AC 2011-1785: SPATIAL VISUALIZATION SKILLS: IMPACT ON CONFIDENCE AND SUCCESS IN AN ENGINEERING CURRICULUM

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Spatial Visualization Skills: Impact on Confidence in an Engineering Curriculum

Abstract

Spatial visualization skills have been found to be important in STEM careers, and research has been conducted at a few universities to investigate the impacts of spatial training with STEM students. At Michigan Technological University, all engineering freshmen are given the Purdue Spatial Visualization Test: Rotations (PSVT:R) during orientation. In Fall 2007 and Fall 2008, these students were also given a survey to assess their confidence in their choice of engineering major and in their preparation for and ability in certain aspects related to an engineering curriculum. This paper examines the impact of spatial visualization skills as measured by the PSVT:R on the students' confidence levels at the beginning and at the end of their first year in an engineering curriculum. Spatial skills of students selecting different majors are compared to determine if spatial skills may be a factor in a person's choice of major (e.g., do most mechanical engineering majors have highly developed spatial visualization skills while more computer engineering majors have less developed spatial visualization skills?). These analyses are also performed by gender.

Background

Spatial skills are important for a variety of careers. Smith (1964)[1] identified at least 84 career areas for which spatial skills are important. Spatial skills, and in particular the ability to rotate images in one's mind, are especially important for technical fields such as engineering (Maier, 1994)[2]. Studies have shown that spatial visualization skills are a factor in the success of engineering students. Gimmestad (1989)[3] found that students' spatial visualization skills were a stronger predictor of success in an engineering design course than math ACT scores or experience in a high school shop or drafting class. Blasko et al. (2004)[4] found that incoming spatial skills predicted 20 % of the total variance in course grades, with nearly half of the credits outside of engineering in general education. This was more than the variance in course grades predicted by math SAT scores.

Sorby (2009)[5] found that students who had poorly developed spatial skills and received spatial skills training as engineering freshmen had higher grades in first-year engineering and math courses and higher retention rates than students with poorly developed spatial skills who did not receive the spatial training. Blasko and Holliday-Darr (2010)[6] found that students receiving spatial training performed just as well or slightly better in statics, physics, math, and chemistry classes as those who did not receive the training but had higher math SAT scores. Anecdotally, instructors of spatial training courses have noticed a marked increase in students' confidence levels over the course of the spatial training. Could a student's confidence (and therefore their spatial skills) influence their success and their career choices?

Studies have shown the impact of confidence or self-efficacy on student success. For example, Lent et al. (1984)[7] found that students reporting high self-efficacy (confidence in their ability to successfully complete various scientific and engineering degrees) achieved higher grades and persisted longer in scientific and technical programs than those that reported low self-efficacy.

Additionally, Towle et al., (2005)[8] found that an engineering student's self efficacy for completing a spatial task is directly correlated with their score on a spatial test, indicating these students were able to fairly accurately predict how well they could perform on a spatial test.

What previous studies have not shown is the impact students' spatial visualization skills may have on choosing to pursue an engineering degree, selecting an engineering major, and their confidence in being able to succeed in an engineering curriculum.

Present Study

In the fall of 2007 and 2008, all engineering freshmen were given a survey adapted after one developed by Chris Brus[9] of Iowa State University. Among other things, this survey asked students to rate how confident they were that engineering was the right career for them and that their current major was right for them. The survey also asked them to rate their confidence in their abilities and preparation in several subjects related to engineering. The surveys were administered to students on the first day of their engineering class in the fall semester of 2007 and 2008. A post survey was administered during the last week of class in the spring of 2008, and in the spring of 2009, students were emailed in mid-May (two weeks after the end of the spring semester) and asked to complete the survey online for a chance to win a gift certificate to the university bookstore. In the fall of 2007, 602 students completed the pre-survey, and 773 students completed the pre-survey in the fall of 2008. In the spring of 2008, 489 students completed the post-survey while 222 students completed the post-survey in the spring of 2009.

In order to gain some insight into how students' spatial visualization skills might impact their choice of major, two questions were analyzed: 1) Do students with stronger spatial skills, as measured by the PSVT:R, have more confidence in their choice to pursue engineering? and 2) Do students that selected engineering majors thought to be more spatially oriented have higher PSVT:R scores than students in engineering disciplines where spatial skills may be considered to be less important?

