

## **A Qualitative Study Examining the Spatial Ability Phenomenon from the Chinese Student Perspective**

Helen W. Kang, James, L. Mohler, and Soyoung, Choi  
Purdue University, West Lafayette, Indiana

Yuehua Chen and Chunhui Zheng  
Harbin Institute of Technology, Harbin, China

### **Abstract**

The authors used holistic and structured interviews to examine Chinese student perspectives on their own spatial ability. The results of this study were compared and contrast with a previous study that was conducted by Mohler (2008) of Caucasian student perspectives in United States. Findings of the current study agree with other literature that Chinese student spatial ability may be culturally formed. Their background, experiences, and upbringing may contribute to Chinese student development of spatial ability and appear to differ significantly from students in United States. Recommendations and educational implications are discussed in the following contribution.

As an educator in the field of graphics and engineering, Mohler (2008) questioned whether suitable intervention techniques would improve student spatial ability. There is a general agreement that spatial ability involves one's mental operation. Lohman defined spatial ability as being related to one's ability to mentally "generate, manipulate, and retain abstract information and/or images" (1979, p. 188). Spatial ability has been acknowledged to be integral for success not only in engineering graphics but also in architecture, art, design, and the medical field. Thus, early intervention to improve spatial ability for individuals is critical.

There are different opinions regarding whether spatial ability is innate or acquired through experience (El Koussy, 1935). Thurstone (1938) and Piaget and Inhelder (1971) strongly agreed that spatial ability is an innate ability. Nevertheless, numerous studies have argued that spatial ability can be obtained and improved through appropriate motivation, training, and activities (Kang & Mohler, 2010; Lohman, 1993; Sorby, 1999). There are many inconsistencies regarding the effects of practice and training on spatial ability (Kyllonen, Lohman, & Snow, 1984; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990), that is, some individuals still struggle with spatially related tasks even with specifically designed intervention. Also, variances in spatial performance among age, gender, and different ethnicities have emerged throughout these studies (Demetrious, Kui, Spanoudis, Christou, Kyriakides, & Platsidou, 2005; Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006; Silverman, Choi, & Peters, 2007).

Mohler (2008) noted that many studies focused only on developing specific training methods to enhance one's spatial ability even if one does not benefit from it. No one has considered the effect of an individual's perspective and experiences that may contribute to spatial ability using a qualitative method until recently (Mohler, 2008). The current study examined the perspective of Chinese students regarding their own spatial ability. Furthermore, a qualitative approach to the current study provided unique information regarding cultural experiences that may influence the Chinese student's spatial performance compared with students in the United States.

### **Relevant Literature**

Individual differences in spatial ability have been studied by a number of researchers. Differences in age, gender, and strategies that are used to solve spatial problems have been more widely studied. There has been a recent interest in examining the spatial ability between different racial ethnicities (Demetrious, Kui, Spanoudis, Christou, Kyriakides, & Platsidou, 2005; Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006; Silverman, Choi, & Peters, 2007). For instance, Silverman, Choi, and Peters (2007) compared the difference in spatial ability performance over 40 countries and Demetrious and others (2005) compared the performance of over 3,000 participants with various ethnicities. These studies have attempted to unlock the secret of why one race was able to outperform others in spatial tasks.

One of the reasons behind the latest interests could be due to the variances of academic success that have been displayed among racial ethnicities in the learning environment. General academic success is assumed to be closely correlated with spatial ability. Over the years many studies acknowledged that student mathematics achievement is highly correlated with spatial ability (Kang & Mohler, 2010). Specifically, student scores on the visualization factor of spatial ability appear to be associated with their ability to learn geometry (Kang & Mohler, 2010). Therefore, studies have examined the spatial ability phenomenon among ethnic races in an effort to identify the reasons behind the academic success in mathematics.

It has been acknowledged that many East Asians (Japanese, Chinese, Korean, and Thai for example) tend to outperform Caucasians in mathematics. Some researchers claimed that the Asians' performance and achievement in mathematics could be attributed to the method of mathematics teaching and curricula that are outlined within their country's educational policies (Geary, Salthouse, Chen, & Fan, 1996; Wang & Lin, 2005). This is reasonably credible because studies have acknowledged the vigorous nature of content coverage, instructional requirements, and structures that were demonstrated in East Asian countries. However, educators have criticized this aspect of teaching by indicating that these students may be able to perform the arithmetic (which includes skills in addition, subtraction, multiplication, and division) but they lack reasoning capabilities (Wang & Lin, 2005).

