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Preservice Secondary Education Majors and Visual-Spatial Perception: An Important Cognitive Aptitude in the Teaching of Science and Mathematics

Thomas Lord and Melinda Holland

Department of Biology, 114 Weyandt Hall, Indiana University of Pennsylvania, Indiana, Pennsylvania 15705-1090, USA

The ability to picture words or images in your mind, then manipulate the vision while maintaining the icon in your thoughts, is known as visual-spatial aptitude. Everyone has some ability to do this, but research has found that some people are much better at it than others. For example, if you were asked how many passageways between rooms in your home or apartment had no hinged or sliding door with them, you would probably form a mental image of your residence and count the number of doorless passageways between rooms. Most people have at least two or three in their residences (e.g., between a dining room and a living room). When this question was asked of students in a large-group life science class at a mid-sized eastern university before the week-long spring vacation, the students all gave an answer they thought was correct. Over 40% of the 94 students returned after visiting home during the vacation to report they were wrong on the answer they had given before they left. Interestingly, nearly three times as many women had erred on the question than men.

Do men always do better than women in spatial exercises? The majority of studies performed over the last few decades suggest that they do (Burns & Reynolds, 1988; Gallagher & Johnson, 1992). Not all studies, however, agree that men are better than women in spatial thinking. Research by Richmond (1980), Lord (1987), and Howe and Doody (1989) found there was no difference between the sexes in spatial aptitude. In fact, a few studies even found that many women are higher in spatial ability than men. Bodner and McMillen (1986) found that female students scored significantly better on chemistry problems that involved visual-spatial thinking than the male students did.

Recently, a review of the literature on the gender-spatial perception question (Sanders, 1995) revealed that about a third of all studies that were concerned about the topic did not find a significant gender difference in spatial discrimination. Linn and Peterson (1985) argued that, in most of the investigations where gender differences were observed, the researchers had not controlled for experimental biases in the investigation which dramatically influenced the outcome.

Research also reveals that people with good visual-spatial skills tend to migrate toward specific occupations while individuals with poor visual-spatial skills tend to avoid those same careers (Keen, Fredman, & Rockford, 1988; Millroy, 1985; Rockford, Fairall, Irving, & Hurly, 1989; Smith, 1964). Bishop (1978) found that diagnosing problems in an automobile required an extremely high level of spatial thinking. The auto mechanic must be able to "evaluate the varied sounds of the engine and 'visualize' the relationship of the sounds with the correct workings of the car" (Bishop, 1978, p. 21). Artists, sculptors, and drafters think in a similar fashion when they create their masterpieces. The other areas that attract people with high spatial ability are the mathematics- and science-related disciplines (Mitchelmore, 1980; Siemonkowski & MacKnight, 1971). Engineers visualize structures before they draft them, and organic chemists form icons of the chemicals with which they work. Geologists imagine the underlying folds of a landscape, and biologists appreciate sagittal slices of complicated internal organs.

Since people with high spatial ability tend to be more successful in science and mathematics careers, it is important that teachers instructing science and mathematics courses have a high spatial awareness. Sanders (1995) states that,

> *because the tremendous variety of scientific equipment that a science teacher must manipulate, instructing the course requires a large range of spatial motor skills; they also require the cognitive spatial skills which will enable them to form mental pictures showing spatial relationships between structures with which they are working. (p. 2)*

Reid and Beveridge (1990) and Constable, Campbell, and Brown (1988) found that teachers in science and mathematics utilize visual aids (e.g., maps, models), illustrations (e.g., three-dimensional figures, charts, diagrams), and laboratory procedures (e.g., microscopy, dissections) that require a high understanding of spatial relationships much more often than teachers in other disciplines.

Since a high level of spatial ability is important for science and mathematics teachers, one would expect that the students interested in becoming teachers in those disciplines would also have a higher than average level of the aptitude. Logic would also support the contention that females specializing in the teaching of science (e.g., physics, geology), mathematics (e.g., geometry, trigonometry), architecture (e.g., drafting), and engineering (e.g., structural design) would be as high as their male colleagues in the aptitude. The hypothesis investigated in this study was that preservice teachers specializing in science or mathematics would score significantly higher on spatial ability tests than preservice teachers specializing in areas outside of science and mathematics. In addition, this study investigated whether differences in spatial ability existed between male and female undergraduate students majoring in secondary education programs in science and mathematics.