Student confidence levels in their preparation for and ability in academic areas such as math, science, engineering, technology, and graphical communication at the beginning and end of a first year engineering curriculum were compared for students with various levels of spatial skills to see if students with lesser developed spatial skills were less confident in their abilities than students with higher spatial skills.

Findings

To determine if students with stronger spatial visualization skills were more confident in choosing engineering than students with lower spatial visualization skills, the students were divided into quartiles based on their PSVT:R score. It was found that students scoring in the highest quartile had PSVT:R scores of 28 – 30, students in the second highest quartile had scores of 25 – 27, and scores in the third highest quartile ranged from 22 – 24. Students could score a maximum of 30 on the test. Mean confidence levels to the following questions were compared for students in each quartile.

1) Currently, how confident are you that engineering is the right career for you?

2) How confident are you that your current major in engineering is right for you?

The five Likert-scale responses the students could choose were:

a) Completely confident
b) Very confident
c) Moderately confident
d) Slightly confident
e) Not at all confident.

The responses were rated on a scale of 1 to 5 with 5 corresponding to the "Completely confident" response, and 1 corresponded with the "Not at all confident" response.

Student responses at the beginning and end of their first year in an engineering curriculum are shown in Table 1 below. It should be noted that if students had not declared a specific discipline in engineering as their major, they were instructed not to answer the question about how confident they were that their current major in engineering is right for them. However, some of these students did provide a response to this question.

Table 1: Comparisons of confidence in choice of engineering and engineering major at beginning of first year by quartiles based on PSVT:R score. p's reported inside table are statistical significance of difference between a response and the response from the group that scored 21 and below on the PSVT:R.

PSVT:R score	28 - 30	25 – 27	22-24	21 and below
	Mean response	Mean response	Mean response	Mean response
Engineering is right choice	3.94[3] p< 0.0001 n = 316	3.92[3] p<0.0001 n = 412	3.81 p = 0.0003 n = 303	3.58 n = 344
Engineering major is right choice	3.50[1] p = 0.23 n = 272	3.66 p = 0.06 n = 350	3.57 p = 0.45 n = 265	3.56 n = 305

[1] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.05$
[3] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.05$

Student responses averaged from 3.58 to 3.94 showing that on average, students are moderately to very confident that engineering is the right career for them. However, the table above shows students scoring in the lowest quartile on the PSVT:R have a statistically significant lower confidence level in engineering as the right choice for them than students in all other quartiles. Students scoring in the highest two quartiles also are significantly more confident in an engineering career choice than students with PSVT:R scores in the second lowest quartile. There is little difference in confidence in choice of engineering discipline between students in the different quartiles as mean responses ranged from 3.50 to 3.66. Here, students scoring in the highest quartile on the PSVT:R seemed to be least confident in their choice of engineering discipline.

The average scores on the PSVT:R were averaged for all students in each engineering major to determine if there is a difference in spatial skills among the different engineering disciplines. As shown in Table 2, there are only small differences in the mean PSVT:R scores for each major, with mechanical, general, and computer engineering students having the highest average scores

and environmental and geological engineering having the lowest scores. While the differences are small, mechanical and general engineering students have a statistically significant ($p<0.05$) higher average PSVT:R score than biomedical, civil, and environmental students. Additionally, the environmental engineering students have a lower score than chemical, civil, and electrical engineering students which is statistically significant at the $p<0.05$ level and significantly lower than computer, mechanical, and general engineering students at the $p<0.005$ level.

Table 2: Comparison of average student PSVT:R score out of 30 possible points by engineering major

Major	All		Male		Female	
	n	average	n	average	n	average
Biomed	97	23.3	53	24.6	44	21.8
Chemical	147	23.9	104	24.9	43	21.4
Civil	195	23.6	162	24.2	33	20.6
Computer	96	24.2	96	24.2	7	23.7
Electrical	110	24.1	101	24.6	9	19.0
Environmental	63	22.1	38	24.4	25	18.6
Geological	3	21.3	3	21.3	0	
Materials	27	23.5	20	25.2	7	18.9
Mechanical	385	24.4	356	24.5	29	22.7
General/Undecided	250	24.4	205	24.9	45	22.0
Eng. Technology	1	24	1	24	0	