Other studies have speculated that Chinese student success in mathematics appears to begin even before they enter kindergarten and, consequently, performance differences between Chinese and Caucasians escalate as both groups move through their formal schooling (Huntsinger, Jose, Larson, Krieg, & Shaligram, 2000; Wang & Lin, 2005). East Asian teaching techniques, student self-expectation, and family involvement in their children's education have been acknowledged as factors contributing to these differences.

However, one of the more interesting factors that studies have depicted was that Chinese student mathematic ability is greatly influenced by the Chinese language itself (Li, Nuttall, & Zhao, 1999; Stevenson & Stigler, 1992). As indicated earlier, spatial ability plays a crucial role in student understanding of mathematics. Spatial ability also appears to be highly correlated with their performance in geometry. Respectively, Chinese students outperform Caucasians by at least 15 points in spatially related tasks (Jensen, 1998), a trend that has been exhibited in numerous other studies as well (Demetrious, Kui, Spanoudis, Christou, Kyriakides, & Platsidou, 2005; Peters, Lehmann, Takahira, Takeuchi, & Jordan, 2006; Silverman, Choi, & Peters, 2007). Studies assert that not only does Chinese language appear to convey mathematical concepts better than English, the ability to read and write Chinese characters also may play a fundamental role in the development of spatial ability (Demetrious, Kui, Spanoudis, Christou, Kyriakides, & Platsidou, 2005). Hence, persons who can read and write Chinese could have a higher spatial ability, which can lead to a better success rate in mathematics.

Researchers claimed that Chinese speakers use the visuo-premotor part of the brain to process mathematical information. Thus, when a Chinese speaker is given a mathematical problem, the information that is written in Chinese characters is decoded and processed as a shape and converted as non-language contents (Tang, et al., 2006). When Chinese linguistics was further investigated, the Chinese characters appear to be constructed based on meaning rather than phonology (Ho & Bryant, 1999). Also, Chinese usually is written without spaces; most words are formed by two or more characters (Bai, Yan, Zang, Liversedge, & Rayner, 2008). Therefore, significant spatial and visual-orthographic awareness is needed by the reader as Chinese does not have spaces and contains "high visual complexity" (Tang, et al., 2006, p. 8781). Furthermore, the Chinese numeral is constructed based on the ten numbering system, which may assist learners with counting and arithmetic skills (Wang & Lin, 2005). These reports were also supported when native Chinese students and Chinese-American students performed mental rotation tasks (Li, Nuttall, & Zhao, 1999). This particular study concluded that those students who were able to read and write Chinese scored significantly higher in the mathematics portion of the SAT and mental rotation tasks than those students who could not read or write the language.

The literature has indicated various factors that may be attributed to Chinese student spatial ability. The current study conducted interviews as a primary method to determine whether Chinese student perspectives on spatial ability are culturally formed. The

particular areas of Chinese student experiences and background were observed. Moreover, the previous study conducted by Mohler (2008), which examined the perspective of high and low spatial performers in the United States, was compared with Chinese participants of the current study.

### **Significance**

As stated by Mohler (2008), quantitative research has been widely used to measure the unique nature of spatial ability among individuals. However, there has been little research conducted in order to understand why some participants succeed or fail in performing spatially related tasks. The performance differences that were demonstrated among different racial ethnicities are even more difficult to answer. Literature indicates that this difference in spatial ability may be cultural in nature and questioned whether spatial ability is culturally formed (Silverman, Choi, & Peters, 2007; Tang, et al., 2006; Wang & Lin, 2005). Studies suggested that qualitative research may be the key to discovering how spatial ability is culturally formed. Examining participant background, experiences, and environmental factors may explain this particular phenomenon (Demetrious, Kui, Spanoudis, Christou, Kyriakides, & Platsidou, 2005; Silverman, Choi, & Peters, 2007; Wang & Lin, 2005).

