Learning and Individual Differences xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Learning and Individual Differences

journal homepage: www.elsevier.com/locate/lindif

Mental rotation ability in relation to self-perceptions of high school geometry

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ARTICLE INFO

Article history:
Received 27 July 2012
Received in revised form 11 September 2013
Accepted 11 October 2013
Available online xxxx

Keywords:
Mental rotation ability
Geometry
Mathematical self-perceptions
Spatial thinking
STEM

ABSTRACT

The study examined relations among mental rotation ability, mathematics achievement and mathematical self-perceptions among 113 high school students. Each participant completed a mental rotations test, an assessment of self-perceptions of geometry and self-perceptions of algebra. Geometry and algebra grades along with a standardized geometry test were used as measures of mathematics achievement. Significant relations emerged between mental rotation and both geometry grades and the standardized geometry measure; no significant relation emerged between mental rotation and algebra grades. A significant relation also emerged between mental rotation and self-perceptions of doing well in geometry and algebra, but not between mental rotation and self-perceptions of either liking geometry or algebra. Implications pertaining to the improvement of spatial thinking as they relate to encouraging students' interests in mathematical and scientific careers are addressed.

1. Introduction

Spatial ability refers to an individual's ability to generate, retain, retrieve and transform well-structured visual images (Lohman, 1996). Its use is obvious in many facets of life from leisure (e.g., puzzles, model building, craftwork) to occupational choice (e.g., architecture, cartography, radiology). Proficiency in spatial ability is often associated with success in cognitively demanding disciplines, such as engineering and science (Shea, Lubinski, & Benbow, 2001) that are quantitatively driven. Although spatial ability has been found to be strongly related to quantitative ability (Lubinski & Humphreys, 1990) but distinct from verbal ability (Dixon, 1983), it is believed to function in combination with both in the acquisition of new knowledge (Gardner, 1993). In other words, it is complementary in the process of learning. Given what is then known, spatial ability is a key dimension in human capability that affords unique information in a portrait of cognitive diversity.

Reasons why individuals differ in spatial ability vary in that some argue in favor of a biological predisposition (e.g., Thomas & Kail, 1991), whereas others favor environmental influences (e.g., Sanz de Acedo Lizarraga & Garcia Ganuza, 2003), or both (e.g., Casey, Nuttall, & Pezaris, 1999). The two latter positions assume that spatial ability can be improved with experience. Along these lines, Ericsson, Nandagopal, and Roring (2005) have proposed that the development of enhanced performance in any domain may very well be a reflection of relevant experiences that involve extended practice. In the effort to explain why students with well-developed spatial ability are more likely to perform better in mathematics (e.g., Battista, 1990; Battista, Wheatley, & Talsma, 1982; Casey, Nuttall, & Pezaris, 1997; Delgado & Prieto, 2004), it may be that these individuals have had a greater repertoire of experiences to nurture this ability. For instance, research has shown that participation in certain spatially oriented activities (e.g., playing videogames, the piano, or soccer) relates to strength in types of spatial skills (e.g., Cherney, 2008; Rauscher, 1999; Weckbacher & Okamoto, 2012). If this assertion is correct, then efforts to improve spatial ability may well lead to improved performance in geometry — a weaker content areas in mathematics among US students (Battista, 1999; Corbishley & Truxaw, 2010; Gonzales et al., 2009; Mullis, Martin, Gonzalez, & Chrostowski, 2004).

1.1. Mental rotation ability and geometry

Types of spatial ability are well documented (e.g., Hermelin & O'Connor, 1986; Linn & Petersen, 1985; Lohman, 1996; McGee, 1979); however, some spatial abilities tend to be far more studied than others likely due to their relevance to certain aspects of performance, such as mathematics achievement. One pertinent example is mental rotation. This type of spatial thinking involves the ability to mentally rotate two- or three-dimensional objects encountered in everyday life, including figural depictions in mathematics textbooks. In considering the variety of factors that could potentially influence mathematics achievement, mental rotation has been frequently cited as a factor in determining successful problem solving performance, notably geometry (e.g., Battista; Battista et al., 1982; Casey et al., 1997; Casey, Nuttall, Pezaris, & Benbow, 1995; Delgado & Prieto, 2004; McGee, 1979).