Method

Two hundred fifty undergraduate students majoring in a number of subject disciplines in secondary education were tested for their spatial aptitude. The majors were nearly equally divided into one of five categories: (a) science and mathematics, (b) English and humanities, (c) mechanical and fine arts, (d) allied health and physical education, and (e) history and social studies. The majority of the participants were in their third year at the university, and as many males as females were included in the study.

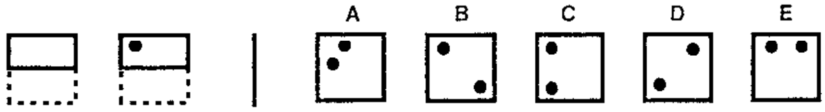
Two pencil-and-paper tests for determining spatial ability--one for spatial orientation and one for spatial visualization--were selected for the study. Spatial orientation is "the ability to perceive spatial patterns or to maintain orientations with respect to objects in space" (Ekstrom, French, Harman, & Dermen, 1976, p. 149) while spatial visualization is "the ability to manipulate or transform the image of spatial patterns into other arrangements" (Ekstorm et al., 1976, p. 173). Both cognitive abilities have been shown to be important in predictive, analytical, and critical thinking processes (Purcell, 1984).

The spatial visualization component, Paper Folding Test, required the preservice teachers to visualize a 8 1/2 inch by 11 inch sheet of paper folded several times, with a hole punched through all or several of the creases in the paper (see Figure 1). The preservice teacher was asked to predict where holes would appear when the sheet of paper was unfolded. The three-minute timed test was composed of ten folded figures for students to analyze. The second test was introduced and administered to each group immediately after the spatial visualization questions were collected.

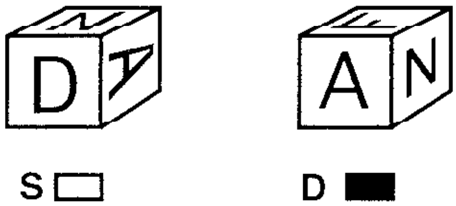
During the spatial orientation component, Cube Rotation Test, the preservice teachers were asked to predict whether two blocks with a single alphabet letter on each of their six faces could be the same block in a different position or two different blocks (see Figure 1). Students had three minutes to compare as many of the 21 sets of blocks as they could.

Figure 1. *Examples of the two spatial tests used in the study.*

Paper Folding--a spatial visualization task



Block Rotation--a spatial orientation task



Twelve to 30 preservice teachers were tested at a time during one of their required secondary education classes. Instructions concerning the tests were read out loud, and students practiced the exercises on examples provided with the tests. When everyone was clear on the procedure, the instructor administered the tests for the directed amount of time. At the end of the session, all the tests were collected and scored by a computer grading program.

Scores were examined according to the subject discipline each preservice teacher was studying. A two-way analysis of variance (ANOVA) was run on the scores to see if differences existed between genders and among academic majors. The populations were also compared with a Scheffe contrasting statistic to identify differences between the two groups.

Results

The treatment revealed that a significant difference ($F : 5.73, p < 0.05$) existed between some of the groups (see Table 1). An ANOVA F value of 2.05 was recorded for differences in spatial understanding between males and females, and a significant F of 6.14 was revealed among the different populations on the spatial measures. The follow-up Scheffe contrast statistic revealed that the mathematics/science, mechanical/fine arts, and allied health/physical education groups scored significantly higher on the spatial measures than the history/social studies and English/humanities populations ($F : 6.14$, $p < 0.05$). When the results were broken down by academic majors, it was found that the group with the highest spatial aptitude in the study were the science/mathematics preservice teachers (see Table 2). This group scored a mean of 14.0 on the block rotation and 8.3 on the paper folding. Immediately behind the science/mathematics preservice teachers were the mechanical/fine arts preservice teachers with a 13.8 mean on the block rotation and 8.1 on the paper folding. The allied health/physical education preservice teachers also scored very well on the test with a score of 13.7 on the block rotation and 8.0 on the paper folding. There was no significant difference between the means on these spatial tests of the three groups.