### **Purpose**

Mohler (2008) conducted a research study in efforts to answer the question: "What was it like for a student to experience the spatial ability phenomenon?" He analyzed the background, life experiences, and perspectives of typical engineering students in the United States who performed at varying levels in spatial tasks. The purpose this present study was to compare and contrast Mohler's (2008) study and pose the same research question relative to Chinese students. The study examined whether there are differences in Chinese student perspectives toward the spatial ability phenomenon due to dissimilarity in culture, life experiences, and upbringing.

### **Methodology**

The sample for this study was selected from students in Media Technology who were enrolled in *Spatial Ability – Research & Assessment*, a course held during the fall semester of 2009 at Harbin Institute of Technology in China. The participants were graduate students who were in their third and fourth semesters of their master's degree. The major concentration of this group of students varied from 3D modeling and animation to visual effects and multimedia.

As suggested by Mohler (2008) and Patton (2002), a qualitative study and design can be used to investigate the spatial ability phenomenon of individuals in extreme and unusual cases. For this reason and also to replicate Mohler's study, Chinese participants ( $n = 35$ ) were given the Vandenberg Mental Rotation Test (1971) as an in-class activity. The Vandenberg Mental Rotation Test has been acknowledged as a

reliable instrument to measure spatial ability due to its validity and convenience. Specifically, when the test and retest of the Vandenberg Mental Rotation Test was performed, Vandenberg and Kuse (1978) reported the reliability value of .83. Once the tests were scored ( $M = 12.31$ ,  $SD = 5.41$ ), those students who scored high (3.5 standard deviation units above the mean) and low (3.5 standard deviation units below the mean) on this test were selected as extremes among individuals.

There have been varying opinions concerning the number of participants that are required for single case qualitative studies. Mohler (2008) interviewed 12 students, but the numbers of participants can range from three to 10 participants when one is trying to understand subject experiences and background (Creswell, 1998). In an effort to meet the high end of participant numbers suggested by various studies, eight subjects participated in the study for in-depth interviews.

### **Data Collection**

Scores for the Vandenberg Mental Rotation Test were rated to depict students with the high and low spatial ability. Four students who scored high and four students who scored low in MRT were selected and they participated in approximately 90-minute interviews in English. Due to the language barrier among participants, some of the interviews lasted under 90 minutes. As suggested by Mohler, interviews were divided into two subsections. The first part of the interview was designed to understand background and experiences that might have affected participant perspectives on spatial ability. The second part of the interview consisted of a summative activity in which participants reflected on their development of spatial ability through their daily activities. The interviews were administered with pre-determined questions for consistency. Interview questions were developed based on the findings of Mohler (2008) to facilitate a comparative analysis between Mohler (2008) and this current study. All interviews were audio-recorded.

### **Data Analysis**

The researchers followed the coding procedures of Mohler (2008). In Mohler's (2008) study, he used three procedural steps of bracketing, intuiting, and describing as a method of analysis. This particular method of analysis procedure was also suggested by Giorgi (1985 & 1997). A similar approach was used in the present study. Bracketing sets aside presupposition and examines overall textual descriptions within the data. Intuiting requires the development of meaning units that are used to summarize sections of the textual description. Describing is the process of creating a structural description of the meaning units (Giorgi, 1985).

Interviews were transcribed without pre-determined coding scheme to identify participants' background and experiences that might have affected perspectives on spatial ability. Any identified codes were used as an evolving lens to reread the data and the patterns emerging across students were explored. Based on this preliminary

analysis, coding scheme of students' background and experiences was developed, tested and revised by several rounds of analysis. A comparative analysis was conducted to find similarity and differences in background and experiences between low and high Chinese participants and also with participants studied by Mohler (2008). To triangulate data analysis and ensure consistency in coding, the researchers participated in coding a subset of data.

### **Invariant Themes**

Based on the interviews with Chinese participants, researchers were able draw out five specific themes related to the participant perspectives on spatial ability development. Comparable themes also appeared in Mohler's (2008) study which included childhood toys, musical experiences, favorite school subjects, parental involvement, and feelings. The following section is divided into these themes to discuss the findings in further detail.

#### **Childhood Toys**

Some effective spatial ability interventions include using animated visuals and/or providing physical hands-on activities such as Lincoln Logs, Tinker Toys, and Legos (Anglin, Towers, & Moore, 1997; Pak, 2001). These tools have emerged because many studies claimed that spatial ability is not an innate ability but one that can be nurtured by the right tools and experiences. Specifically, Thurstone (1938) and Piaget and Inhelder (1971) strongly agreed that spatial ability is an intelligence that is presented at birth. Nevertheless, numerous studies have argued that spatial ability can be developed and improved through appropriate motivation, training, and activities (Alderton, 1989; Lohman, 1993).

