that mathematics skills can be improved by practicing a mental rotation task in young children; however, no studies with adults have examined change in mathematical performance on the same standardized measure. Since spatial skills are related to mathematical performance (Mix & Cheng, 2012), it is likely that participants who participate in the spatial visualization course will display a significant improvement in math scores over time.

2b. Does gender predict changes in math computation scores from pre- to posttest controlling for college readiness?

Hypothesis 2b. Gender will predict changes in math computation scores from pre- to posttest controlling for college readiness.

Rationale. Little research has examined the relation between spatial training and mathematics outcomes; however, Ferrini-Mundy (1987) did find some preliminary evidence that spatial skills training might be especially helpful for women in some areas of mathematics. Although men are more likely to show advantages on mathematics tests that involve complex problem solving and that are high-stakes (Corbett et al., 2008; Halpern et al., 2007), others have found that spatial skills might mediate the relation between gender and mathematics (Casey et al., 1995; Casey et al., 1997).

Secondary Questions and Hypotheses

Research Question 3. Do males and females significantly differ in mindset?

Hypothesis 3. Males will have higher levels of growth mindset than females.

Rationale. Dweck (2007; 2008a) suggests that high-achieving females might be especially likely to hold a fixed mindset. Early studies found that among precocious elementary students, girls were more likely to perform poorly on tasks that included confusing material, while boys seemed energized by challenging tasks (Licht & Dweck, 1984; Licht, Linden, Brown, & Sexton, 1984; Licht & Shapiro, 1982). High-achieving females are often praised for their intelligence (Dweck 2008a) and placed into high ability classes (Boaler, 1997). The idea that they are naturally intelligent might lead to a need to maintain the image of having high intelligence and difficulty coping with failure (Boaler, 1997). Although the research is limited with college age participants, it is hypothesized that males will have higher growth mindsets than females; especially since STEM fields are traditionally stereotyped as masculine (Cheryan et al., 2009; DiDonato & Strough, 2013; Diekman et al., 2010). Stereotypes represent fixed mindset beliefs since they imply that individuals need to be part of a certain group to have biologically determined abilities (Dweck, 2008b).

Research Question 4. Do the intervention and control groups significantly differ in mindset?

Hypothesis 4. Individuals in the intervention condition will have higher levels of growth mindset than those in the control condition.

Rationale. Students with a growth mindset are more likely to believe that their ability can be cultivated through effort and are more geared toward mastery-oriented learning goals (Dweck, 2000; Dweck, 2008a; Dweck & Leggett, 1988). Conversely, students with a fixed mindset are more likely to give up on challenging tasks where they have to exert more effort (Dweck, 2000; Dweck, 2008a; Dweck & Leggett, 1988). The students in the current study will be identified because they have deficits in spatial ability. Therefore, it is hypothesized that the students' mindsets will differ depending on whether they participate in the spatial visualization course. More specifically, students who espouse a growth mindset will be more likely to participate in the intervention since they are more likely to believe that their initially low spatial visualization skills can be increased through effort and then take mastery-oriented steps toward increasing their learning (Dweck, 2000).

CHAPTER 3

METHODS

Study Design

The present study used a quasi-experimental, non-equivalent control group, pre- and post-intervention research design. This study involved human participants and so it was submitted to the Institutional Review Board (IRB) at Michigan State University (MSU) and was found to be exempt. First-year undergraduate students at MSU who declared their major as engineering were recruited to participate as part of a larger ongoing study under the ENGAGE Engineering project. This project is based on work done at Michigan Technological University (MTU) and focuses on enhancing students' spatial skills in order to improve the retention and diversity of engineering students (Sorby, 2009; Sorby et al., 2013).

Participants

Participants included 67 (male n=47, females n=20) in the intervention and 24 (male n=10, females n=14) in the control group. They were identified for recruitment during the summer prior to the spatial visualization course. All incoming first-year students who declared their major as engineering were asked to complete an online version of the *Purdue Spatial Visualization Test: Rotations* (*PSVT:R*; Bodner & Guay, 1997) prior to attending or during summer orientation. Individuals who agreed to participate in the ENGAGE Engineering project provided consent during orientation that allowed their *PSVT:R* results to be used for research purposes. Students who scored lower than 60% (less than or equal to 17 points) on the *PSVT:R* were invited to enroll in a one-credit course designed to improve three-dimensional spatial skills. The course has been offered since Fall 2014 at MSU, but is not currently required by the Engineering Program.

Students who enrolled in the spatial visualization course were recruited for the intervention group of the current study. They were provided with an in-person overview of the project and were asked to sign a consent form if they chose to participate during their first class. Students who chose not to enroll were recruited to participate for the control group of the study via an email flyer (see Appendix A). Since participation required them to schedule and participate in two one-hour test sessions outside of their courses, they were compensated $20.00 for their time and travel expenses after they finished the posttest measures. Due to difficulties in obtaining enough control group participants, a second wave of recruitment was conducted via email (see Appendix B). The second group was asked to just take the online *PSVT-R* at the end of the semester and was compensated with $10.00 due to decreased time and travel demands.

All individuals who agreed to participate in the study provided consent to participate and to complete the assessment measures (Appendix C-F). As approved by the IRB, demographic information, summer orientation assessment scores, and data surrounding normally assigned spatial visualization coursework was obtained through waived consent since it was already being collected by the ENGAGE project. The data from the ENGAGE project and the current project were de-identified using the same hashing macro, which uses a one-way encryption scheme (SHA-1, n.d.). The encryption cannot be reversed, but the datasets could be combined since the macro produced a unique identifier (i.e., string of characters) for each individual.

Collapsing groups. A series of One-Way ANOVAs were used to determine whether the spatial visualization course sections displayed significant group differences on the continuous variables. Although there were four sections of the spatial visualization course, the sections did not significantly differ in terms of ACT Composite ($F(3,53) = 1.87$, $p = .146$), mindset ($F(3, 34) = .03$, $p = .993$), spatial visualization at times one ($F(3,63) = .23$, $p = .877$) or two ($F(3,57) =$

1.01, $p = .396$), or mathematics scores at times one ($F(3,62) = .32$, $p = .813$) or two ($F(3, 52) = .08$, $p = .970$). Chi-square tests were used to determine whether there were group differences on categorical variables. Due to the small frequency counts in some cells, likelihood ratio statistics were calculated. The groups did not differ by gender ($\chi^2(3) = 4.97$, $p = .174$), age ($\chi^2(6) = 3.86$, $p = .696$), ethnicity ($\chi^2(12) = 11.54$, $p = .483$), engineering major ($\chi^2(30) = 36.78$, $p = .184$), or first math course taken at MSU ($\chi^2(15) = 23.05$, $p = .083$); therefore, the sections were combined to create the intervention group.

Similarly, a series of T-Tests were conducted on the continuous variables and the two control groups did not significantly differ on ACT Composite ($t(18) =.13$, $p = .895$), Mindset ($t(13) = -.49$, $p = .631$), or spatial visualizations scores at times one ($t(22) = .33$, $p = .742$) and two ($t(18) = .63$, $p = .535$). Chi-square tests using likelihood ratio statistics were again used to determine whether there were group differences on the categorical variables. The groups did not differ by gender ($\chi^2(1) = 1.40$, $p = .238$), age ($\chi^2(1) = .85$, $p = .358$), ethnicity ($\chi^2(1) = 3.40$, $p = .493$), or engineering major ($\chi^2(1) = 12.76$, $p = .237$), thus the groups were combined.

Spatial skills training intervention. The spatial skills intervention was a one-credit course that was offered during the Fall Semester at MSU. The course included one lecture (50 minutes) per week across 12 weekly sessions. Lecture sessions typically involved a combination of didactic content, in-class activities, and the collection of homework assignments. MSU offered four sections of the course with a maximum of 49 students in each section. A graduate teaching assistant performed the majority of instruction with some instruction by the lead faculty member. Two senior undergraduate students served as teaching assistants in order to assist with student homework questions and grade lecture homework and quizzes.

The ENGAGE project's curriculum included the "Developing Spatial Thinking" instructional software, the "Developing Spatial Thinking Workbook" (Sorby, 2011), and lecture presentations and quizzes (Higher Education Services, 2015a). Students were also loaned 30 hand2mind® Snap Cubes, which are ¾ inch interlocking, plastic cubes. The instructor typically began each lecture by collecting homework and facilitating a 5- to 10-minute in-class activity. Students then participated in a 15- to 20-minute lecture. The course covered 10 modules including: "solids of revolution, combining solids, isometric sketching, orthographic projection, incline and curved surfaces, flat patterns, rotation of objects about one axis, rotation of objects about two axes, object reflection and symmetry, and cutting planes" (Higher Education Services, 2015b). Students then practiced applying the lecture's topic to a number of example problems and received a homework assignment based on the skills they learned in lecture. Overall, the course concluded with the administration of the post-test of the *PVST:R.*

Independent and Dependent Variables

Gender. Participant gender was obtained from the ENGAGE project's pre-existing data and was used as a grouping/independent variable. Gender was coded as 0 for males and 1 for females.

Mathematics. Mathematical skills were measured using the Math Computation subtest of the *Wide Range Achievement Test-Fourth Edition (WRAT4*; Wilkinson & Robertson, 2006). The test was administered in a group format and alternate forms were used at pretest (i.e., blue) and posttest (i.e., green). Two graduate level research assistants administered the tests to the intervention group during the participants' first and last regularly scheduled class, while the participants in the control group were asked to schedule a time to take the pre- and posttest with a third research assistant. However, due to the control group's small sample size for math computation, only the intervention group's math computation standard scores were used in subsequent analyses.

The Math Computation subtest is composed of two parts (i.e., oral math and math computation); however, the math computation section is the only part applicable for individuals older than seven years. The math computation section asks individuals to solve 40 computation problems within a 15-minute time limit without the use of calculators. Items include single and multi-digit mathematics computation problems (e.g., addition, subtract, multiplication, division), calculating the percentage of numbers, solving for missing values, simplifying algebraic expressions, and calculating interest. The section can be administered individually or in small groups. The *WRAT4* was normed using the 2001 U.S. Census with a sample size of slightly over 3,000 participants ranging in age from 5 to 94 years. The sample matched census data by race/ethnicity, gender, educational attainment, and geographic region.