Table 1

Two-way ANOVA on Block Rotation and Paper Folding for Gender and Discipline Specialization

Source of Variation	Sum of Squares	df	Mean	F Value
Main Effect	33.7	11	3.18	5.73*
Gender	6.2	1	6.2	2.05
Major	28.3	9	3.1	6.14*
2-way	0.49	9	0.06	0.12

* $p < 0.05$

The Scheffe revealed a statistical difference ($p < 0.05$) among the three areas and the history/social studies and English/humanities preservice teachers. The preservice teachers specializing in history or social studies had a mean of 9.9 on the block rotation and a 5.5 on the paper folding while the preservice teachers majoring in English or humanities scored a 10.0 on the block rotation and a 5.5 on the paper folding.

When the results of the test were separated by gender, the males were found to have significantly outperformed the females on the tests (see Table 2). When the genders were examined according to their academic majors, it was discovered that in only the history/social studies preservice teachers and the English/humanities preservice teachers was there a large gender discrepancy favoring the males (see Table 3). Mean differences of 1.5 to 2.0

points were found for preservice teachers in these two groups. No significant differences were found, however, between the males and females in the mechanics/fine arts, science/mathematics, and allied health/physical education preservice teachers. Here, the means differed less than one point between males and females in these three populations.

Table 2

Scheffe Contrast for Spatial Tests for Gender and Discipline Major

	N	Mean	SD	SE	Difference Between
Sex					
Males	250	2.03	1.13	0.52	< females
Females	250	18.3	1.35	0.48	> males
Discipline					
Sci/Math	50	22.3	1.44	0.76	> his/sst/Eng/hum
Mech/Arts	50	22.1	1.08	0.47	> his/sst/Eng/hum
Health/PE	50	21.6	1.72	0.53	> his/sst/Eng/hum
Hist/SSt	50	15.2	1.39	0.44	< sci/ma/me/arts/hlth/PE
Engl/hum	50	15.5	1.51	0.62	< sci/ma/me/arts/hlth/PE

Discussion

The results of this study support the claims by some researchers that several disciplines require a higher than average spatial ability (Smith, 1964; Roe, 1952) and that students that succeed in the courses that lead to those professions are good in spatial thinking (Morris & Upton, 1979; Baker, 1983). The question whether the aptitude is present before the students choose their courses or whether the courses the students take produce the high level of spatial ability was not answered by this study. Earlier studies, however, have shown that children with strong spatial abilities tend to perform well in subjects with strong science and mathematics components (Purcell, 1984; Smith & Schroeder, 1979; Lord & Nicely, in press). Since this study found that preservice teachers in certain academic majors are higher in their spatial ability than preservice teachers in other majors, it reinforces the claim that students are more interested in certain specific subjects over others because they are good at forming and manipulating icons in their minds.

If the scores are compared to the national means for the two exercises (Ekstrom et al., 1976), the three groups that scored highest in this study