The average PSVT:R scores for males and females for each major is also shown in Table 2. Consistent with previous studies[4-5,10-13], the average score for the males is higher than the average score for the females in all majors. The average scores for the male students range from 21.3 for geological engineering students to 25.2 for material science and engineering students, while the average scores for the female students ranged from 18.6 for environmental to 23.7 for computer engineering students. For the male students, the differences between the high (chemical and general engineering) scores and low (geological) scores were statistically significant ($p<0.05$). The average PSVT:R score for the female computer engineering students was statistically higher ($p<0.05$) than the average for electrical, environmental, and materials. The female materials science and engineering students had a statistically lower score ($p<0.05$) than the biomed, computer, mechanical, and general engineering students. The female environmental engineering students had a statistically lower average score ($p<0.05$) than female

chemical and computer engineering and statistically lower average ($p<0.005$) than female biomedical, mechanical, and general engineering students.

While the differences are small in the average PSVT:R scores for the different engineering disciplines, it appears that those students in disciplines that are perceived as more spatially oriented such as mechanical engineering do indeed score higher on average than those students in disciplines that are perceived as less spatially oriented such as environmental engineering.

Because students are unlikely to choose a major they do not feel they are capable of successfully completing, students were asked to rate their self-confidence in their ability and preparation in eight academic areas related to engineering. Student confidence levels were then compared based on PSVT:R scores as shown in Tables 3 and 4 below. Students could respond with the same 5-point Likert responses as listed previously and responses were coded such that a five corresponded to complete confidence and three corresponded to moderate confidence. The questionnaire defined technology ability as the use of computers and software packages. Engineering ability was defined as using math and science to solve real-world problems, graphical tools ability was the ability to use programs such as CAD, and graphical communication ability was their ability to understand engineering drawings and 2-D representations of 3-D objects.

Table 3: Comparisons of confidence in abilities at beginning of first year by quartiles based on PSVT:R score. p's reported inside table are statistical significance of difference between a response and the response from the group that scored 21 and below on the PSVT:R.

PSVT:R score	28 – 30 n = 316	25 – 27 n = 412	22-24 n = 303	21 and below n = 344
	Mean response	Mean response	Mean response	Mean response
Math	4.02[1,3] p< 0.0001	3.92 p=0.0004	3.87 p = 0.005	3.72
Science	3.95[1,3] p< 0.0001	3.83 p = 0.002	3.81 p = 0.008	3.67
Technology	3.78[2] p< 0.0001	3.60 p = 0.005	3.67 p = 0.0002	3.42
Engineering	3.84[1,3] p< 0.0001	3.73 p< 0.0001	3.71 p< 0.0001	3.41
Graphical tool	3.38[2,4] p< 0.0001	3.13 p = 0.0006	3.10 p = 0.003	2.84
Graphical Communication	4.03 [2,4] p< 0.0001	3.86 p< 0.0001	3.75 p< 0.0001	3.33
Writing	3.36[1] p = 0.17	3.25 p = 0.004	3.35 p = 0.14	3.43
Speaking	3.35 p = 0.25	3.28 p = 0.04	3.26 p = 0.03	3.40

[1] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.05$
[2] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.005$
[3] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.05$
[4] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.005$

Table 3 shows that students with PSVT:R scores in the lowest quartile were significantly less confident in their abilities in all academic areas specifically related to engineering. Students in the highest quartile were statistically significantly more confident in these same abilities than students in all other quartiles with the exception of Technology ability, where they were not significantly more confident than students in the third quartile. It should also be noted that slightly less than half of the students in the lowest quartile had been told they "failed" the PSVT:R and could benefit from additional spatial visualization training before they took the confidence survey. This could be a factor in their low confidence level in their graphical communication ability. Although writing and speaking are key engineering skills, these skills are not generally associated specifically with engineering and are likely not important factors in a student's decision to pursue engineering. Here, the students in the lowest quartile were most confident in their speaking and writing abilities, with some significant differences from students in the second and third quartiles.