Technical data indicate that the *WRAT4* Math Computation subtest has adequate psychometric properties (Wilkinson & Robertson, 2006). The median internal reliability coefficient is slightly below .90 (.89 for the Blue Form, .87 on Green Form). The average alternate-form reliability is .88 for immediate retest and .83 for delayed retest within one month. The *WRAT4* Math Computation subtest is also related to mathematical scores on other standardized achievement tests including: the Number Operations (r = .92), Mathematics Reasoning (r = .84), and Mathematics Composite (r = .92) scores on the *Wechsler Individual Achievement Test-Second Edition* (The Psychological Corporation, 2002); the Broad Mathematics (r = .67), Mathematics Calculation (r = .64), and Mathematical Reasoning (r = .71) scores on the *Woodcock-Johnson III Tests of Achievement* (Woodcock, McGrew, & Mather, 2001); the Math Concepts & Application (r = .50), Math Computation (r = .75), and Math

Composite (r = .73) scores on the *Kaufman Test of Educational Achievement: Second Edition-Comprehensive Form* (Kaufman & Kaufman, 2004); and the Mathematics Composite (r = .73) score on the *Kaufman Test of Educational Achievement-Brief Form* (Kaufman & Kaufman, 2005).

The *WRAT4* Math Computation subtest does vary in difficulty depending on the alternate forms. Form difficulty and item variability was accounted for by using standard scores in subsequent analyses. Since age data were missing for many individuals (see Table 2) the ages 18:0-19:11 standard score conversion table was used to convert raw to standard scores. The vast majority of individuals with age data were between 18 and 19 years old (see Table 7). There was only one known 20 year old in the sample whose standard scores were the same regardless of using the ages 18:0-19:11 or 20:0-24:11 score conversion tables. It is very likely that the individuals with missing age data were also within the 18-19 year old range since the sample only included first-year college freshmen.

Spatial ability. A computerized version of the *Purdue Spatial Visualization Test: Rotations (PSVT-R)* (Guay, 1976) was used to measure three-dimensional mental rotation ability. Participants took the *PSVT-R* online at home or at summer orientation to obtain pretest (control) scores. Students were asked to complete the online *PSVT-R* again during approximately the thirteenth week of the fall semester to obtain posttest scores (dependent variable). The *PSVT-R* is a 30-item test that is limited to 20 minutes. As noted previously, the test requires individuals to study the rotational relation between two identical objects, mentally apply the same rotation to a target object, and identify the resulting figure from an array of five choices (Figure 1). The test has good reliability and validity. Split-half reliabilities range between .78 and .85, and the *PSVT:R* was shown to be correlated with the Vandenberg Mental Rotation Test by a correlation of .61 (Sorby & Veurink, 2010b). Maeda and Yoon (2011) also found a Cronbach's internal consistency reliability of .849 with a sample of 585 first-year engineering students. Raw scores on the test are typically converted to fail (0-17), marginal pass (18-20), and pass (21-30) (Sorby & Veurink, 2010b); however, raw scores were used in the current study to examine growth over time.

Theories of intelligence/mindset. Consistent with mindset research, the *Theories of Intelligence Scale-Self Form for Adults* (Dweck, 2000) was used to measure students' views about intelligence (Appendix F). Participants were asked to complete the measure online at home or during summer orientation prior to completing the *PSVT-R*. The measure comprises eight questions that ask individuals to rate to what extent they agree with statements about the malleability of intelligence using a Likert scale from one (i.e., strongly agree) to six (i.e., strongly disagree). Incremental items were reverse scored and a mean theory of intelligence score was calculated. Lower scores represent a more entity theory of intelligence, while higher scores represent a more incremental theory of intelligence.

Research has found that variations of the scale have moderate to high levels of reliability and validity (Dweck, 2000). Dweck and colleagues (1995) found that a three-question version had high internal reliability with correlations ranging from .94 to .98 and test-retest reliability of .80 over a two-week interval. The measure also displayed discriminant validity by being independent from measures of political affiliation, gender, age, self-presentation concerns, religion, cognitive ability, confidence in intellectual ability, optimism about other people and the world, and political views. Blackwell and colleagues (2007) used a variation of the measure with seventh grade students and found an internal reliability of .78 and a test-retest reliability of .77 over a two-week interval. Similarly, research using a Norwegian version of Dweck's scale found internal reliabilities of .84 to .92 (Braasch, Bråten, Strømsø, & Anmarkrud, 2014; Bråten & Strømsø, 2005).

Covariates

College readiness. College readiness was assessed using participants' ACT Composite scores from their academic transcripts. Students took the ACT exam as part of their admission to MSU. The ACT is a standardized, college readiness assessment that comprises four multiple-choice tests (i.e., English, mathematics, reading, and science) and an optional writing test (ACT, 2014a). The Composite score represents the average of the four multiple-choice tests and all scores range from 1-36 (ACT, 2014a). The 2014 ACT administration yielded a national Composite score mean of 21.0 (ACT, 2014b).

Research suggests that the ACT is acceptable to use as a proxy for general cognitive ability (*g)* (Koenig et al., 2008; Coyle & Pillow, 2008). Koenig and colleagues (2008) used a subsample (n=1075) of the National Longitudinal Survey of Youth 1979 to analyze the relation between the ACT and *g*. They found that the total ACT score (i.e., the sum of mathematics and English) correlated with the Armed Services Vocational Aptitude Battery (*ASVAB*) (r=.77, p<.001), the SAT (r=.87, p<.001), and six standardized intelligence tests (r= .55-.81, p<.01). The researchers also studied the relation between the ACT Composite score and the Raven's Advanced Progressive Matrices of 149 undergraduate students (n=72 male) and found a correlation of .61 (p=.01).

Coyle and Pillow (2008) also examined the relation between college readiness assessments, *g*, and grade point average (GPA). They investigated data from a university sample (n=161) and found that ACT scores were significantly correlated with subtests of the Wechsler Adult Intelligence Scale-Third Edition (*WAIS-III*) (i.e., Digit Span (r=.28, p<.01), Information

(r=.45, p<.01), and Picture Completion (r=.24, p<.001)), the Wonderlic Personnel Test (r=.71, p<.001), and the Raven's Advanced Progressive Matrices (r=.42, p<.001). The researchers might not have adequately captured the relation between intellectual ability and the ACT using the WAIS-III, however, since the subtests they used were not the best estimates of reasoning ability. Their results also indicated that the ACT was significantly related to the SAT (r=.83, p<.001), as well as the participants' GPA from the first (r=.25, p<.01) and second (r=.22, p<.01) semester of freshmen year. The researchers found similar results when analyzing the data from a subsample of the 1997 National Longitudinal Study of Youth (n=1075). They found that the ACT was significantly related to the SAT (r=.87, p<.01), first (r=.33, $p<.01$) and second semester (r=.29, p<.01) GPA, and the computer-adaptive Armed Services Vocational Aptitude Battery (CAT-ASVAB) subtests (r=.29-.67, p<.01).

The ACT seems especially predictive of freshmen year college performance. Coyle and Pillow (2008) found that the ACT significantly predicted GPA after removing *g*. Similarly, Randunzel and Noble (2012) found that the ACT Composite score was indirectly related to long-term college success (i.e., degree completion, annual cumulative credits obtained, and cumulative grade point average (GPA)) via first-year college GPA at both two- and four-year college institutions. Each ACT multiple-choice test was also independently related to long-term college success, with the Mathematics and Science tests being most predictive.

Demographic Information

Demographic information was also obtained via the ENGAGE project's pre-existing data including participants' age, major, ethnicity, and mathematical course history. Preliminary analyses were conducted to determine if the intervention and gender groups differed on these demographic factors and whether they should have been included as control variables.

Analyses

The Statistical Package for the Social Sciences (SPSS) version 24.0 was used to prepare and analyze the data. A summary of the primary and secondary research questions, variables, and analyses are presented in Tables 3 and 4, respectively.

Research Questions 1 and 2: Are intervention group membership and gender related to spatial visualization score changes over time? Do time and gender predict changes in the math computation scores of the intervention group? Linear mixed modeling (LMM) was used to examine questions one and two. LMM uses hierarchical data structure when modeling repeated measures because time points (level 1) are nested within the individuals (level 2) (Field, 2013). LMM was chosen in lieu of a Repeated Measures Multivariate Analysis of Covariance (MANCOVA) since it provides more robust results when there is missing data and small sample sizes (West, Welch, & Gałecki, 2015). MANCOVAs require analyses by complete-cases, while LMM preserves the cases by estimating the parameters with the data that are available (Field, 2013; West et al., 2015). LMM also takes into account the variance of regression slopes and intercepts by allowing the researcher to model the variability explicitly in the model (Field, 2013).

A variance components structure was used to analyze the random effects, which included random intercepts and slopes. The unstructured covariance matrix was initially used but was met with errors, possibly because there were only two time points. Restricted Maximum Likelihood Estimation (REML) methods were used to estimate the covariance parameters since it produces more precise random variance estimates (Field, 2013). Although LMM is more resistant to biases within the data, one assumption that holds is that variables are normally distributed (West et al., 2015). Normality was examined using the Komogorov-Smirnov test of normality, visual inspections of the data (i.e., *Q-Q* plots, histograms, boxplots), and the z-scores of kurtosis and skew. Results of Kolmogorov-Smirnov tests suggest that spatial visualization raw scores at pretest (D(91) = .16, p = .000) and posttest (D(81) = .14, p = .000) significantly deviated from normal and so square transformations were performed which resulted in z-scores within normal limits ($-2 \le Z \le 2$). Math standard scores at pretest (D(77) = .15, p = .000) and posttest (D(63) = .12, p = .034) also significantly deviated from normal; however, z-scores of kurtosis and skew were within acceptable limits and so the untransformed standard scores were used in subsequent analyses (see Table 1).

Table 1 Degree of Spatial and Math Score Kurtosis and Skewness

		Pretest			Posttest		
		Statistic	Std. Error	*Z*	Statistic	Std. Error	*Z*
Spatial	Skewness	-.76	.25	-3.00	-.97	.27	-3.64
	Kurtosis	-.06	.50	-.12	.46	.53	.87
Spatial_sq	Skewness	-.38	.25	-1.52	-.22	.27	-.82
	Kurtosis	-.89	.50	-1.78	-.81	.53	-1.53
Math	Skewness	.15	.27	.56	-.19	.30	-.61
	Kurtosis	.11	.54	.21	.17	.60	.28

Research Questions 3 and 4: Do males and females significantly differ in mindset? Do the intervention and control groups significantly differ in mindset? Originally college readiness was going to be used as a control variable since high-achieving individuals are more often praised for their intelligence which fosters a fixed mindset (Dweck, 2008b); however, mindset scores were not significantly correlated with ACT Composite scores ($r(53) = -.14$, p = .384) and so ACT scores were not included in the model to preserve parsimony. According to the results of a Kolmogorov-Smirnov test, the mindset variable significantly deviated from normal (D(53) = .12, p = .041). The amount of skew was within normal limits (Z = -.29), but the distribution was kurtotic (Z = -2.08). A visual inspection of the histogram showed a polymodal distribution (Figure 2). Due to this deviation from normality and the unequal group sizes between males and females, Mann-Whitney U tests were used to determine whether the median mindset scores differed by gender and intervention group.