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1041-6080/$ – see front matter © 2013 Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.lindif.2013.10.007

Among the general population, a male advantage in mental rotation ability is a well-established finding (e.g., Battista, 1999; Casey et al., 1995; Casey et al., 1997; Cherney, 2008; Delgado & Prieto, 2004; Hult & Brous, 1986; Linn & Petersen, 1985; Vandenberg & Kuse, 1978; Voyer, 1998). Thus, in light of males' superior mental rotation ability, studies that examined the relation between this skill and performance in geometry often draw equal attention to the role of gender. For instance, according to Casey et al. (1997), geometry items account for approximately one-third of the items on some SAT-M tests, and these items tend to have the largest gender difference of all the items on the test (Rosser, 1989). In their study that explored the basis for the gender difference in the SAT-M, Casey et al. (1997) applied path analytic techniques to trace the causal pathways of key variables that might function as possible mediators of the gender–SAT-M relation. They determined that mental rotation, in comparison to math self-confidence, math anxiety and geometry grades, is the most critical factor contributing to a gender difference in SAT-M. On the other hand, Delgado and Prieto also investigated the mediating role of mental rotation within the context of gender. They predicted that mental rotation would mediate mathematical abilities (e.g., geometry) typically favoring males. Interestingly, no statistically significant gender differences surfaced in regard to the participants' performance in geometry. At a descriptive level only, females performed better than males in arithmetic, males performed better than females in geometry and word problems. Though mental rotation added to the prediction of performance in geometry, it accounted for little variance. Similarly, Friedman's (1995) meta-analysis of correlations concerning spatial abilities (including mental rotation) and geometry showed little evidence of gender differences.

The inconsistency in the findings reported above suggests that there is good reason to assume that mental rotation is merely one variable that may influence performance in geometry. Even though males tend to outperform females in mental rotation, the patterns of findings with respect to geometry are less clear cut. According to Casey et al. (1997), this is not surprising given how such studies vary widely in age, the ability level of participants, the choice of instruments for measuring both spatial and math abilities as well as the choice of variables studied. With respect to the latter, one variable that has been well investigated pertains to students' self-perceptions of their mathematics achievement, yet seemingly little research has been conducted in the area of geometry.

1.2. Self-perceptions of mathematics achievement

Differences in any area of mathematics performance, however, should not be interpreted as the byproduct of ability alone. There is a good deal of research that has shown how mathematics performance is also related to students' self-perceptions of their quantitative abilities. Conceptually speaking, the study of self-perceptions in mathematics can be considered multifaceted. Mathematics self-concept (i.e., knowledge and perceptions about oneself with respect to mathematics) and mathematics self-efficacy (i.e., convictions about oneself with respect to mathematics performance) are two domain-specific constructs that have been shown to predict motivation, emotion, and performance in mathematics to varying degrees (Bong & Skaalvik, 2003). An interrelated dimension is mathematics attitude (e.g., Ganley & Vasilyeva, 2011; Vandecandelaere, Speybroeck, Vanlaar, De Fraine, & Van Damme, 2012) that takes into account how confidence and anxiety can affect performance. According to Utley (2007), students begin to develop an attitude toward mathematics as soon as they are exposed to it; these attitudes can therefore have an effect on subsequent mathematical learning. In sum, findings have revealed that students who hold positive attitudes toward mathematics tend to have higher mathematics course grades (e.g., House, 1993) with greater achievement expectancies (e.g., Wong, 1992) and stronger participation in advanced mathematics coursework (e.g., Ma, 2006).

In Ma and Kishor's (1997) meta-analytic review of the relation between attitude and achievement in mathematics, findings showed that the relation between attitude toward mathematics and achievement in mathematics is similar for both males and females. Moreover, there were no significant interactions among gender, grade and ethnic background in their attempt to detangle this complex relation. Grade level, however, did emerge as a significant influence. In line with Utley's (2007) argument that students develop an attitude toward mathematics from an early age, Ma and Kishor target junior high school (i.e., 7th and 8th grades), as the time that a student's liking or disliking of mathematics begins to stabilize. As a result, achievement in mathematics can be significantly influenced. This suggests that a negative attitude toward mathematics prior to high school can adversely affect a student's performance in any or all subsequent mathematics courses, and therefore be a major factor in the choice of undertaking advanced courses in both high school and college.