Table 4 shows that students in the lowest PSVT:R quartile were also least confident in their preparation in the six engineering-specific academic areas. This difference was statistically significant from all other quartiles in all areas. Students in the highest PSVT:R quartile were most confident in their preparation, but the confidence in their science, technology, and engineering preparation was not significantly higher than students in the middle two quartiles. Confidence in writing and speaking preparation was not significantly different for the four groups, and the lowest quartile had the most confidence in these areas.

Table 4: Comparisons of confidence in preparation at beginning of first year by quartiles based on PSVT:R score. p's reported inside table are statistical significance of difference between a response and the response from the group that scored 21 and below on the PSVT:R.

PSVT:R score	28 – 30 n = 316	25 – 27 n = 411 - 412	22-24 n = 301 – 303	21 and below n = 344
	Mean response	Mean response	Mean response	Mean response
Math	3.97[1] p= 0.00015	3.85 p=0.036	3.87 p = 0.015	3.75
Science	3.80 p= 0.0039	3.75 p = 0.017	3.76 p = 0.016	3.64
Technology	3.61 p< 0.0001	3.50 p = 0.0062	3.55 p = 0.00075	3.33
Engineering	3.57 p< 0.0001	3.55 p< 0.0001	3.54 p< 0.0001	3.20
Graphical tool	3.07[1,3] p< 0.0001	2.90 p = 0.00765	2.84 p = 0.044	2.67
Graphical Communication	3.72 [2,4] p< 0.0001	3.54 p< 0.0001	3.47 p< 0.0001	3.11
Writing	3.46 p = 0.0498	3.37 p = 0.00085	3.47 p = 0.063	3.57
Speaking	3.34 p = 0.036	3.30 p = 0.0078	3.31 p = 0.015	3.46

[1] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.05$
[2] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.005$
[3] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.05$
[4] Mean response is significantly different than the 22 – 27 quartile response with $p < 0.005$

If students' spatial visualization skills and confidence play a role in the selection of engineering as a career choice, then they may also play a role in retention in an engineering curriculum. To see if students who began their engineering curriculum with less developed spatial skills were less confident after a year in an engineering curriculum than those who initially had stronger spatial skills, student responses on post surveys given at the end of the first year were analyzed in the same manner as the pre-surveys. Table 5 shows the confidence levels in engineering as a career choice and in selecting a specific major at the end of their first year of study in an engineering curriculum.

Table 5: Comparisons of confidence in choice of engineering and engineering major at end of first year by quartiles based on PSVT:R score. p's reported inside table are statistical significance of difference between a response and the response from the group that scored 21 and below on the PSVT:R.

PSVT:R score	28 - 30	25 – 27	22-24	21 and below
	Mean response	Mean response	Mean response	Mean response
Engineering is right	3.76 n = 171 p = 0.09	3.88 n = 200 p = 0.006	3.89 n = 158 p = 0.004	3.63 n = 182
Engineering major is right	3.63[4] n = 164 p = 0.29	3.68[3] n = 190 p = 0.46	3.92 n = 149 p = 0.01	3.69 n = 170

[3] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.05$
[4] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.005$

At the end of the first year, students who initially were in the lowest quartile of PSVT:R scores were still significantly less confident that engineering was the right career choice for them than the students in the second and third quartiles. However, there was no significant difference between the lowest and highest quartiles. When compared to responses at the beginning of their first year, students in the lowest two quartiles became slightly more confident while students in the upper two quartiles became slightly less confident. Students in the third quartile were significantly more confident in their selection of an engineering discipline than students in all other quartiles.

In their first year at Michigan Tech, most engineering students would have taken two math courses: 30% of the students would have taken Pre-calculus and Calculus I, while the majority of the remaining students would have taken Calculus I and II. The majority of students would have taken Chemistry I their first semester, and over half of the students would have taken Physics I their second semester. All students would have taken engineering courses both semesters. The topics in the engineering courses include technical communication, spatial visualization, solid modeling, engineering problem solving, use of computational tools, computer programming, and engineering design projects.