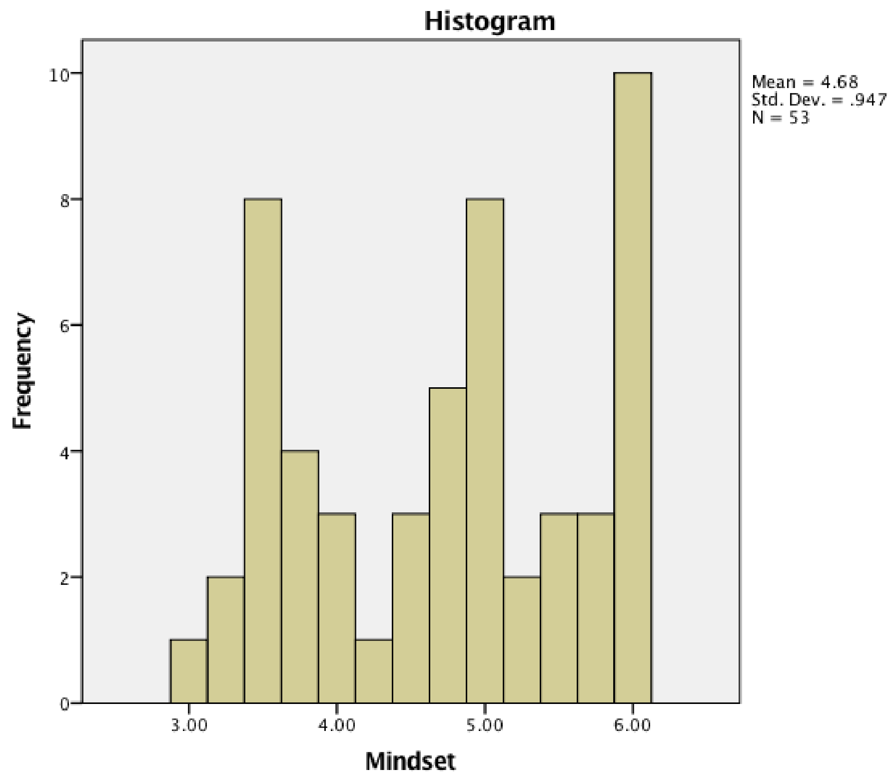

Figure 2 Distribution of Mindset Scores

Missing data. There were many missing data items across the variables (Table 2), but the missing data were considered for each of the analyses. LMM assumes that data are missing at random (MAR) and accounts for missing data by basing inferences on maximum likelihood estimation (Field, 2013; West et al., 2015). For the questions on mindset, two Chi-square tests were calculated to determine whether the frequency of missing mindset scores differed by gender and intervention group membership. Results suggest that males (42.1%) and females (41.2%) were missing the same proportion of mindset scores ($\chi^2(1) = .01$, $p = 1.000$). Similarly, there was no significant interaction between the frequency of missing mindset scores and intervention group membership ($\chi^2(1) = .24$, $p = .640$). Those in the intervention (43.3%) and control (37.5%)

were missing a comparable proportion of mindset scores.

Table 2 Missing Data

	Intervention (n = 67)		Control (n = 24)	
Variables	n	%	n	%
Age	30	44.8%	9	37.5%
Males	22	46.8%	3	30.0%
Females	8	40.0%	6	42.9%
Gender	0	0.0%	0	0.0%
Males	0	0.0%	0	0.0%
Females	0	0.0%	0	0.0%
Ethnicity	5	7.5%	2	8.0%
Males	5	10.6%	0	0.0%
Females	1	10.0%	1	7.1%
First Math Course	3	4.5%	1	4.2%
Males	1	2.1%	0	0.0%
Females	2	10.0%	1	7.1%
Major	3	4.5%	1	4.2%
Males	1	2.1%	0	0.0%
Females	2	10.0%	1	7.1%
PSVT:R (Time 1)	0	0.0%	0	0.0%
Males	0	0.0%	0	0.0%
Females	0	0.0%	0	0.0%
PSVT:R (Time 2)	6	9.0%	4	16.7%
Males	5	10.6%	4	40%
Females	1	5.0%	0	0.0%
WRAT4 (Time 1)	1	1.5%	13	54.2%
Males	1	2.1%	4	40.0%
Females	0	0.0%	9	64.3%
WRAT4 (Time 2)	11	16.4%	17	70.8%
Males	8	17.0%	8	80.0%
Females	3	15.0%	9	64.3%
Mindset	29	43.3%	9	37.5%
Males	21	44.7%	3	30.0%
Females	8	40.0%	6	42.9%
ACT Composite	10	14.9%	4	16.7%
Males	8	17.0%	2	20.0%
Females	2	10.0%	2	14.3%

Note: PSVT-R=Purdue Spatial Visualizations Test: Rotations, WRAT4= Wide Range Achievement Test-Fourth Edition

Table 3 Primary Questions, Variables, and Analyses

Questions	Variables	Analyses
Question 1. Are intervention group membership and gender related to spatial visualization score changes over time? **Question 1a.** Does intervention group membership predict the amount of spatial visualization score change from pre- to posttest controlling for college readiness? **Question 1b.** Does gender predict the amount of spatial visualization score change from pre- to posttest controlling for college readiness? **Question 1c.** Is there an interaction between intervention group membership and gender when predicting the amount of spatial visualization score change from pre- to posttest controlling for college readiness?	**Fixed Effects:** ACT Composite Time Intervention Intervention x Time Gender Intervention x Gender Time x Gender Time x Intervention x Gender **Random Effects:** Intercept + Time **Dependent Variables:** Spatial Pretest & Posttest	Linear Mixed Modeling
Question 2. Do time and gender predict changes in the math computation scores of the intervention group? **Question 2a.** Does the intervention group's math computation scores change over time controlling for college readiness? **Question 2b.** Does gender predict changes in math computation scores from pre- to posttest controlling for college readiness?	**Fixed Effects:** ACT Composite Time Gender Time x Gender **Random Effects:** Intercept + Time **Dependent Variables:** Math Pretest & Posttest	Linear Mixed Modeling

Table 4 Secondary Questions, Variables and Analyses

Questions	Variables	Analyses
Question 3. Do males and females significantly differ in mindset?	**Independent Variable:** Gender **Dependent Variable:** Mindset	Mann-Whitney U Test
Question 4. Do the intervention and control groups significantly differ in mindset?	**Independent Variables:** Intervention Group Membership **Dependent Variable:** Mindset	Mann-Whiney U Test

CHAPTER 4

RESULTS

Preliminary Analyses

Preliminary analyses were conducted in order to better understand the dataset. Descriptive statistics (i.e., means and standard deviations) for all continuous variables are presented in Tables 5 and 6 and categorical variables in Tables 7 and 8. A series of Independent T-Tests were used to examine intervention group differences on all continuous predictors and covariates to determine whether the groups significantly differed at time one. A dummy variable for intervention group was created for group membership (i.e., control, intervention). Overall, the intervention and control group did not significantly differ at time one in spatial visualization raw scores ($t(89)=.98$, $p=.331$), math computation standard scores ($t(75)=.04$, $p=.971$), or ACT Comprehensive ($t(75)=1.13$, $p=.261$) scores. Chi-square tests were also conducted using likelihood ratio statistics on the categorical variables and showed no group differences in age, ethnicity, engineering major, or first math course taken (see Table 7). However, there were group differences in the gender proportions between the two groups ($\chi^2(1) = 6.13$, $p = .016$) with a higher proportion of females in the control group (58.3%) versus the intervention group (29.9%).

Preliminary analyses were also conducted to examine whether the gender by intervention membership groups significantly differed at time one. A One-Way ANOVA was conducted on all continuous predictors and covariates using a dummy variable for group membership (i.e., Male_Control, Female_Control, Male_Intervention, Female_Intervention). Overall, the groups did not significantly differ at time one in spatial visualization raw scores ($F(3, 87) = 2.31$, $p = .082$), math computation standard scores ($F(3, 73) = 2.61$, $p = .058$), or ACT Comprehensive ($F(3,73) = 1.00$, $p = .398$) scores. Chi-square tests were also conducted using likelihood ratio statistics on the categorical variables and showed no group differences in age, ethnicity, engineering major, or first math course taken (see Table 8).

Table 5 Descriptive Statistics by Intervention Group

	Intervention		Control	
	M/**Mdn**	SD	M/**Mdn**	SD
ACT Composite	23.93	3.81	25.10	4.44
PSVT-R (Time 1)	13.84	2.78	14.46	2.36
PSVT-R (Time 2)	23.63	4.25	12.70	6.64
WRAT4 (Time 1)	106.41	11.36	106.55	11.15
WRAT4 (Time 2)	107.09	11.51	111.00	8.68
Mindset	**4.75**	.92	**5.00**	1.04

Note: PSVT-R=Purdue Spatial Visualizations Test: Rotations Raw Scores, WRAT4= Wide Range Achievement Test-Fourth Edition Standard Scores

Table 6 Descriptive Statistics by Intervention Group and Gender

	Intervention				Control			
	Males		Females		Males		Females	
	M/**Mdn**	SD	M/**Mdn**	SD	M/**Mdn**	SD	M/**Mdn**	SD
ACT Composite	23.56	4.10	24.72	3.03	26.00	2.88	24.50	5.27
PSVT-R (Time 1)	13.81	2.77	13.90	2.88	16.00	1.05	13.36	2.44
PSVT-R (Time 2)	24.65	3.53	21.37	4.89	16.00	7.54	11.29	5.95
WRAT-4 (Time 1)	106.61	11.46	105.95	11.41	98.17	5.15	116.60	6.77
WRAT-4 (Time 2)	108.92	11.14	102.88	11.56	107.50	13.44	112.40	7.70
Mindset	**4.75**	.90	**4.75**	1.00	**5.13**	.97	**4.44**	1.15

Note: PSVT-R=Purdue Spatial Visualizations Test: Rotations Raw Scores, WRAT4= Wide Range Achievement Test-Fourth Edition Standard Scores