Mohler (2008) reported in his study that both high and low spatial performers acknowledged playing or having access to Legos. Both high and low spatial Chinese participants of the current study indicated that they also had access to Legos (they referred to Lego as *Jimoo* in Chinese) or different types of building blocks. Interestingly, low spatial participants indicated that they rarely played with these particular toys. See Table 1 for more details regarding the differences between high and low spatial Chinese participants of the current study and Mohler (2008).

#### **Musical Experience**

Over the last 30 years, psychological music researchers have reported that individuals with musical experiences performed significantly higher in spatial cognition tasks (Mohler, 2008; Tai, 2010). Studies also indicated that musical involvement had a positive association with other cognitive abilities, such as in mathematical and verbal tasks. Also, formal exposure to music during childhood has a small but positive impact on student IQ and academic performance (Schellenberg, 2006). Consequently, the

current study interviewed Chinese students to see whether participant musical experiences had influenced their perspectives on spatial ability.

Table 1.  
*Comparison between Mohler (2008) and the Current Study*

Themes	Current Study (2010)	Mohler (2008)
Childhood Toys	Low participants rarely played with Legos & Building Blocks.	Both High and Low Participants played and had access to Legos.
Musical Experience	Did not indicate any association between musical experiences and spatial ability.	Indicated visualizing music by hearing musical notes in mind and play by the ears.
Favorite School Subjects	High participants: Mathematics Low participants: Reading and Writing	High participants: Mathematics Low participants: Reading and Writing
Feelings	All participants showed frustration, confusion and intimation	
Parents Involvement (New Emerged Theme in the Current Study)	Great parental involvement for high participants in academic achievement. (Possibly due to parents' educational background and occupations.)	

\*Highlighted: themes that indicated possible association with spatial ability

Almost all of the Chinese participants had some type of musical experiences. Both high and low spatial performers had various musical lessons (e.g., violin, harp, piano, guitar, and Chinese flute), and indicated that these lessons started at a very young age (two to four years of age). Only one of the high spatial participants was still playing an instrument and was a member of band. Other remaining low and high spatial performers reported that they quit playing instruments after several years of lessons. Also, these participants did not report any association between musical experiences and spatial ability, what Mohler described as “visualize music by hearing the musical note in mind and play by the ear” (p.6, 2008), in their short musical experiences.

### Favorite School Subjects

Numerous studies stated that students with higher spatial ability also perform significantly better in mathematics than students with low spatial ability. Studies also indicated that person who can read and write Chinese have demonstrated greater performance in spatial tasks (Demetrious, Kui, Spanoudis, Christou, Kyriakides, & Platsidou, 2005; Li, Nuttall, & Zhao, 1999; Stevenson & Stigler, 1992). Therefore, researchers presumed that Chinese students with high spatial ability might indicate their favorite school subject as reading or writing Chinese. Surprisingly, high spatial ability participants reported that their favorite subject was mathematics and believed themselves to be strong in the subject. The low spatial ability participants indicated their

preference toward reading and writing as their favorite subjects. The participants stated that they found mathematics rather difficult and uninteresting. This result was also shown in Mohler's high and low spatial participants.

### **Parental Involvement**

One of the factors that might be attributed to Chinese students' success in mathematics and spatial ability could be parental involvement in their children's education (Wang & Lin, 2005). Many studies concluded that parental support for Chinese students is stronger than parental support for students in the United States. Chinese parents usually set up more structured time frames to assist their children's instruction after formal schooling. Furthermore, Chinese parents set higher goals for their children to succeed in mathematics. These efforts appear to play a leading role in Chinese students' higher achievement in mathematics (Wang & Lin, 2005).

Therefore, it was not unexpected to discover much more of parental involvement for Chinese participants with higher spatial ability. When high spatial participant backgrounds were further analyzed, the current study revealed that parental occupations were things such as engineer, professor, accountant, and teacher (i.e., white collar workers). The parents of low spatial performers were farmers, policemen, and workers at the local factory (i.e., blue collar workers). This is a new theme that emerged from the current study of Chinese students and their perspectives of spatial ability compared to Mohler's previous (2008) study.