Within studies that focus on students' self-perceptions of mathematics, a number of instruments have been employed (e.g., direct observation, interviews, questionnaires) to assess various affective variables as they relate to students' mathematics achievement. These variables include motivation (e.g., Marat, 2005), self-efficacy (e.g., Lopez, Lent, Brown, & Gore, 1997), and attributes for success (House, 2006) to name just a few. What is lacking, however, is a focus on how certain affective variables relate to a *specific* mathematical content area (e.g., "I like geometry.") because students are likely to vary in both their self-perceptions as well as their performance in one area of math (e.g., algebra) versus another (e.g., geometry). Aside from the development of a few scales, such as the Utley Geometry Attitude Scale (Utley, 2007), which has yet to be tested with school-age students, there seems to be little effort to minimize this gap.

The need to explore a relation between students' self-perceptions and performance in geometry is clear as evidenced in a study (Corbishley & Truxaw, 2010) regarding the mathematical readiness of entering college freshmen. Findings revealed that university faculty members perceive average freshman students as mathematically unprepared, partly in the area of geometry. For instance, mean skill levels were found to be poor to adequate for finding the area of two-dimensional objects and from very poor to poor for three-dimensional analysis — skills that should be mastered at the middle school and high school levels respectively (National Council of Teachers of Mathematics, 2000). It is reasonable to speculate that prior to college, these students, and well likely others, may not have felt particularly strong about mathematics and their mathematical abilities. In corroborations with this view, there is a growing need to nurture students' interest and performance in geometry given the continual lack of preparation in the US for careers that tend to be very much rooted in geometric and spatial-type thinking (Armstrong, 2003; National Science Board, 2009), otherwise known as STEM (science, technology, engineering and mathematics).

1.3. Significance and purpose of the study

The current study draws attention to the significance of spatial ability as it relates to students' self-perceptions of their performance in geometry, a fundamental subject area that is intimately tied to many STEM fields. However, geometry tends to be a weaker content domain among US students (e.g., Gonzales et al., 2009), which may partly explain why the US is lagging with respect to conferred degrees in STEM compared to other countries (Bharucha, 2008; Hughes, 2009). By nurturing students' spatial ability from an early age, it is possible that with extended and deliberate practice (Ericsson et al., 2005), "high-space" individuals may be more apt to capitalize on their intellectual strengths with a greater appreciation for math–science expertise throughout their education (Webb, Lubinski, & Benbow, 2007). This effort lends support toward modifying educational curricula for spatially talented students who can potentially help meet the growing demand of STEM fields in the US.

To date, it seems that researchers have made few attempts to simultaneously investigate both cognitive and affective influences on

Please cite this article as: Weckbacher, L.M., & Okamoto, Y., Mental rotation ability in relation to self-perceptions of high school geometry, *Learning and Individual Differences* (2013), http://dx.doi.org/10.1016/j.lindif.2013.10.007

US students' geometry achievement. The purpose of the current study was to integrate these two lines of research by exploring a possible link between strength in spatial ability (in this context, mental rotation) and students' self-perceptions of geometry. Conceptually speaking, we defined self-perceptions as the degree to which a person likes geometry as well as the ability to do well in the subject.

Along with students' self-reports on whether they like and/or do well in geometry, data analyses included examining the relation between mental rotation ability and achievement in both geometry and algebra, which adds a new direction to this area of inquiry. We attempted, therefore, to specifically address the following research questions:

1. How are mental rotation ability, geometry achievement and algebra achievement related?
2. How do differences in mental rotation ability relate to students' self-perceptions of geometry?

2. Method

2.1. Participants

One hundred and thirteen 10th–12th grade students (57 males, 56 females) from a private high school in northeastern Pennsylvania participated in the study. The school is located in an urban area that predominantly consisted of a middle-class European-American population. Based upon the demographics of the school's population, all of the students who participated spoke fluent English. The mean age of the total sample was 16.98 years ($SD = .74$); for males and females, their mean ages were 17.01 ($SD = .76$) years and 16.95 ($SD = .73$) years respectively.