Table 7 Descriptive Statistics of Intervention Group Demographic Characteristics

Variables	Intervention n (%)	Control n (%)	χ^2	p
N	67	24		
Age			.73(2)	p = 1.00
18	33 (89.2%)	14 (93.3%)		
19	3 (8.1%)	1 (6.7%)		
20	1 (2.7%)	0 (0.0%)		
Gender			6.13(1)	p = .016*
Males	47 (70.1%)	10 (41.7%)		
Females	20 (29.9%)	14 (58.3%)		
Ethnicity			3.06(4)	p = .601
Caucasian	30 (48.4%)	9 (40.9%)		
African American	12 (19.4%)	2 (9.1%)		
Hispanic	6 (9.7%)	4 (18.2%)		
Asian	13 (21.0%)	6 (27.3%)		
Multiple Ethnicities	1 (1.6%)	1 (4.5%)		
Major			6.20(10)	p = .899
Applied Engineering (Eng.)	2 (3.1%)	3 (13.0%)		
Biosystems Eng.	2 (3.1%)	1 (4.3%)		
Chemical Eng.	9 (14.1%)	2 (8.7%)		
Civil Eng.	4 (6.3%)	1 (4.3%)		
Computer Eng.	7 (10.9%)	3 (13.0%)		
Computer Science	6 (9.4%)	3 (13.0%)		
Electrical Eng.	6 (9.4%)	1 (4.3%)		
Environmental Eng.	3 (4.7%)	1 (4.3%)		
Materials Science & Eng.	1 (1.6%)	1 (4.3%)		
Mechanical Engineering	15 (23.4%)	6 (26.1%)		
No Preference-Eng.	9 (14.1%)	1 (4.3%)		
First Math Course			10.64(7)	p = .155
MTH 1825: Intermediate Algebra	6 (9.4%)	3 (13.0%)		
MTH 103: College Algebra	8 (12.5%)	3 (13.0%)		
MTH 114: Trigonometry (Trig.)	0 (0.0%)	1 (4.3%)		
MTH 116: College Algebra & Trig.	22 (34.4%)	3 (13.0%)		
MTH 132: Calculus I	22 (34.4%)	8 (34.8%)		
MTH 133: Calculus II	5 (7.8%)	4 (17.4%)		
MTH 152H: Honors Calculus I	1 (1.6%)	0 (0.0%)		
MTH 235: Differential Equations	0 (0.0%)	1 (4.3%)		

*Note: *p < .05*

Table 8 Descriptive Statistics of Intervention Group by Gender Demographic Characteristics

Variables	Intervention Males n (%)	Intervention Females n (%)	Control Males n (%)	Control Females n (%)	χ^2	p
Age						
18	21 (84.0%)	12 (100.0%)	6 (85.7%)	8 (100.0%)	5.70(6)	p = .531
19	3 (12.0%)	0 (0.0%)	1 (14.3%)	0 (0.0%)		
20	1 (4.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)		
Ethnicity					7.32(12)	p = .910
Caucasian	20 (47.6%)	10 (50.0%)	4 (44.4%)	5 (38.5%)		
African American	8 (19.0%)	4 (20.0%)	1 (11.1%)	1 (7.7%)		
Hispanic	4 (9.5%)	2 (10.0%)	2 (22.2%)	2 (15.4%)		
Asian	10 (23.8%)	3 (15.0%)	2 (22.2%)	4 (30.8%)		
Multiple Ethnicities	0 (0.0%)	1 (5.0%)	0 (0.0%)	1 (7.7%)		
Major						
Applied Engineering (Eng.)	2 (4.3%)	0 (0.0%)	0 (0.0%)	3 (23.1%)	38.30(30)	p = .295
Biosystems Eng.	1 (2.2%)	1 (5.6%)	0 (0.0%)	1 (7.7%)		
Chemical Eng.	5 (10.9%)	4 (22.2%)	0 (0.0%)	2 (15.4%		
Civil Eng.	3 (6.5%)	1 (5.6%)	0 (0.0%)	1 (7.7%)		
Computer Eng.	6 (13.0%)	1 (5.6%)	2 (20.0%)	1 (7.7%)		
Computer Science	6 (13.0%)	0 (0.0%	3 (30.0%)	0 (0.0%)		
Electrical Eng.	4 (8.7%)	2 (11.1%)	0 (0.0%)	1 (7.7%)		
Environmental Eng.	1 (2.2%)	2 (11.1%)	0 (0.0%)	1 (7.7%)		
Materials Science & Eng.	0 (0.0%)	1 (5.6%)	1 (10.0%)	0 (0.0%)		
Mechanical Engineering	12 (26.1%)	3 (16.7%)	3 (30.0%)	3 (23.1%)		
No Preference-Eng.	6 (13.0%)	3 (16.7%)	1 (10.0%)	0 (0.0%)		
First Math Course					25.66(21)	p = .220
MTH 1825: Intermediate Algebra	5 (10.9%)	1 (5.6%)	1 (10.0%)	2 (15.4%)		
MTH 103: College Algebra	4 (8.7%)	4 (22.2%)	0 (0.0%)	3 (23.1%)		
MTH 114: Trigonometry (Trig.)	0 (0.0%)	0 (0.0%)	1 (10.0%)	0 (0.0%)		
MTH 116: College Algebra & Trig.	16 (34.8%)	6 (33.3%)	2 (20.0%)	1 (7.7%)		
MTH 132: Calculus I	15 (32.6%)	7 (38.9%)	5 (50.0%)	3 (23.1%)		
MTH 133: Calculus II	5 (10.9%)	0 (0.0%)	1 (10.0%)	3 (23.1%)		
MTH 152H: Honors Calculus I	1 (2.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)		
MTH 235: Differential Equations	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (7.7%)		

Note: MTH is the acronym used at Michigan State University to designate math course numbers

Research Question 1: Are Intervention Group Membership and Gender Related to Spatial Visualization Score Changes Over Time?

Question one examined whether intervention group membership, gender, and the interaction between intervention group membership and gender predicted participants' change in spatial visualization scores over time. The model used to examine the data is as follows:

$Y_{ij} = \beta_0 + u_{0j} + (\beta_1 + u_{1j})(Time_{ij}) + \beta_2(ACT_i) + \beta_3(Intervention_i) + \beta_4(Intervention_i)(Time_{ij}) + \beta_5(Gender_i) + \beta_6(Intervention_i)(Gender_i) + \beta_7(Time_{ij})(Gender_i) + \beta_8(Time_{ij})(Intervention_i)(Gender_i) + \varepsilon_{ij}$

This linear equation models each individual's spatial scores at pre- and post-test by nesting the time points (level 1) within the individuals. The *i*s in the equation denote the individual participants and the *j*s reflects the levels over which the model varies (i.e., time). Y_{ij} is the spatial raw score for each time point (i.e., *j*) nested within each individual (i.e., *i*). β_0 represents the intercept; u_{0j} is the variance of the intercept; β_1 reflects the slope of time; u_{1j} represents the variance of the slope of time; β_2 represents the slope of the individual's ACT Composite score; β_3 represents the slope of whether the individual took the intervention; β_4 represents the slope of the interaction between intervention group membership and time; β_5 denotes the slope of whether the individual is male of female; β_6 represents the slope of the interaction between intervention group membership and gender; β_7 is the slope of the interaction between gender and time; β_8 reflects the slope of the interaction between time, intervention group membership, and gender; and ε_{ij} represents the residual.

The results of the LMM suggest that intervention group membership (β_4 = 356.57, p = .000) but not gender (β_7 = -122.21, p = .193) predicted changes in spatial visualization raw scores over time. The main effect of gender (β_5 = -66.40, p = .036) and the interaction between intervention group membership and gender (β_6 = -79.20, p = .035) did significantly predict spatial visualization raw scores in general. Notably, these outcomes are less meaningful since they do not take into account the repeated measurement. The interaction between gender and intervention group membership did not predict changes in spatial visualization over time (β_8 = -22.29, p = .822) (see Table 9). The final full model showed significant variance in intercepts Var(u_{0j}) = 3703.33, $\chi^2(1)$ = 2.31, p = .021 and slopes Var(u_{1j}) = 27412.94, $\chi^2(1)$ = 4.90, p = .000 across participants, which supports their designation as random effects (see Table 10).

Table 9 Question 1 Parameter Estimates

Fixed Effects	Estimate	Standard Error	Approximate *df*	*t*	*p*
Intercept	290.01	56.90	72.04	5.10	.000**
ACT	-1.27	1.99	71.89	-.64	.525
Time	46.37	69.69	66.11	.67	.51
Intervention	-60.86	26.73	72.03	-2.28	.026*
Time*Intervention	356.57	75.60	66.10	4.72	.000**
Gender	-66.40	31.06	72.02	-2.14	.036*
Intervention*Gender	79.20	36.83	72.02	2.15	.035*
Time*Gender	-112.21	85.38	66.07	-1.31	.193
Time*Intervention*Gender	-22.29	98.84	66.04	-.23	.822

*Note: *p < .05, **p < .01*

Table 10 Question 1 Covariance Parameters

Parameter	Estimate	Standard Error	Wald Z (χ^2)	*p*
Residual	886.18	1485.17	.60	.551
Intercept (u_{0j})	3703.33	1602.43	2.31	.021*
Time (u_{1j})	27412.94	5592.40	4.90	.000**

*Note: *p < .05, **p < .01*

In order to further examine the relation between group membership and spatial visualization raw scores over time, an independent-samples t-test was conducted with the difference between the untransformed spatial visualization raw scores over time entered as the dependent variable. Consistent with the LMM results, there was a significant difference in the change in spatial visualization raw scores over time between the intervention (M=9.45, SD=4.44) and the control group (M=-1.45, SD=6.58); t(25)=-6.91, p = .000 (see Figure 3). Levene's test indicated unequal variances (F=6.78, p =.011) so degrees of freedom were adjusted from 79 to 25. Together these results suggest that participating in the spatial visualization course was related to improvements in spatial visualization raw scores over time, regardless of gender. On average, individuals who took the spatial visualization course increased their spatial visualization raw scores by approximately nine correct problems.