### **Feelings**

Mohler (2008) stated that almost all of his participants showed some level of frustration, confusion, and intimidation when they were given spatial tasks. He also concluded that the level of these feelings might obstruct participant ability to solve problems. A majority of Chinese participants stated that they also felt less confident about their spatial ability. Only two of the high spatial participants indicated that they were strong spatial performers. Most participants felt frustrated and intimidated while taking the Vandenberg Mental Rotation Test.

Studies have specified that even though Chinese students felt less confident about their ability and skills, they do substantially better in mathematics and spatially related tasks than students in the United States. Perhaps one of the reasons behind their increased performance in mathematics or in other cognitive tasks could be because Chinese students devote more time and effort to their learning. A significant number of East Asian students view their academic success and failure on their own and they take personal responsibility for success or failure. When Chinese students feel less sure of their skills, they drive themselves to achieve better scores by devoting more time and effort to the subject matters. Therefore, this perspective could motivate Chinese students to attain higher achievement rather than hinder their performance in the area in which they lack confidence. Even though Chinese participants felt intimidated and



frustrated with the spatial problems, the feeling may motivate them to do better on the task (Wang & Lin, 2005).

## **Conclusions**

There have been countless efforts to enhance student spatial ability. Many interventions have been developed and tested to measure their effectiveness. However, these interventions have not worked wholly with all groups and people. Spatial ability is necessary to perform any job at an adequate level. Approximately half the adult population has difficulty with spatial ability, and researchers have found that a lack of spatial skill has hindered adult career progression (Maccoby & Jacklin, 1974; McGee, 1979). The purpose of current study was to investigate Chinese student background and experiences and how these factors might contribute to student spatial ability. Studies revealed that Chinese students usually outperform students in the United States in mathematics. Also, spatial performance of Chinese students, which is associated with success in mathematics, is higher than spatial performance of Caucasian students in the United States. Thus, the findings of the study may allow educators to examine and develop appropriate methods to nurture student spatial ability. Furthermore, researchers may be able to apply these methods to students in United States and perhaps influence their choice of future careers.

The current study revealed that both high and low spatial performers had access to Legos and building blocks that provided physical hands-on activities. However, low spatial participants spent more time playing with friends than participating in hands-on activities. The researchers also found it interesting that even though the majority of participants were females, they were provided Legos and buildings blocks as childhood toys. Specifically, one of the participants in high spatial group said:

“Yes, I played with Jimmo (indicating Legos in Chinese). I think everyone had one when they were little to aum... building. Build tall building and then aum... break.”

It was suggested that there are differences in spatial ability between genders because males were nurtured with these types of toys when they were young and females were not. Legos and building blocks have been recognized as toys that facilitate spatial ability, but females are usually given dolls and stuffed animals. Researchers speculated that because of the Chinese one-child policy, the parents may have wanted to provide their child with a variety of toys regardless of their child's gender.

Consistent with the literature, musical experiences during childhood also assist in developing spatial ability. Even though most participants had musical experiences that ranged from playing instruments to formal training in voice, they did not associate musical experiences as a factor that may have attributed to their spatial ability. This claim may be due to the fact that the majority of students had a very short musical experience. Studies claimed that Chinese students spent more time studying to improve

their performance in general academics. For example, students are encouraged to set a specific time frame after school to study mathematics rather than participate in extracurricular activities such as music (Wang & Lin, 2005).

Chinese parents usually join their child when they are studying after school in order to provide additional support. Parental involvement in Chinese student learning is much stronger than parental involvement in the United States. These additional efforts appear to play a leading role in higher achievement of Chinese students in school. High spatial Chinese participants' parents were more involved in their studies, perhaps, because the parents were white collar workers (e.g., teacher, professor, and engineer) who may themselves be highly educated or who understand the importance in obtaining formal education.

Because of the correlation between spatial ability and mathematics, it was not surprising to find that high Chinese spatial performers indicated mathematics as their favorite subject. Literature claims that students who can read and write Chinese may have a higher spatial ability because Chinese linguistics are formed with high visual complexity. However, none of the participants stated that Chinese reading and writing were their favorite subjects. Especially low spatial participants felt that mathematics were very difficult for them to comprehend. On contrary, when the same question was asked to high spatial participants, all participants indicated mathematics as their favorite subject. Especially, one of the participants said:

“Mathematics have multiple parts, I really liked geometry, but not numbers...I liked theories, problems, lines and drawings in geometry.”