2.2. Measures

As a group administration by grade, each participant completed Vandenberg and Kuse's (1978) Mental Rotations Test (MRT). The full-scale version of this test involves two parts (10 items each part). For the present study, only Part 1 (10 items) was used due to time limitations. Each item is a three-dimensional configuration of 10 blocks. The goal is to determine a match between a primary configuration of blocks and two of four configurations rotated in different positions. In terms of scoring, two credits are awarded if the two items chosen are correct, or one credit if only one item is chosen and correct. To control for guessing, no credit is awarded if two items are chosen but only one is correct. The total time for completion is 5 min. Vandenberg and Kuse reported that the Kuder–Richardson 20 coefficient was .88. In the current study, the Cronbach's alpha was .72.

A questionnaire on cognitive learning style and self-assessment in mathematics adapted from the Santa Barbara Learning Style Questionnaire (Mayer & Massa, 2003) was also completed. Of the 23 items, four were included in the present analysis (“I like geometry.” “I do well in geometry.” “I like algebra.” “I do well in algebra.”). The questionnaire's format consisted of a Likert-type scale (6 = strongly agree and 1 = strongly disagree).

While a good deal of research has shown that spatial ability (particularly mental rotation) and geometry are well linked (e.g., Battista et al., 1982; Delgado & Prieto, 2004; McGee, 1979), the spatial aspects of students' mathematical thinking have been less linked to algebra (e.g., Kinach, 2012; Tolar & Lederberg, 2009). The participants' grades (each out of 100) in geometry and algebra thus served as a basis for comparing performance in two mathematical content areas that tend to differ with respect to spatial ability. The Figural Geometry Measure (FGM), developed from the National Assessment of Educational Progress' item pool (U. S. Department of Education, 2006), also served as index of geometry achievement. The FGM consisted of 20 questions. Each question required the use of figural information in either a narrative or graphical format to solve a given problem. Question format was either a multiple choice or short-constructed response totaling a possible 20 points with one point awarded for each correct answer. Total time for completion was not to exceed 30 min. The Cronbach's alpha for the FGM was .69.

The measures were administered in the following order: (1) MRT, (2) the adapted Santa Barbara Learning Style Questionnaire (Mayer & Massa, 2003), and (3) the FGM. The FGM was administered last considering that problem-solving performance on this measure could potentially impact the participants' responses to liking and doing well in geometry. All data were collected over the course of three school days, and students were welcomed to contact the principal investigator regarding the results of their individual and class performance shortly thereafter.

3. Results

Respective means and standard deviations for all variables appear in Table 1. At a descriptive level, it can be seen that for the total sample, geometry grades ($M = 88.57$) tended to be slightly lower than algebra grades ($M = 89.13$). Students were more apt to agree that they do well in geometry ($M = 4.19$) and algebra ($M = 4.56$) than liking either subject area respectively ($M = 3.74$, $M = 4.13$). Across all variables, mean performance and questionnaire responses favored males indicating that not only were males ($M = 12.77$) stronger in mental rotation ability compared to females ($M = 9.54$), but they were also stronger in mathematics achievement overall. Males were also more likely to report liking geometry ($M = 4.11$ for males, $M = 3.38$ for females) and algebra ($M = 4.33$ for males, $M = 3.93$ for females) as well as doing well in geometry ($M = 4.58$ for males, $M = 3.80$ for females) and algebra ($M = 4.82$ for males, $M = 4.29$ for females).

A closer examination of these performance patterns revealed a main effect for gender [$F(8, 103) = 2.98$, $p < .01$]; however, tests of between-subjects effects further revealed that across all variables, significant performance differences only emerged on the MRT [$F(1, 110) = 6.68$, $p < .001$] and self-perceptions in liking [$F(1, 110) = 5.17$, $p < .05$] and doing well in geometry [$F(1, 110) = .6.86$, $p < .01$] all in favor of males.

To determine the relations among mental rotation ability, mathematics achievement, and students' self-perceptions of both geometry

Table 1
Descriptive statistics and gender differences for the Mental Rotations Test, Mathematics Achievement Measures, and Self-Perception Statements for the total sample, males, and females.