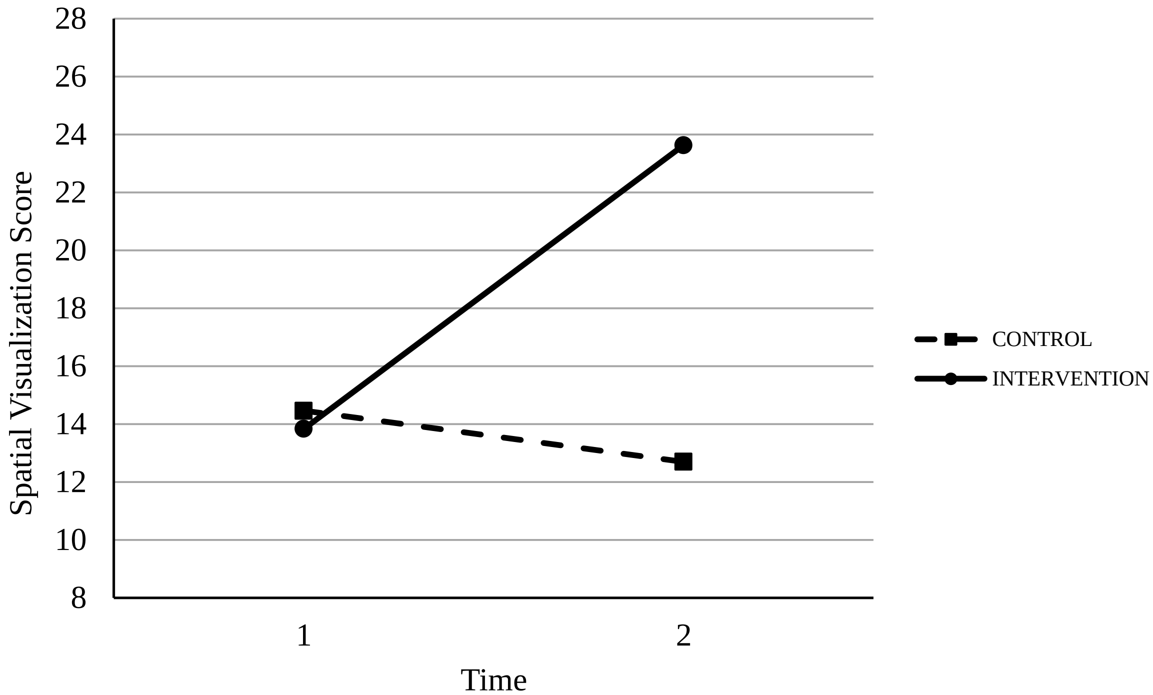

Figure 3 Mean Spatial Visualization Raw Scores Over Time by Intervention Group

Research Question 2: Do Time and Gender Predict Changes in the Math Computation Scores of the Intervention Group?

Question two examined whether the intervention group's math computation standard scores changed over time and whether gender predicted the changes in the scores. The following model was used to examine the data:

$$Y_{ij} = \beta_0 + u_{0j} + (\beta_1 + u_{1j})(Time_{ij}) + \beta_2(ACT_i) + \beta_3(Gender_i) + \beta_4(Time_{ij})(Gender_i) + \varepsilon_{ij}$$

This linear equation models each individual's math scores at pre- and posttest by nesting the time points (level 1) within each individual (level 2). The model examined the differences in math computation standard scores over time between females and males. The *i*s in the equation denote the individual participants and the *j*s reflect the levels over which the model varies (i.e., time). Y_{ij} is the math computation standard score for each time point (i.e., *j*) nested within each individual (i.e., *i*). β_0 represents the intercept; u_{0j} is the variance of the intercept; β_1 reflects the slope of time; u_{1j} represents the variance of the slope of time; β_2 represents the slope of the individual's ACT Composite score; β_3 represents the slope of the individual's gender; β_4 represents the slope of the interaction between gender and time; and ε_{ij} represents the residual.

The results of the LMM suggest that the mathematics standard scores of the intervention group were comparable at pre- and posttest (β_1 = 1.02, p = .422) and that the change in scores did not significantly differ by gender (β_4 = -4.05, p = .068) (see Table 11). See Figure 4 for a graphical representation of the change in scores over time. The final model showed significant variance in intercepts Var(u_{0j}) = 70.40, $\chi^2(1)$ = 4.30, p = .000 across participants but the variance in slopes Var(u_{1j}) = 7.63, $\chi^2(1)$ = .39, p = .693 was not significant across participants (see Table 12). These results suggest that the intervention group's spatial visualization gains did not transfer to higher mathematics standard scores over time.

Table 11 Question 2 Parameter Estimates

Fixed Effects	Estimate	Standard Error	Approximate *df*	*t*	*p*
Intercept	70.66	7.83	55.02	9.02	.000**
ACT Composite	1.49	.33	54.85	4.57	.000**
Time	1.02	1.26	47.55	.81	.422
Gender	-3.23	2.76	53.01	-1.17	.247
Time*Gender	-4.05	2.16	46.91	-1.87	.068

*Note: *p < .05, **p < .01*

Table 12 Question 2 Covariance Parameters

Parameter	Estimate	Standard Error	Wald Z (χ^2)	*p*
Residual	21.27	10.42	2.04	.041*
Intercept (u_{0j})	70.40	16.38	4.30	.000**
Time (u_{1j})	7.63	19.34	.394	.693

*Note: *p < .05, **p < .01*

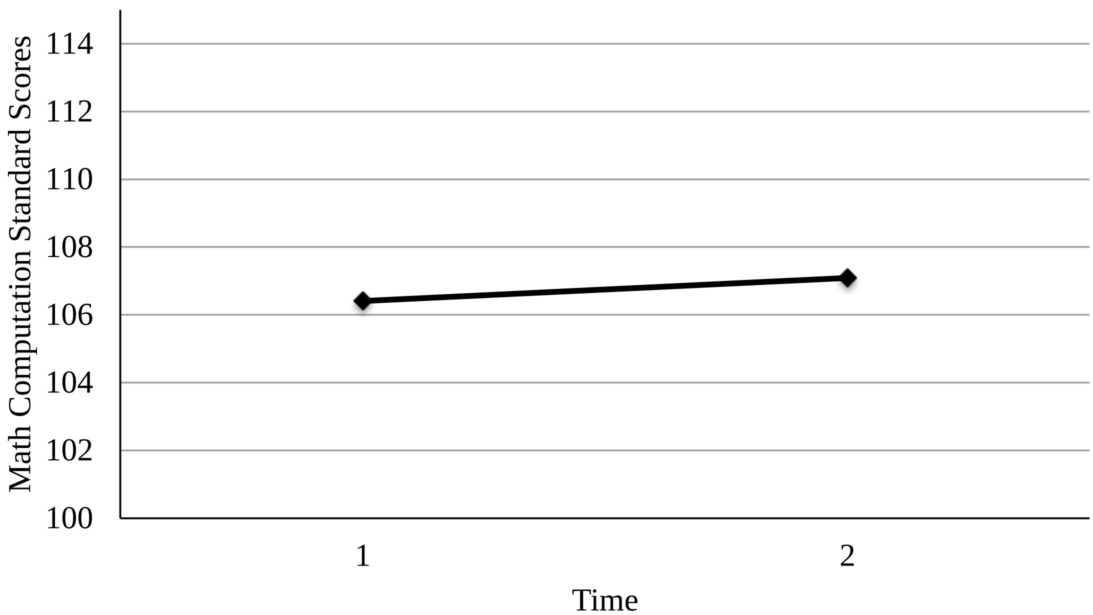

Figure 4 Mean Intervention Group Math Computation Standard Scores Over Time

Research Questions 3 and 4: Do Males and Females Significantly Differ in Mindset? Do the Intervention and Control Groups Significantly Differ in Mindset?

Due to the polymodal nature of the distribution of mindset scores (see Figure 2), group differences in mindset were examined using Mann-Whitney U tests. Results suggest that males

(*Mdn* = 5.00) and females (*Mdn* = 4.75) displayed comparable mindset scores (*U* = 328.00, p = .975). Similarly, mindset was not significantly different for intervention (*Mdn* = 4.75) or control (*Mdn* = 5.00) groups (*U* = 272.50, p = .810). These results suggest that all participants in the sample demonstrated similar median mindset scores, regardless of gender or intervention group membership.

CHAPTER 5

DISCUSSION

Increased efforts have been devoted to improving women's representation in science, technology, engineering, and math (STEM) fields; however, women remain less likely to pursue undergraduate STEM degrees, especially in engineering (Beede et al., 2011; Hill et al., 2010). Researchers have investigated a myriad of possible environmental and biological factors when examining the etiology of gender differences in STEM (Ceci & Williams, 2010). However, gender differences in spatial tasks that involve mental rotation (Geiser et al., 2008; Maeda & Yoon, 2013; Voyer er al., 1995) and complex mathematical problem solving skills (Corbett et al., 2008; Halpern et al., 2007) are particularly salient to the field of engineering since they are related to engineering success (Budny et al., 1998; Honken & Ralston, 2013; Shea et al., 2001; Uttal & Cohen 2012; Van Dyken et al., 2015; Wai et al., 2009; Webb et al., 2007; Yoon et al., 2014).

There have been increased efforts to improve engineering students' spatial skills through training. Sorby and colleagues at Michigan Technological University (MTU) created a spatial visualization course that appears especially promising (Sorby & Baartmans, 2000). Previous studies found that students who participated in the course made gains in spatial visualization scores, performed better in subsequent engineering courses, and had higher retention rates (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013). Researchers outside of MTU have found similar results (Basko & Holliday-Darr, 2010; Walton et al., 2015).

Moreover, some studies have found that spatial training gains may predict higher success in mathematics courses (Sorby, 2009; Sorby et al., 2013; Sorby & Veurink, 2010b); however, the research remains inconclusive. No known study had examined whether spatial training is associated with changes in college-age students' mathematical performance on a standardized measure of mathematical ability, which is especially important since females often get comparable or slightly higher math course grades (Bridgeman & Wendler, 1991; Hill et al., 2010; Voyer & Voyer, 2014), while males tend to show an advantage on tests that involve more complex problem solving (Halpern et al., 2007; Corbett et al., 2008). Furthermore, previous studies had not accounted for the degree to which students believed that they could actually change their cognitive skills.

The purpose of the current study was to attempt to replicate previous research from MTU that found that all students, regardless of gender, improve their spatial visualization skills after participating in a comprehensive spatial visualization course (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013). Preliminary research at Michigan State University has found similar results (Walton et al., 2015); however, the current study added a control group in order to better control for the maturation of participants. Moreover, the current study attempted to examine whether spatial training gains transferred to a standardized measure of mathematics. Last, the study examined whether there were gender and intervention group differences in mindset to better determine whether mindset should be explored further in future research.

Changes in Spatial Visualization Scores

The current study examined whether participation in the spatial visualization course and/or gender was related to changes in spatial visualization raw scores over time. Results were consistent with previous research (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013) in that individuals who took the spatial visualization course displayed greater improvements than the control group in spatial visualization raw scores over time. On average, students who participated in the intervention, regardless of gender, improved their spatial visualization raw scores by approximately nine correct problems. These results are consistent with previous work done at Michigan State University (Walton et al., 2015); however, the current study included a control group, which provides evidence that the improvement in spatial visualization was not merely an artifact of maturation since the intervention group showed more growth over time than the control group.

Although women and men made comparable gains in spatial visualization raw scores, there could have been gender differences that were not captured in the current study due to small sample size and how spatial ability was measured. Terlecki and colleagues (2008) found preliminary evidence that men and women show different spatial growth patterns during training. Women and men with more spatial experiences showed a larger rate of growth at the beginning of treatment, but the growth for men significantly decreased over time while women's remained stable. Women with lower spatial experience showed slower initial growth that significantly increased over time. This suggests that future research on the spatial visualization curriculum should take into account spatial experiences and assess spatial visualization multiple times over the course of the intervention to better understand whether there are gender differences in spatial visualization growth trajectories.