A lack of confidence in the subject also emerged when the researchers asked the participants how they viewed their own spatial ability. Almost all participants voiced confusion, intimidation, and uncertainty. Studies indicated that these feelings may actually help the Chinese student performance. When the Chinese students recognize their weakness in an area, they are more likely to put extra time and effort to improve their skills. Therefore, it would be interesting to perform a longitudinal study to observe the Chinese student performance for a longer period of time with suitable support and guides from the educator to see if these feelings subside.

The background, experience, and upbringing of Chinese students are significantly different due to culture. The current study provides valuable information that educators and parents may use to develop and nurture spatial ability of students in the United States. It appears that the Chinese student perspective on spatial ability and their performance may indeed be culturally formed. With the use of qualitative research methods, this study found that early intervention is a key to success in spatial ability. First, it is important to understand the spatial phenomenon of an individual. Second, as educators or parents, it is necessary to provide a variety of toys to a child, encourage participation in musical experiences, and be involved in the child's learning process.

Lastly, the current study concludes that these steps may benefit every individual; it is not limited to whether the student is Chinese, Caucasian, or another ethnicity.

### References

- Alderton, D. L. (1989, March). *The fleeting nature of sex differences in spatial ability*. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.
- Anglin, G. J., Towers, R. L., & Moore, K. C. (1997). The effect of dynamic and static visuals on the recall and comprehension of information using computer-based instruction. *Journal of Visual Literacy*, 17(2), 25-37. Retrieved from <http://www.ohio.edu/visualliteracy>
- Bai, X., Yan, G., Zang, C., Liversedge, S. P., & Rayner, K. (2008, October). Reading spaced and unspaced Chinese text: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, 34(5), 1277-1287. doi:10.1037/0096-1523.34.5.1277
- Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage Publications.
- Demetrious, A., Kui, Z. X., Spanoudis, G., Christou, C., Kyriakides, L., & Platsidou, M. (2005). The architecture, dynamics, and development of mental procession: Greek, Chinese or Universal? *Intelligence*, 33(2) 109-141. doi: 10.1016/j.intell.2004.10.003
- El Koussy, A. A. H. (1935). The visual perception of space. *British Journal of Psychology*, 20, 1-80.
- Geary, D. C., Salthouse, T. A., Chen, G.-P., & Fan, L. (1996). Are east Asian versus American differences in arithmetical ability a recent phenomenon? *Developmental Psychology*, 32(2), 254-262.
- Giorgi, A. (1997). The theory, practice and evaluation of the phenomenological methods as a qualitative research procedure. *Journal of Phenomenological Psychology*, 28, 235-260.
- Giorgi, A. (Ed.). (1985). *Phenomenology and psychological research*. Pittsburgh, PA: Duquesne University Press.
- Ho, C. S.-H., & Bryant, P. (1999). Different visual skills are important in learning to read English and Chinese. *Educational and Child Psychology*, 16(4), 4-14.
- Huntsinger, C. S., Jose, P. E., Larson, S. L., Krieg, D. B., & Shaligram, C. (2000). Mathematics, vocabulary, and reading development in Chinese American and