Measure	Total sample ($N = 113$)	Males ($n = 57$)	Females ($n = 56$)
MRT (20)[a]			
M (*SD*)	11.17 (4.94)	12.77 (4.56)***	9.54 (4.82)
GEO grades			
M (*SD*)	88.57 (8.43)	90.54 (6.91)**	86.53 (9.39)
ALG grades			
M (*SD*)	89.13 (7.38)	89.61 (6.32)	88.64 (8.35)
FGM (20)[a]			
M (*SD*)	15.19 (2.90)	15.53 (2.83)	14.84 (2.95)
SPS 1 (“*I like geometry.*”)			
M (*SD*)	3.74 (1.80)	4.11 (1.71)*	3.38 (1.83)
SPS 2 (“*I do well in geometry.*”)			
M (*SD*)	4.19 (1.65)	4.58 (1.48)**	3.80 (1.73)
SPS 3 (“*I like algebra.*”)			
M (*SD*)	4.13 (1.66)	4.33 (1.56)	3.93 (1.73)
SPS 4 (“*I do well in algebra.*”)			
M (*SD*)	4.56 (1.47)	4.82 (1.26)	4.29 (1.63)

Note. MRT = Mental Rotations Test. GEO = Geometry. ALG = Algebra. FGM = Figural Geometry Measure. SPS = Self-Perception Statement.
[a] Total possible scores are in parentheses after respective measures.
* $p < .05$, two-tailed.
** $p < .01$, two-tailed.
*** $p < .001$, two-tailed.

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and algebra, correlations between all variables were calculated. According to Table 2, geometry grades and algebra grades were significantly and positively correlated ($r = .68$, $p < .001$), along with similar correlations between geometry grades and the FGM ($r = .38$, $p < .001$), and algebra grades and the FGM ($r = .35$, $p < .001$). Performance on the MRT was significantly and positively correlated with geometry grades ($r = .24$, $p < .05$) and the FGM ($r = .26$, $p < .01$) but not algebra grades ($r = .13$, $p = .18$). No significant relations emerged between the MRT and students' self-perceptions of liking geometry ($r = .14$, $p = .15$) or algebra ($r = .10$, $p = .3$). On the other hand, significant positive correlations also emerged between performance on the MRT and students' self-perceptions of doing well in geometry ($r = .27$, $p < .01$) and algebra ($r = .19$, $p < .05$).

4. Discussion

The correlations among students' geometry grades, algebra grades and the standardized geometry measure (i.e., the FGM) suggest that students who do well in geometry are likely to do well in algebra; however, their mental rotation ability seems to bear minimal if any influence on algebra achievement. Consistent with previous findings (e.g., Battista, 1990; Delgado & Prieto, 2004), students with stronger mental rotation ability tended to be stronger in geometry achievement. This same pattern of performance did not hold true for algebra, which is not surprising given that algebraic problem solving, unlike geometry, is far less dependent on the ability to visualize an object or figure and then rotate it accordingly. Battista's (1981) research involving the study of algebraic structures and spatial visualization ability lends support to this finding. Still, continued work to more strongly determine if mental rotation ability might in some way influence different levels of algebraic thinking is in need considering such little research has been conducted in this area.

In general, students with stronger mental rotation ability were more likely to report that they do well in geometry and algebra, yet no relation emerged between strength in this skill and actually liking either subject area. With respect to gender differences, males significantly outperformed females in mental rotation ability as expected (e.g., Battista, 1990; Cherney, 2008; Delgado & Prieto, 2004; Linn & Petersen, 1985). Significant differences in students' self-perceptions of liking and doing well in geometry also favored males; no significant gender differences emerged in liking or doing well in algebra.

The findings of this study are of considerable importance in that if a student dislikes a particular subject area like geometry, then it is unlikely she (or he) may pursue advanced study, nonetheless a related career path that heavily involves the application of this subject's respective content and skills. Given that geometry can be considered a gateway course for advanced mathematical study, strength in spatial ability is one advantage that could help ease the challenge and complexity of more sophisticated mathematical problem solving. Consequently, an enjoyment or positive attitude regarding one's quantitative abilities may well lead to enhanced problem solving performance. For instance, House (2006) reported that students who enjoyed learning mathematics were more likely to earn higher geometry test scores. In contrast, students who said that they would like mathematics much more if it were not so difficult were more likely to show lower geometry test scores. Moreover, students who earned lower geometry test scores were more likely to have felt that mathematics is boring. House's findings, in corroboration with the current findings, might also help to explain why the US has fallen behind other nations in STEM education (Scott, 2012; Thompson & Bolin, 2011). By raising interest and confidence in mathematics and related STEM disciplines, it is possible that as a nation, the US can move toward ensuring a sufficient number of experts in STEM fields (Hossain & Robinson, 2012).