Future research should also investigate whether the spatial visualization course is related to changes in neurological activation. Research has found that adult males and females show different neurological activation patterns when completing spatial visualization tasks that involve mental rotation using fMRI (Butler et al., 2006; Semrud-Clikeman, Fine, Bledsoe, & Zhu, 2012). The results of these studies suggest that males often show greater activity in areas that involve more automatic and effortless processing than females (Butler et al., 2006; Semrud-Clikeman et al., 2012). It could be that males and females make similar performance gains through the spatial visualization course, but that there are differences at the neurological level. It would also be helpful to measure the response time for each item to help determine if the spatial visualization course is related to greater gains in automaticity.

Last, it may be helpful to use supplemental measures of spatial visualization when assessing the interaction of the intervention and gender on spatial visualization scores. The Purdue Spatial Visualizations Test: Rotations (*PSVT:R*; Guay, 1976) is considered the "gold standard" for measuring spatial skill in engineering education (Waller & Lourenco, 2010); however, research suggests that the most consistent and robust gender differences are found on mental rotation tests that use Shepard and Metzler's (1971) geometric figures (Linn & Petersen, 1985; Voyer et al., 1995). Although the measures are similar in that they ask the individual to identify the rotated target figures among an array of choices, the *PSVT:R* uses more complex figures while Shepard and Metzler's (1971) stimuli are created through cubes. Thus, Shepard and Metzler's (1971) geometric figures may be more difficult to rotate for individuals who employ verbally mediated strategies over more holistic approaches since the figures offer little context. The *PSVT:R* also presents the problems analogically since the test requires individuals to first study the rotational relation between two identical objects and then apply the rotation in the same manner for a novel object. Therefore, test performance may be influenced by analogical reasoning skills and may not be a true representation of pure mental rotation ability.

Spatial Visualization Training, Mathematics, and Gender

The current study also investigated changes in the intervention group's math computation standard scores and whether the changes were related to gender. The results indicated that the intervention's math computation standard scores did not significantly change from pre- to posttest, irrespective of gender. An interesting finding is that the intervention group's performance on math computation was solidly within the average range compared to others their age. This was surprising as success in high school mathematics and science courses are related to pursuing engineering in college (Robinson, 2003). Errors were expected for more difficult items that required more complex problem solving, but many individuals struggled on basic multi-digit computation problems (i.e., addition, subtraction, multiplication, division) and items that involved fractions or decimals. For example, at both pre- and posttest 34 individuals incorrectly answered a question that asked them to multiply a three-digit by a two-digit number. One possible reason the spatial intervention was not related to increased mathematical performance is that the individuals have not yet mastered more basic rote math skills upon which more complex skills are built. Alternatively, the individuals may typically rely on external aides (e.g., calculators) to perform more basic calculations.

Research suggests that the relation between mental rotation ability and mathematics is especially strong for specific mathematical areas including: geometry (Battista, 1990; Delgado & Prieto, 2004; Kyttälä & Lehto, 2008; Sherman, 1979; Weckbacher & Okamoto, 2014) and problem solving (Hegarty & Kozhevnikov, 1999; Sherman, 1979). Sorby and colleagues (2013) found that spatial visualization training was related to improvements in a calculus course which require more complex skills than basic computations. It could be that the spatial visualization course is associated with increased performance on these types of math problems, but that the *WRAT4* Math Computation subtest did not adequately align with the types of higher-order mathematical courses seen in engineering programs (e.g., calculus, trigonometry, geometry).

Although the *WRAT4* Math Computation subtest has adequate psychometric properties (Wilkinson & Robertson, 2006), the consistency of the standard scores over time may have been influenced by form variability. The average alternate-form reliability is .88 for immediate retest and .83 for delayed retest within one month; however, it is unclear how reliable the alternate-forms are for longer periods of time. The posttest form was also slightly more difficult than the pretest form and included slightly different problems (e.g., finding annual interest). The difference in form difficulty was accounted for by using the standard scores, but form variability could have still influenced the results. For example, approximately 79% of the intervention group finished the entire test at pretest compared to 54% at posttest. The posttest of the *WRAT4* was also administered to the intervention group during their last regularly scheduled class. The individuals may have devoted less attention to the *WRAT4* due to the increased cognitive load of assignments and finals at the end of the semester.

Future research should also take into account the handedness of participants when investigating the relation between the intervention and gender on transfer to spatial skills. Studies have found that mental rotation skills may mediate the relation between gender and math (Casey et al., 1995; Casey et al., 1997), but that this relation may be influenced by handedness. Casey and colleagues (1992) found that mental rotation skills only predicted mathematical skills for males, non-right handed females, and right-handed females with non-right handed relatives. This suggests that for women especially, the spatial visualization intervention may work differently depending how their brain is organized. The lateralization of cerebral functions is related to handedness (Annett, 1992) and gender (Butler et al., 2006; Jordan & Wustenberg, 2010; Semrud-Clikeman et al., 2012). For approximately 95% of right-handed and 70% of left-handed individuals, language is lateralized in the left hemisphere, while it is lateralized in the right hemisphere or bilaterally in the rest of the population (Springer & Deutsch, 1998). Historically, the right hemisphere has been associated with more nonverbal functioning including visual-spatial ability (Weisenberg & McBride, 1935). Some studies suggest that females' brains are more bilaterally organized as well (Jancke & Steinmetz, 1994). Jordan and Wustenberg (2010) found that mental rotation tasks are associated with increased activation of the intraparietal sulcus in general; however, males tend to exhibit larger right hemispheric activation of the intraparietal sulcus and the left superior lobule. Women displayed increased bilateral activation of the intraparietal sulcus.

The current study highlights the need for better, standardized measures of complex mathematical problem solving that can be used to measure skills over time. The *WRAT4* was used because it was normed on college-aged individuals and could be quickly administered in a group format; however, it had a minimal number of items that required higher order mathematical problem solving. This is especially important when investigating gender differences in the mathematical progress of engineering students since a small male advantage is more consistently found on mathematical tests that involve complex problem solving and that are high-stakes (Corbett et al., 2008; Halpern et al., 2007), but not in mathematical course work (Hill et al., 2010). Moreover, problem-solving skills are critical in mathematics-intensive fields like engineering and so it would be beneficial to be able to measure growth in these high-level skills over time (Hyde et al., 1990).

Although the current study was not able to detect spatial transfer gains to mathematics, the relation between the course and mathematics should be further explored. Studies have found that success in undergraduate mathematics courses are related to success and retention in engineering (Budny et al., 1998; Honken & Ralston, 2013; Van Dyken et al., 2015; Yoon et al., 2014) and that students often leave engineering due to the difficulty of mathematics courses (Budny et al., 1998). Furthermore, there is preliminary evidence that spatial training gains may predict subsequent mathematics grades (Sorby, 2009; Sorby et al., 2013; Sorby & Veurink, 2010b).

Spatial Visualization, Mindset, and Gender

A secondary goal of the current study was to examine whether there were gender and intervention group differences in mindset to determine whether mindset should be explored in future studies. Results suggest that individuals in the sample held similar mindset scores regardless of their gender and whether they chose to take the intervention. The individuals in the control group may have shown similar mindset scores since they elected to become involved in a study that tested a skill in which they previously scored poorly. This finding also suggests that more efforts should be expended to determine if other barriers (e.g., course schedule) prevent students with a growth mindset from taking the spatial visualization course in general.

It should be noted that all individuals in the sample held some degree of growth mindset and that no participant exhibited a mindset that was truly fixed. Although the current study did not include individuals from other programs, it is likely that the participants in the current study held some degree of a growth mindset because they pursued engineering in general despite low spatial visualization scores and average mathematical ability. First semester engineering students may have an unrealistic understanding of engineering and their motivations for studying engineering may be unrelated to their mindset since they have not yet started to struggle with the mathematics course work. It may also be that those with comparable scores and a fixed mindset are more likely to pursue other areas of study outside of STEM. Last, there could have been a social desirability bias in which the individuals endorsed more incremental views of ability to appear more favorable.

Individuals can actually have different mindsets depending on the area (Dweck, 2008a). It could be that males and females in the sample displayed similar overall views on the malleability of intellectual ability, but that they show differences in mindset specifically for mathematics and spatial skills. The women in the study had already decided to pursue engineering despite negative gender stereotypes and social pressure; therefore, it is likely that these females have greater growth mindset than females in fields that are more consistent with stereotyped gender roles. Mindset was measured more generally in the current study due to practical limitations. Michigan State University's engineering department was already administering a mindset measure and so the pre-existing data were used in order to limit the duration of class time needed to administer the assessments. However, future studies should more specifically measure participants' mindsets for spatial visualization and mathematical skills.

Research should also investigate whether promoting a growth mindset and mastery goals while teaching the spatial visualization curriculum are related to greater improvements in spatial visualization and mathematics over time. Research suggests that providing growth mindset messages and specifically teaching individuals that their performance can change over time has been related to improvements in both mathematics (Blackwell et al., 2007; Dar-Nimrod & Heine, 2006; Good et al., 2003) and spatial ability (Moé et al., 2009; Moé & Pazzaglia, 2010). This may be especially important for women, as research has shown that holding a growth mindset may be a protective factor for women against the influence of negative mathematics and spatial ability gender stereotypes (Good et al., 2007; Good et al., 2012). Good and colleagues (2012) found that women's sense of belonging decreased when they perceived fixed mindset messages and gender stereotypes in the environment. This is especially important in STEM fields like engineering which are highly gender stereotyped as masculine (Cheryan et al., 2009; DiDonato & Strough, 2013; Diekman et al., 2010).

Limitations and Future Research

The individuals in the current study self-selected into the intervention and control group and so there could be confounding variables that were not controlled. One finding from the current study is that the control and intervention group showed similar mindset scores and so the degree to which they thought they could improve their intellectual abilities was at least comparable. The groups were also similar in terms of age, engineering major, ethnicity, ACT Comprehensive scores, as well as spatial visualization and mathematics scores at time one. However, there were a greater proportion of females in the control group than in the intervention group.

Gains in spatial visualization scores following the spatial skills curriculum have been shown consistently over time (Basko & Holliday-Darr, 2010; Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013; Walton et al., 2015); however, even more convincing inferences could be made if future research uses a randomized-control design or a multiple baseline design that includes multiple intervention groups, but staggers the start of the intervention conditions over time. This would have been especially helpful in the current study since the intervention and control groups inherently had different motivations for taking the assessments as the intervention group took the assessments as part of their regularly scheduled class, while the control group were provided monetary compensation for the extra time and travel expenses. A multiple baseline design would remedy this limitation since all individuals would be taking the assessments as part of their regularly scheduled class. A multiple baseline design would also be more ethically sound than a randomized-control design since all participants would receive the intervention, which has consistently been shown to be related to spatial visualization gains over time (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013).