Confidences in preparation and abilities at the end of the first year are shown in Tables 6 and 7 below. At the end of the first year, students in the lowest PSVT:R quartile are no longer significantly less confident in their math abilities than students in the second and third quartiles, nor are they significantly less confident in their graphical tool abilities than students in the third quartile. They remain most confident in their speaking and writing abilities. In general, most

groups were slightly more confident in their abilities at the end of the first year. Largest increases were in the graphical tool abilities for all students. This could be attributed to the training on solid modeling the students had during their first year engineering courses. Another marked increase was in the graphical communication ability of the fourth quartile. The increased confidence in graphical communication ability in the lowest quartile could be attributed to the engineering graphics they had in their first year courses and the fact that some of the students took a spatial visualization training course their first semester.

Table 6: Comparisons of confidence in abilities at end of first year by quartiles based on PSVT:R score. p's reported inside table are statistical significance of difference between a response and the response from the group that scored 21 and below on the PSVT:R.

PSVT:R score	28 – 30 n = 171	25 – 27 n = 200	22-24 n = 156 - 158	21 and below n = 181 - 182
	Mean response	Mean response	Mean response	Mean response
Math	4.04[1,3] p = 0.0006	3.88 p=0.07	3.84 p = 0.15	3.75
Science	3.92[1] p< 0.0002	3.73 p = 0.12	3.84 p = 0.008	3.63
Technology	3.89 p< 0.003	3.80 p = 0.04	3.84 p = 0.01	3.64
Engineering	4.02[1,3] p< 0.0001	3.85 p = 0.004	3.84 p = 0.008	3.65
Graphical tool	3.98[2,4] p< 0.0001	3.65 p = 0.03	3.59 p = 0.10	3.45
Graphical Communication	4.30 [2,4] p< 0.0001	4.02 p = 0.0004	3.94 p = 0.008	3.71
Writing	3.66 p = 0.06	3.66 p = 0.06	3.68 p = 0.10	3.81
Speaking	3. 58 p = 0.034	3.57 p = 0.02	3.57 p = 0.03	3.76

[1] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.05$
[2] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.005$
[3] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.05$
[4] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.005$

At the end of their first year, students in the lowest quartile remain significantly less confident in their preparation than students in all the other quartiles in all engineering-specific areas except science, where they are significantly less confident than only the highest quartile. In comparison to their confidence levels at the beginning of the year, students in the lowest quartile were less confident in their preparation in all engineering-specific areas, students in the third quartile were less confident in their preparation in all engineering-specific areas except math, students in the second quartile were less or just as confident in all engineering-specific areas except technology, and students in the highest quartile were more confident in their math, science, and graphical tool preparation at the end of the first year than they were at the beginning. This is not surprising as engineering students admitted to Michigan Tech rank mostly in the top 20% of their high school classes. When comparing themselves to their new peer group at the University, most students find they no longer outperform most of their peers. All students were more confident in their writing and speaking preparation at the end of the first year. It may be that through the course of

their first year, they found their writing and speaking abilities were on the same level as their fellow engineering freshmen.

Table 7: Comparisons of confidence in preparation at end of first year by quartiles based on PSVT:R score. p's reported inside table are statistical significance of difference between a response and the response from the group that scored 21 and below on the PSVT:R.

PSVT:R score	28 – 30 n = 316	25 – 27 n = 411 - 412	22-24 n = 301 - 303	21 and below n = 344
	Mean response	Mean response	Mean response	Mean response
Math	4.06[1] p< 0.0001	3.85 p=0.0032	3.95 p = 0.0002	3.57
Science	3.89[1,3] p= 0.0039	3.68 p = 0.231	3.73 p = 0.11	3.61
Technology	3.59[1,3] p< 0.0001	3.38 p = 0.0016	3.36 p = 0.0036	3.04
Engineering	3.43[1,3] p< 0.0001	3.22 p< 0.0001	3.23 p< 0.0001	2.78
Graphical tool	3.14[2,4] p< 0.0001	2.74 p = 0.0072	2.68 p = 0.023	2.39
Graphical Communication	3.56 [2,4] p< 0.0001	3.12 p = 0.0002	3.03 p = 0.0025	2.64
Writing	3.83[1] p = 0.47	3.66 p = 0.047	3.67 p = 0.077	3.82
Speaking	3.60 p = 0.39	3.48 p = 0.062	3.51 p = 0.12	3.63

[1] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.05$
[2] Mean response is significantly different than the 25 – 27 quartile response with $p < 0.005$
[3] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.05$
[4] Mean response is significantly different than the 22 – 24 quartile response with $p < 0.005$