5. Conclusions

As a nation, the US has one of the lowest STEM to non-STEM degree rates in the world (Thompson & Bolin, 2011). In other words, US students are less apt to pursue degrees in science, technology, engineering and mathematics despite talent in these areas (Heilbronner, 2011); students in countries like China and India are earning degrees in STEM fields far more effectively, posing a threat to our nation's global competitiveness (Bharucha, 2008; Hughes, 2009). In China, for instance, a large proportion of top students choose to enter STEM fields with the requisite preparation prior to entry. Similarly, students in India choose courses relative to a future career path as early as the ninth grade. As a result, these students begin to develop specializations early on. By contrast, the US tends to endorse a more broadly based approach to the education of our youth prior to college. With respect to college major, business majors continue to attract the largest proportion of US students followed by the social sciences, health professions and education respectively. Conferred degrees in engineering, but more so computer and information sciences, continue to lag behind (U. S. Department of Education, 2012).

Reasons pertaining to cross-cultural differences in the pursuit of STEM careers relate to how Asian cultures tend to value science and engineering as status fields, and children with scientific aptitude are steered to follow that path (Bharucha, 2008). In a recent study (Roysircar, Carey, & Koroma, 2010), parents' preferences for science and math, partly due to a sense of prestige, significantly contributed to their children's preferences for science and math, even among parents in non-science occupations. Moreover, these second-generation students were more likely to report that their college majors were in science and math even though they preferred non-science majors. According to the authors, career development is therefore best understood when taking such generational and cultural contexts into account. Other reasons have been well investigated ranging from the belief in one's ability to achieve in STEM (Heilbronner), high school ranking (Thompson & Q3 Bolin), and strength in cognitive capabilities such as spatial thinking Q4 (Wai, Lubinski, & Benbow, 2009).

Table 2
Correlations among the Mental Rotations Test, Mathematics Achievement Measures, and Self-Perception Statements.

Measure	MRT	GEO grades	ALG grades	FGM	SPS 1	SPS 2	SPS 3	SPS 4
MRT	–	.24*	.13	.26**	.14	.27**	.10	.19*
GEO grades		–	.68***	.38***	.32**	.37***	.38***	.36***
ALG grades			–	35***	.24**	30**	.45***	.54***
FGM				–	.30**	35***	35***	.33***
SPS 1 (“*I like geometry.*”)					–	.84***	50***	.38***
SPS 2 (“*I do well in geometry.*”)						–	.46***	.49***
SPS 3 (“*I like algebra.*”)							–	.81***
SPS 4 (“*I do well in algebra.*”)								–

Note. MRT = Mental Rotations Test. ALG = Algebra. GEO = Geometry. FGM = Figural Geometry Measure. SPS = Self-Perception Statement.
* $p < .05$, two-tailed.
** $p < .01$, two-tailed.
*** $p < .001$, two-tailed.

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Though this study only focused on one aspect of spatial thinking (i.e., mental rotation), we acknowledge that others are nonetheless important (e.g., spatial relations, spatial orientation) and widely contribute toward academic and professional pursuits. According to Newcombe (2010), spatial thinking is a key to STEM success. Though we all think spatially in everyday situations, such as reading a map or assembling a household appliance, "spatial thinkers" (meaning those individuals who are exceptionally strong in this type of thinking) are more likely to be interested in science and math, and more likely to pursue degrees in STEM. One of the most frequently asked questions in regard to the relation between spatial thinking and STEM addresses whether or not spatial thinking can be improved, or in the words of Newcombe, "Can we educate children in a way that would maximize their potential in this domain?" (p. 31). Newcombe, in conjunction with a good number of other researchers (e.g., Cherney, 2008; Kail, 1986; National Research Council, 2006), would inarguably respond yes. Research has shown that the impact of relevant experiences involving deliberate practice (Ericsson et al., 2005) can lead to improvements in spatial skills such as mental rotation (Terlecki, Newcombe, & Little, 2008). With improvements in spatial skills, mathematical performance may also improve. This is especially relevant for geometry in which case spatial thinking is more common than in other areas of mathematics. What then does this imply for today's educators in their efforts to help students develop interest and talent in STEM?