Another limitation of the current study was that it included a small sample size, which limits the ability to generalize the findings to the general population and to adequately detect group differences over time. There were also challenges in control group recruitment, which may have influenced results. Two different control group recruitment conditions were used since an adequate sample was not acquired through initial recruitment efforts. This made it especially difficult to analyze changes in mathematics over time since as only seven participants completed both the pre- and posttest mathematics measure. There were also missing data in the study which could have confounded results; however, more robust statistical procedures were used in order to try to account for the missing data. Despite the missing age data, the ages 18:0-19:11 standard score conversation tables were used to convert the math computation raw to standard scores. Although the vast majority of the participants with known ages were between 18 and 19 years old, some individuals with unknown age may have fallen within the 20- to 25-year-old range. Out of the thirty individuals who had missing age data, the standard scores would only change for six individuals at pretest and six individuals at posttest if the ages 20:0-24:11 score conversion table was used. Moreover, the standard score would only change by one point for eleven of the scores and two points for one of the scores, which is well within the confidence interval.

The last limitation was in how the different skills were measured. Efforts were made to minimize the amount of time required to participate in the study since incoming engineering students at Michigan State University are already asked to participate in multiple research projects and to complete a variety of measures. The study also wanted to limit the amount of time taken out of the spatial visualization course to take the assessments. As previously noted, it may be helpful to use different spatial ability measures and to measure reaction time for each item's completion, especially when trying to analyze the interaction between gender and the intervention over time. Mental rotation tests that use Shepard and Metzler's (1971) geometric figures appear especially promising as they show the largest and most consistent gender differences (Linn & Petersen, 1985; Voyer et al., 1995). It is essential that future studies use an additional post-test measure (e.g., mental rotation tests) to determine if the gains in spatial visualization generalize to other measures of spatial ability. It is currently unclear whether the improvements on the *PSVT:R* (Guay, 1976) truly reflect an increase in spatial visualization skill or if the individuals were just taught how to improve their performance on the test.

Similarly, future research would benefit from using a standardized mathematical measure that involves more complex problem solving and better aligns with mathematical courses seen in engineering programs; however, it is unknown whether such a measure exists that is sensitive enough to capture growth over time. Last, the more general mindset measure was used since it was already being administered through the engineering department as part of a larger study; however, measuring mathematics and spatial visualization mindset more specifically may help to determine whether gender differences exist and whether mindset should be addressed in spatial training research further.

Clinical Implications

The current study found that on average, all individuals who took the spatial visualization course benefitted, regardless of gender. These results are consistent with previous research completed by the developers of the spatial visualization curriculum (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013). The study also extends on previous work done at Michigan

State University (Walton et al., 2015) by including a control group, which provides more evidence that the improvement in spatial visualization was not just due to maturation gains. Although women and men showed similar growth, a larger number of women would likely benefit from participating in the spatial visualization course since they are more likely to display low spatial visualization scores (Geiser et al., 2008; Maeda & Yoon, 2013; Voyer er al., 1995).

The current study also investigated changes in the intervention group's math computation scores and whether the changes were related to gender. The results were surprising as the intervention group's math computation scores, regardless of gender, actually decreased over time. Subsequent analyses suggested that the control group had similar decreases in scores and so the results were likely spurious or due to alternate forms being used. Perhaps the largest conclusion that can be drawn from the results is that more efforts should be expended to create a standardized measure of complex problem solving that is sensitive to higher order mathematical skill growth over time. This is especially important for engineering since studies have shown that students often leave engineering because of difficulty in mathematics courses (Budny et al., 1998).

Although research suggests that mathematics and spatial visualization skills are important to engineering persistence and success (Budny et al., 1998; Honken & Ralston, 2013; Shea et al., 2001; Uttal & Cohen 2012; Van Dyken et al., 2015; Wai et al., 2009; Webb et al., 2007; Yoon et al., 2014), spatial visualization skills may become less important as students gain expertise in the field (Uttal & Cohen, 2012). Undergraduate engineering students are most likely to drop out around the third semester (Min et al., 2011), but spatial training may help retain engineering students, especially females (Sorby, 2009; Sorby & Baartmans, 2000; Sorby et al., 2013). It could be that the spatial training is especially helpful in retaining female students until spatial visualization skills are deemphasized. It may also be useful to provide more spatial experiences to students at a younger age (e.g., middle school, high school) to improve spatial visualization scores before individuals start college-level engineering and mathematics coursework.

The current study found that individuals in the sample had similar mindset scores, regardless of gender and intervention group membership. However, it could be that there are differences in mindset specifically for mathematics and spatial visualization skills. Preliminary research suggests that promoting a growth mindset and mastery goals has been related to improvements in both mathematics (Blackwell et al., 2007; Dar-Nimrod & Heine, 2006; Good et al., 2003) and spatial ability (Moé et al., 2009; Moé & Pazzaglia, 2010). Moreover, research has shown that holding a growth mindset may be a protective factor for women against the influence of negative mathematics and spatial ability gender stereotypes (Good et al., 2007; Good et al., 2012). Future research should investigate whether the interaction between spatial visualization training and the promotion of a growth mindset is related to even larger gains in spatial visualization scores and retention in engineering over time.

This study involved investigating internal processes (i.e., mathematics, spatial visualization, mindset); however, larger societal and environmental factors need to be addressed, especially when trying to attenuate gender differences in STEM. The spatial visualization curriculum may help provide more spatial experiences; however, efforts should simultaneously be exerted to making STEM environments more appealing and welcoming to females. Women may be deterred from STEM careers like engineering because they are characterized as more masculine fields (Cheryan et al., 2009; DiDonato & Strough, 2013; Diekman et al., 2010). STEM environments may also intensify women’s feelings of isolation (Hewlett et al., 2008) since women often experience gender discrimination (Hewlett et al., 2008; Settles et al., 2012) and have to work especially hard to show their competence since stereotypes suggest that men naturally excel in STEM occupations (Heilman, et al., 2004). Gender stereotypes represent fixed mindset beliefs since they suggest that abilities are biologically dependent (Dweck, 2008b). Stereotypes are especially dangerous as these beliefs can actually lead to underperformance on the stereotyped tasks and thus the perpetuation of the stereotypes (Steele & Aronson, 1995). Although promoting a growth mindset may be a protective factor against environmental stereotypes (Good et al., 2007), it is important to continue to challenge the gender stereotypes themselves in order to show that women can and do succeed in engineering.

APPENDICES

APPENDIX A

Control Group Recruitment Flyer (Version One)

MICHIGAN STATE UNIVERSITY

ENGINEERING SPATIAL TRAINING STUDY

PARTICIPATE IN RESEARCH AND GET PAID!

OUR STUDY

- This study is evaluating the effectiveness of a spatial skills course and related variables.
- The study is also examining the development of the spatial and math skills of first year undergraduate engineering students.

WHAT WILL YOU DO?

- You will be asked to complete some in-person and online assessments at the beginning and end of the Fall 2016 semester.
- In-person assessments will be administered at MSU.
- The total amount of time required for the study will range from one hour to one hour and thirty minutes.
- After you complete the second round of assessments you will receive a **$20 gift card**.

WHO CAN PARTICIPATE?

- First year students who declare their major as engineering
- Between 18-25 years old
- Must have personally received an email asking to participate
- Must **NOT** be enrolled in EGR 291 Special Topics for Fall 2016

CONTACT

- Engineering Spatial Training Study
  Michigan State University
  Email: [redacted]
  Phone: [redacted]
- **Please call or email to get more information and/or to set up your assessment sessions!**

APPENDIX B

Control Group Recruitment Flyer (Version Two)

MICHIGAN STATE
UNIVERSITY

ENGINEERING SPATIAL TRAINING STUDY

PARTICIPATE IN RESEARCH AND GET PAID!

OUR STUDY

- This study is evaluating the effectiveness of a spatial skills course and related variables.
- The study is also examining the development of the spatial skills of first year undergraduate engineering students.

WHAT WILL YOU DO?

- You will be asked to complete one session of online assessments.
- Assessments will be available from November 21, 2016 to December 2, 2016.
- The total amount of time required for the study will range from twenty to thirty minutes.
- After you complete the assessments you will receive a **$10 gift card**.

WHO CAN PARTICIPATE?

- First year students who declared their major as engineering.
- Between 18-25 years old
- Must have personally received an email asking to participate
- Must **NOT** be enrolled in EGR 291 Special Topics for Fall 2016

CONTACT

- Engineering Spatial Training Study
  Michigan State University
  Email: [redacted]
  Phone: [redacted]
- **Please call or email to get more information and/or to set up your assessment sessions!**

APPENDIX C

Intervention Group Consent Form

Consent for a Research Study
Michigan State University

We are asking that you participate in a research study. Researchers are required to provide a consent form that describes the study, to let you know that participation is voluntary, to explain the risks and benefits of the participation, and to help you make an informed decision. You should feel free to ask the researchers any questions that you have.

Study Title: **Engineering Spatial Training Study**

Researchers: **Jodene Goldenring Fine, Ph.D.,** Associate Professor of School Psychology
Kara Constantine, M.A., Doctoral Candidate, School Psychology

Department: **Department of Counseling, Educational Psychology, and Special Education**

Purpose of the Research
Dr. Fine and Ms. Constantine, along with their student associates, are conducting a research study to evaluate the effectiveness of a spatial skills course and to examine the development of spatial and mathematical skills of first year undergraduate engineering students. We are also examining whether mindset (i.e., individuals' views of the malleability of cognitive skills) should be considered when investigating changes in spatial and mathematical skills over time. We are asking students to perform some spatial and mathematical tasks, as well as answer some questions about their views on the malleability of cognitive skills. You will be one of several students asked to participate in the project. Your participation in this study is voluntary and can be revoked by you at any time.

What You Will Do
The total amount of time required for the study will range from 35 to 45 minutes across two testing sessions. You will be asked to complete a mathematics assessment at the beginning and end of your Spatial Visualization course (EGR 291 Selected Topics). This assessment will be administered during your normal course time. You will also be asked to answer questions about your views of the malleability of cognitive skills at the end of the semester. The information is confidential and will not be shared with anyone without your permission.

Your Rights to Participate, Say No, or Withdraw
Your participation in this research study would be greatly appreciated. However, your participation in this study is entirely voluntary. You have the right to say no. You may change your mind at any time and withdraw from the study. You may refuse to answer or skip any question. Whether or not you choose to participate will have no effect on your grade at Michigan State University.