Conclusions

In this paper the impact of spatial skills on student confidence levels was examined using their score on the PSVT:R and their responses to an attitudinal survey. Students were divided into quartiles based on their PSVT:R score. It was found that at the beginning of the year students in the lowest quartile were significantly less confident in their choice to pursue an engineering degree and in their abilities and preparation in all academic areas related to engineering. After completing their first year, the students in the lowest two quartiles became slightly more confident in their choice of engineering compared to the beginning of the year, while the students in the highest two quartiles became less confident in their choice of engineering. In general, student confidence in their abilities increased from the beginning of the year to the end of the year for all groups, with the largest increases occurring in graphical tool and communication abilities. However, students in the lowest quartile remain significantly less confident in their abilities and preparation in many of the engineering specific areas than students in all other PSVT:R quartiles.

Additionally, when student PSVT:R scores were averaged for each major, students in mechanical engineering, which is perceived as a highly spatial engineering major, did indeed have

significantly higher scores than students in environmental engineering, which may be perceived as being less spatially oriented.

These findings provide evidence that spatial skills do indeed impact student confidence to pursue engineering and spatial skills may influence a student's choice of engineering discipline. This suggests that to attract and retain more individuals in the field of engineering, efforts should be made to develop the spatial skills of all students before they begin to make academic decisions which may impact their career options.

Bibliography

1. Smith, I. M. (1964). *Spatial ability-Its educational and social significance.* London: University of London.
2. Maier, P. H. (1994). *Raeumliches vorstellungsvermoegen*. Frankfurt a.M., Berlin, Bern, New York, Paris, Wien: Lang.
3. Gimmestad, B. J. (1989). Gender differences in spatial visualization and predictors of success in an engineering design course. *Proceedings of the National Conference on Women in Mathematics and the Sciences*, St. Cloud, MN, 133-136.
4. Blasko, D. G., Holliday-Darr, K, Mace, D., & Blasko-Drabik, H. (2004). VIZ: The visualization assessment and training website Behavior Research Methods Instruments & Computers. 36:2
5. Sorby, S. A. (2009). Educational Research in Developing 3-D Spatial Skills for Engineering Students. International Journal of Science Education, 31:3, 459-480.
6. Blasko, D.G. & Holliday-Darr, K. (2010). Longitudinal Analysis of Spatial Skills Training in Engineering Graphics. *Proceedings of the Engineering Design Graphics Division of ASEE 65th Mid-year Conference*, Houghton, MI.
7. Lent , R. W., S. D. Brown, and K. C. Larkin (1984) "Relation of self-efficacy expectations to academic achievement and persistence", *Journal of Counseling Psychology*, 31(3), 356-362.
8. Towle, E., Mann, J., Kinsey, B., O'Brien, E. J. , Bauer, C. F., & Champoux, R. (2005). Assessing the Self Efficacy and Spatial Ability of Engineering Students from Multiple Disciplines. *Proceedings from ASEE/IEEE Frontiers in Education Conference* Indianapolis, IN, S2C-15-S2C19.
9. Brus, C., L. Zhao, L., and J. Jessop (2004). Visual-Spatial Ability in First-Year Engineering Students: A Useful Retention Variable? *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition,* Salt Lake City, UT.
10. Linn, M.C., & Petersen, A.C. (1985). *Emergence and characterization of sex differences in spatial ability: A meta-analysis.* Child Development, *56*, 1479-1498.
11. Sorby, S. A. & Baartmans, B. J. (1996). *A course for the development of 3-D spatial visualization skills.* Engineering Design Graphics Journal, 60(1), 13-20.
12. Sorby, S. A. & Gorska, R. A. (1998). *The effect of various courses and teaching methods on the improvement of spatial ability*. Proceedings of the 8th International Conference on Engineering Design Graphics and Descriptive Geometry, Austin, TX, 252-256.
13. Medina, A. C., Gerson, H. B. P., & Sorby, S. A. (1998). *Identifying gender differences in the 3-D visualization skills of engineering students in Brazil and in the United States.* Proceedings of the International Conference for Engineering Education 1998, Rio de Janeiro, Brazil.