Newcombe (2010) proposed that spatial thinking can be fostered with the right kind of instruction and technology. Many questions remain, nonetheless, as to what kinds of teaching best support spatial learning, and if and how these kinds of teaching should vary across age, socioeconomic status and gender. In spite of this, it is safe to say that volumes of research (e.g., National Research Council, 2006) regarding teaching and learning spatial information have helped to establish a basic foundation from which further modifications to existing K-12 curricula can emerge. As Newcombe explained, teachers first need to understand what spatial thinking means. One step is to enhance their pedagogical content knowledge about the role of visual perception (e.g., verbal versus pictorial representations, mental images, and hierarchical structure of images). According to Gal and Linchevski (2010), building teachers' awareness regarding how students differentially process and interpret visual information can help improve their problem solving performance. That is, as teachers are able to identify and analyze a wide range of visual strategies in problem solving situations, they are better equipped to cope with students' difficulties and offer alternative approaches.

Teacher education, for both pre-service and experienced teachers, should also include introducing types of pedagogical activities and materials that support the development of spatial thinking from an early age, and indoctrinate *why* incorporating certain activities and materials into existing curricula should be strongly considered. For instance, puzzles, maps and diagrams are often affordable and accessible tools that can capture student interest and challenge their thinking. In addition, highlighting spatial elements in mathematical lessons, adding map skills and infusing recreational activities (e.g., videogames like Tetris) are also likely to produce gains in both of these respects. Keeping in mind that the development of spatial thinking takes time and commitment, and does not readily transfer from one task or domain to another, the implementation of spatial thinking across educational contexts (not only mathematics) has therefore emerged as a worthy and practical endeavor (National Research Council, 2006). Thus, if spatial thinking becomes a fundamental component of K-12 curricula, increasing availability of learning opportunities to enhance this invaluable skill might very well encourage pursuit of STEM careers.

5.1. Limitations and suggestions for future research

There are a few critical limitations to this study. First, it is possible that responses to "I like geometry." (and even "I like algebra.") may have reflected some students' emotions toward a single teacher and not the subject matter as Van Putten, Howie, and Stols (2010) revealed in interviews with mathematics education students on their attitudes toward geometry. Each of their interviewees expressed the confusion and frustration at having been taught by teachers who neither mastered the subject nor developed a positive attitude toward it. The second limitation pertains to the generalizability of the findings. The school from which the data were collected can be considered small (approximately less than 100 students in a graduating class), and consequently, there was limited exposure to different mathematics teachers at the high school level. Thus, a larger sample of high school students who have been exposed to a variety of teaching styles across multiple institutions would allow for a greater representation of mathematical self-perceptions as well as differences in mathematics achievement. On that note, the use of grades also limits generalizability taking into account that grading systems across high schools can significantly vary. The inclusion of SAT scores was considered; however, scores were not available for a good number of students at the time the study was conducted.

The present study contributes toward a wealth of research in the area of mathematical learning in that unlike other studies, the relation between a *specific* cognitive skill and self-perceptions toward a *specific* subject area in mathematics is examined. Moving forward, we recommend examining if and how other types of spatial thinking (e.g., multistep manipulation of spatial information) are related to students' self-perceptions of geometry given that research has yet to clearly establish the interplay of cognitive variables that are instrumental to successful geometric problem solving. In addition, self-report items that tap into the enjoyment and usefulness of geometry may also help to create a more comprehensive picture of what differentiates students' self-perceptions toward mathematics in general versus a specific content area, geometry for one.

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Please cite this article as: Weckbacher, L.M., & Okamoto, Y., Mental rotation ability in relation to self-perceptions of high school geometry, *Learning and Individual Differences* (2013), http://dx.doi.org/10.1016/j.lindif.2013.10.007

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Please cite this article as: Weckbacher, L.M., & Okamoto, Y., Mental rotation ability in relation to self-perceptions of high school geometry, *Learning and Individual Differences* (2013), http://dx.doi.org/10.1016/j.lindif.2013.10.007