Privacy and Confidentiality
The data from this research study will be kept confidential. Information about you will also be kept confidential to the maximum extent allowable by law. All test protocols will be stored in a locked file cabinet and will only be marked with an assigned subject number. Data from your assessment will be entered into a database by your subject number and will not be personally identifiable. At no point will your name or testing performance be disclosed to your instructors. The information will be recorded into a secure, password protected database by the researchers. A logbook linking your name and research number will be kept in a locked file cabinet. Only the researchers and the MSU Institutional Review Board (IRB), which is responsible for the oversight of the safety and rights of research participants, will have access to the data. In the event that the results of this research project are presented at a professional conference or published journal article, your identity will be disguised with a pseudonym and other personally identifiable information will not be disclosed. Only researchers will have access to the data. It will be kept for 5 years following the completion of the study and then will be destroyed.

Potential Benefits
It is hoped that this work will lead to a better understanding of the spatial and mathematical benefits of participating in the spatial visualization course and help determine if future research on spatial visualization interventions should examine students' mindsets.

Potential Risks
There are no foreseeable risks to participating in the study outside of day-to-day experiences. You might feel some discomfort (e.g., challenged) by the academic and/or cognitive tests administered. Testing will be discontinued if you express a desire to stop. Researchers will also address any of your questions before, during, or after the testing.

Costs for Being in the Study
It does not cost anything to participate in this study. Administration of the measures will take some time out (15-20 minutes per session) of your course time; however, there will still be adequate time to cover the instruction planned for the class period.

Contact Information for Questions or Concerns
If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researchers:

Jodene Goldenring Fine, Ph.D.
[redacted]

Kara Constantine, M.A.
[redacted]

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact the following, anonymously if you wish:

Michigan State University's Human Research Protection Program
Olds Hall, 408 West Circle Drive, Room 207, East Lansing, MI 48824
Phone: 517-355-2180, Fax: 517-432-4503
Email: irb@ora.msu.edu

Signature and Acknowledgement
By signing below you acknowledge that you have received a copy of the consent document and that you voluntarily agree to participate in the study.

Student Signature: ___________________________Today's Date: ________________________

Returning the Document
Please hand this page to the researcher.

APPENDIX D

Control Group Consent Form (Version One)

Consent for a Research Study
Michigan State University

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Researchers: **Jodene Goldenring Fine, Ph.D.,** Associate Professor of School Psychology
Kara Constantine, M.A., Doctoral Candidate, School Psychology

Department: **Department of Counseling, Educational Psychology, and Special Education**

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Dr. Fine and Ms. Constantine, along with their student associates, are conducting a research study to evaluate the effectiveness of a spatial skills course and to examine the development of spatial and mathematical skills of first year undergraduate engineering students. We are also examining whether mindset (i.e., individuals' views of the malleability of cognitive skills) should be considered when investigating changes in spatial and mathematical skills over time. We are asking students to perform some spatial and mathematical tasks, as well as answer some questions about their views on the malleability of cognitive skills. You will be one of several students asked to participate in the project. Your participation in this study is voluntary and can be revoked by you at any time.

What You Will Do
The total amount of time required for the study will range from one hour to one hour and thirty minutes across two testing sessions. You will be asked to complete a mathematics assessment at the beginning and end of the 2016 fall semester. You will also be asked to complete an online spatial visualization assessment and to answer questions about your views of the malleability of cognitive skills at the end of the semester. These assessments will take place in the College of Education or the College of Engineering at Michigan State University. The information is confidential and will not be shared with anyone without your permission.

Your Rights to Participate, Say No, or Withdraw
Your participation in this research study would be greatly appreciated. However, your participation in this study is entirely voluntary. You have the right to say no. You may change your mind at any time and withdraw from the study. You may refuse to answer or skip any question. Whether or not you choose to participate will have no effect on your grade at Michigan State University.

Privacy and Confidentiality
The data from this research study will be kept confidential. Information about you will also be kept confidential to the maximum extent allowable by law. All test protocols will be stored in a locked file cabinet and will only be marked with an assigned subject number. Data from your assessment will be entered into a database by your subject number and will not be personally identifiable. At no point will your name or testing performance be disclosed to your instructors. The information will be recorded into a secure, password protected database by the researchers. A logbook linking your name and research number will be kept in a locked file cabinet. Only the researchers and the MSU Institutional Review Board (IRB), which is responsible for the oversight of the safety and rights of research participants, will have access to the data. In the event that the results of this research project are presented at a professional conference or published journal article, your identity will be disguised with a pseudonym and other personally identifiable information will not be disclosed. Only researchers will have access to the data. It will be kept for 5 years following the completion of the study and then will be destroyed.

Potential Benefits
You will earn a prize in the value of $20 at the end of the second testing session. It is hoped that this work will lead to a better understanding of the spatial and mathematical benefits of participating in the spatial visualization course and help determine if future research on spatial visualization interventions should examine students' mindsets.

Potential Risks
There are no foreseeable risks to participating in the study outside of day-to-day experiences. You might feel some discomfort (e.g., challenged) by the academic and/or cognitive tests administered. Testing will be discontinued if you express a desire to stop. Researchers will also address any of your questions before, during, or after the testing.

Costs and Compensation for Being in the Study
It does not cost anything to participate in this study. You will receive $20 for completing the study to compensate you for your time and for any travel expenses that you might incur (e.g., gas, parking).

Contact Information for Questions or Concerns
If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researchers:

Jodene Goldenring Fine, Ph.D.
[redacted]

Kara Constantine, M.A.
[redacted]

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact the following, anonymously if you wish:

> Michigan State University's Human Research Protection Program
> Olds Hall, 408 West Circle Drive, Room 207, East Lansing, MI 48824
> Phone: 517-355-2180, Fax: 517-432-4503
> Email: irb@ora.msu.edu

Signature and Acknowledgement
By signing below you acknowledge that you have received a copy of the consent document and that you voluntarily agree to participate in the study.

Student Signature: ___________________________Today's Date: ________________________

Returning the Document
Please hand this page to the researcher.

APPENDIX E

Control Group Consent Form (Version Two)

Consent for a Research Study
Michigan State University (MSU)

We are asking that you participate in a research study. Researchers are required to provide a consent form that describes the study, to let you know that participation is voluntary, to explain the risks and benefits of the participation, and to help you make an informed decision. You should feel free to ask the researchers any questions that you have.

Study Title: **Engineering Spatial Training Study**

Researchers: **Jodene Goldenring Fine, Ph.D.,** Associate Professor of School Psychology
Kara Constantine, M.A., Doctoral Candidate, School Psychology

Department: **Department of Counseling, Educational Psychology, and Special Education**

Purpose of the Research
Dr. Fine and Ms. Constantine, along with their student associates, are conducting a research study to evaluate the effectiveness of a spatial skills course and to examine the development of spatial skills of first year undergraduate engineering students. We are also examining whether mindset (i.e., individuals' views of the malleability of cognitive skills) should be considered when investigating changes in spatial skills over time. We are asking students to perform some spatial tasks, as well as answer some questions about their views on the malleability of cognitive skills. You will be one of several students asked to participate in the project. Your participation in this study is voluntary and can be revoked by you at any time.

What You Will Do
The total amount of time required for the study will range from twenty to thirty minutes. You will be asked to complete an online spatial visualization assessment and may or may not be asked to answer questions about your views of the malleability of cognitive skills. The information is confidential and will not be shared with anyone without your permission.

Your Rights to Participate, Say No, or Withdraw
Your participation in this research study would be greatly appreciated. However, your participation in this study is entirely voluntary. You have the right to say no. You may change your mind at any time and withdraw from the study. You may refuse to answer or skip any question. Whether or not you choose to participate will have no effect on your grade at MSU.

Privacy and Confidentiality
The data from this research study will be kept confidential. Information about you will also be kept confidential to the maximum extent allowable by law. Data from your online assessments will be entered into a database by your subject number and will not be personally identifiable. At no point will your name or testing performance be disclosed to your instructors. The information

will be recorded into a secure, password protected database by the researchers. A logbook linking your name and research number will be kept in a locked file cabinet. Only the researchers and the MSU Institutional Review Board (IRB), which is responsible for the oversight of the safety and rights of research participants, will have access to the data. In the event that the results of this research project are presented at a professional conference or published journal article, your identity will be disguised with a pseudonym and other personally identifiable information will not be disclosed. Only researchers will have access to the data. It will be kept for 5 years following the completion of the study and then will be destroyed.

Potential Benefits
You will earn a prize in the value of $10 after the completion of the online assessments. It is hoped that this work will lead to a better understanding of the spatial benefits of participating in the spatial visualization course and help determine if future research on spatial visualization interventions should examine students' mindsets.

Potential Risks
There are no foreseeable risks to participating in the study outside of day-to-day experiences. You might feel some discomfort (e.g., challenged) by the cognitive tests administered. You can exit out of the assessment if you desire to stop. Please email the researchers with questions before or after the testing.

Costs and Compensation for Being in the Study
It does not cost anything to participate in this study. You will receive a $10 gift card for completing the study to compensate you for your time.

Contact Information for Questions or Concerns
If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researchers:

Jodene Goldenring Fine, Ph.D.
[redacted]

Kara Constantine, M.A.
[redacted]

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact the following, anonymously if you wish:

> Michigan State University's Human Research Protection Program
> Olds Hall, 408 West Circle Drive, Room 207, East Lansing, MI 48824
> Phone: 517-355-2180, Fax: 517-432-4503
> Email: irb@ora.msu.edu

Signature and Acknowledgement

☐I acknowledge that I have received a copy of the consent document and that I voluntarily agree to participate in the study.

☐I am at least 18 years old.

☐I am not currently enrolled in EGR 291 Special Topics for Fall of 2016.

APPENDIX F

Theories of Intelligence Scale-Self Form for Adults **(Dweck, 2000)**

This questionnaire has been designed to investigate ideas about intelligence. There are no right or wrong answers. We are interested in your ideas.

Using the scale below, please indicate the extent to which you agree or disagree with each of the following statements by writing the number that corresponds to your opinion in the space next to each statement.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

____ 1. You have a certain amount of intelligence, and you can’t really do much to change it.

____ 2. Your intelligence is something about you that you can’t change very much.

____ 3. No matter who you are, you can significantly change your intelligence level.

____ 4. To be honest, you can’t really change how intelligent you are.

____ 5. You can always substantially change how intelligent you are.

____ 6. You can learn new things, but you can’t really change your basic intelligence.

____ 7. No matter how much intelligence you have, you can always change it quite a bit.

____ 8. You can change even your basic intelligence level considerably.

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