- European American children over the primary school years. *Journal of Educational psychology*, 92(4), 45-760. doi: 10.1037/0022-0663.92.4.745
- Jensen, A. R. (1998). *The G factor: The science of mental ability*. New York: Praeger.
- Kang, H. W., & Mohler, J. L. (2010) (In review). The effectiveness of spatial visualization training for students with and without Attention Deficit Hyperactivity Disorder (ADHD). *Journal of Special Education Technology*
- Kyllonen, P. C., Lohman, D. F., & Snow, R. E. (1984). Effects of aptitudes, strategy training, and task facets on spatial task performance. *Journal of Psychology*, 76(1), 130-145. doi:10.1037/0022-0663.76.1.130
- Li, C., Nuttall, R. L., & Zhao, S. (1999). The effect of writing Chinese characters on success on the water-level task. *Journal of Cross-Cultural Psychology*, 30(1), 91-105. doi: 10.1177/0022022199030001005
- Lohman, D. F. (1979). *Spatial ability: A review and reanalysis of the correlational literature* (Technical Report No. 8). Arlington, VA: Office of Naval Research.
- Lohman, D. F. (1993). *Spatial ability and G*. Paper presented at the first Spearman Seminar, University of Plymouth.
- Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences*. Stanford, CA: Stanford University Press.
- McGee, M. G. (1979b). *Human spatial abilities: Sources of sex differences*. New York: Praeger Publishers.
- Mitchell, C. E., & Burton, G. M. (1984). Developing spatial ability in young children. *School Science and Mathematics*, 84(5), 395-405. doi: 10.1111/j.1949-8594.1984.tb09567.x
- Mohler, J. L. (2008). Examining the spatial ability phenomenon from the student's perspective. *Engineering Design Graphics Journal*, 72(3), 1-15.
- Morse, J. M. (1994). Designing funded qualitative research. In N.K. Denzin & T.S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 220-235). Thousand Oaks, CA: Sage
- Pak, R. (2001, October). A further examination of the influence of spatial abilities on computer task performance in younger and older adults (pp. 1551-1555). *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, Minneapolis, MN.
- Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

- Peters, M., Lehmann, W., Takahira, S., Takeuchi, Y., & Jordan, K. (2006). Mental rotation test performance in four cross-cultural samples (n = 3367): Overall sex differences and the role of academic program in performance. *Cortex*, 42(7), 1005-1014. doi:10.1016/S0010-9452(08)70206-5
- Piaget, J., & Inhelder, B. (1971). *Mental Imagery in the child*. New York: Basic Books, Inc.
- Salthouse, T. A., Babcock, R. L., Mitchell, D. R. D., Palmon, R., & Skovronek, E. (1990). Sources of individual differences in spatial visualization ability. *Intelligence*, 14, 187-230. doi:10.1016/0160-2896(90)90004-D
- Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, 98(2), 457-468. doi: 10.1037/0022-0663.98.2.457
- Silverman, I., Choi, J., & Peters, M. (2007). The hunter-gatherer theory of sex differences in spatial abilities: Data from 40 countries. *Archives of Sexual Behavior*, 36(2), 261-268. doi: 10.1007/s10508-006-9168-6
- Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal*, 63(2), 21-32.
- Stevenson, H. W., & Stigler, J. W. (1992). *The learning gap: Why our schools are failing and what we can learn from Japanese and Chinese education*. New York: Summit.
- Tai, T. C. (2010). The effect of violin, keyboard, and singing instruction on the spatial ability and music aptitude of young children. *Dissertation*. University of Maryland, College Park.
- Tang, Y., Zhang, W., Chen, K., Feng, S., Ji, Y., Shen, J., et al. (2006, July 11). Arithmetic processing in the brain shaped by cultures. *Proceedings of the National Academy of Science*, 103(28), 10775-10780. doi: 10.1073/pnas.0604416103
- Thurstone, L. L. (1938). Primary mental abilities. *Psychometric Monographs*, No. 1.
- Vandenberg, S. G. (1971). *The Mental Rotations Test*. Boulder: University of Colorado.
- Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, 47, 599-604.
- Wang, J., & Lin, E. (2005). Comparative studies on U.S. and Chinese mathematics learning and the implications for standards-based mathematics teaching reform. *Educational Researcher*, 34(5), 3-13. doi: 10.3102/0013189X034005003

---

## About the Authors

**Helen W. Kang** is a post-doctoral researcher in the Department of Computer Graphics Technology at Purdue University, West Lafayette, Indiana.  
Email: kangwy@purdue.edu

**James, L. Mohler** is Associate Department Head and Professor in the Department of Computer Graphics Technology at Purdue University, West Lafayette, Indiana.  
Email: jlmohler@purdue.edu

**Soyoung, Choi** is a doctoral candidate in the Department of Curriculum and Instruction at Purdue University, West Lafayette, Indiana.  
Email: choi90@purdue.edu

**Yuehua Chen** is Associate Department Head and Professor in the Department of New Media Technology and Arts at Harbin Institute of Technology, Harbin, Heilongjiang Province, China.  
Email: cyh@hit.edu

**Chunhui Zheng** is an engineer in the Department of New Media Technology and Arts at Harbin Institute of Technology, Harbin, Heilongjiang Province, China.  
Email: zch2u@yahoo.com