Table 3

Scheffe Contrast Between Genders in the Discipline Majors

Type of Test	N	Mean	SD	SE	Difference Between
Sci/Math					
Males-BR	25	14.5	1.19	0.43	> male and female
Females-BR	25	13.5	1.04	0.37	his/sst/Eng/hum
Males-PF	25	8.7	0.95	0.31	> male and female
Females-PF	25	7.9	0.72	0.29	his/sst/Eng/hum
Mech/Arts					
Males-BR	26	14.3	1.25	0.35	> male and female
Females-BR	24	13.4	0.99	0.29	his/sst/Eng/hum
Males-PF	26	8.3	0.87	0.19	> male and female
Females-PF	24	7.9	0.70	0.20	his/sst/Eng/hum
Health/PE					
Males-BR	26	14.0	1.41	0.36	> male and female
Females-BR	24	13.3	1.17	0.24	his/sst/Eng/hum
Males-PF	26	8.4	0.72	0.22	> male and female
Females-PF	24	7.6	0.77	0.19	his/sst/Eng/hum
Hist/SStudies					
Males-BR	25	10.7	1.27	0.33	< male and female
Females-BR	25	9.2	1.32	0.29	sci/ma/me/arts/hlth/PE
Males-PF	25	6.3	0.83	0.21	< male and female
Females-PF	25	4.7	0.62	0.16	sci/ma/me/arts/hlth/PE
Engl/Hum					
Males-BR	23	10.6	1.51	0.34	< male and female
Females-BR	27	9.4	1.02	0.24	sci/ma/me/arts/hlth/PE
Males-PF	23	6.1	0.68	0.19	< male and female
Females-PF	27	4.9	0.71	0.22	sci/ma/me/arts/hlth/PE
National Norms					
Males-BR		11.4	2.70	0.33	
Females-BR		10.7	2.21	0.35	
Males-PF		6.8	0.82	0.21	
Females-PF		5.3	0.78	0.18	

(mechanics/fine arts, science/mathematics, and allied health/physical education) scored higher than the national means for the tests. The history /social studies and English/humanities preservice teachers, on the other hand, were below the national norms for the activities.

This study also found that the female secondary preservice teachers in science and mathematics disciplines (as well as females in mechanical arts, fine arts, allied health, and physical education) scored significantly higher on the spatial measures than the female secondary preservice teachers in history/social studies and English/humanities. This finding lends strong support to the research of Linn and Peterson (1985), Lord (1987), and Sanders (1995) that states that many females score as well on spatial tasks as males. It is the population of females with good spatial skills that are choosing to specialize in science and mathematics in their secondary preservice teacher education curriculum.

Conclusion

Preservice secondary education teachers specializing in spatially challenging disciplines such as biology and physics are themselves very high in visual-spatial aptitude while preservice teachers that are not good in spatial perception are usually not found in those subjects. This study recorded positive spatial aptitude-discipline relationships in undergraduate majors in mathematics, science, mechanical arts, fine arts, allied health, and physical education and weak spatial aptitude-discipline relationships with history, social studies, English, and humanities majors. While this is an important finding in itself, it is not that surprising. Several previous studies recorded a strong spatial perception--career linkage--but preservice teachers were never included in the earlier research.

The more important finding of this study is that females that choose to teach in the high spatial-requiring disciplines are as good in spatial ability as the males who teach in them. Female preservice teachers in science, mathematics, mechanical arts, fine arts, allied health, and physical education are not significantly different in their spatial appreciation from the males in those fields. This finding does not support the claim by many researchers that holds that females are significantly below males in spatial perception. This assertion was supported only with preservice teachers in history, social studies, English, and humanities.

It is important that career counselors and guidance directors acknowledge this. They should encourage students who want to be teachers and are good in spatial perception to enter disciplines that utilize this type of thinking. They should also direct students interested in teaching who are poor in visual spatial ability away from majors that require a high level of the aptitude. Alternatively, since research has found that spatial ability can be enhanced through schooling, career counselors could encourage poor spatial visualizers to take courses in science, mathematics, mechanical drawing, drafting, and other subjects that promote the development of spatial thinking.

Furthermore, teacher education institutions should instruct future teachers on ways to enhance visual-spatial thinking in their students. Colleges must demonstrate the importance of three-dimensional manipulatives in lessons, and why it is crucial that preservice teachers encourage their students to reconstruct events in the lesson both physically and mentally. Preservice teachers should be taught that spatial thinking is greatly enhanced when students imagine future events, predict outcomes, and analyze information depicted in tables, charts, and diagrams. Teacher education professors should encourage preservice teachers to form images with their minds and manipulate the images through thinking rather than drawing or writing. They must reinforce the importance of spatial thinking in a student's overall understanding of the lesson. As Young (1978) stated, "The teacher is the key in the learning process for the classroom experiences developed by them ultimately will influence the cognitive potentials of their students in their adult life" (p. 17).

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