Gender Differences in Spatial Reasoning Skills and their Effects on Success and Retention in Engineering Programs

Sheryl A. Sorby
Michigan Technological University

Development of Spatial Skills

- According to Pigetian theory, there are three stages of development of spatial skills:
  - Topological Skills
  - Projective Skills
  - Euclidean Skills

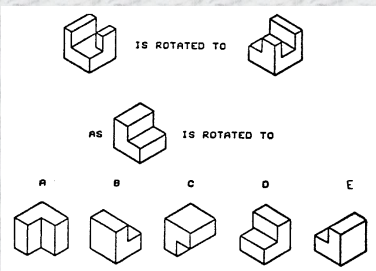
Importance of Spatial Skills

- Many historical scientific discoveries have been linked to well-developed spatial skills
- Well-developed spatial skills have been shown to lead to success in:
  - Engineering
  - Computer Science
  - Chemistry
  - Computer Aided Design

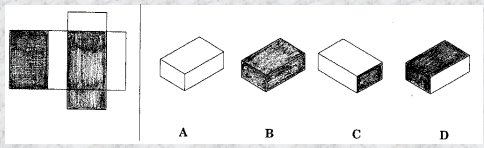
Assessment of Spatial Skills

- Several tests developed to assess spatial skills in the first two stages of development
- Each test is designed to assess a different type of spatial skill
  - Object Rotations
  - Object Cross-sections
  - 2-D to 3-D transformations

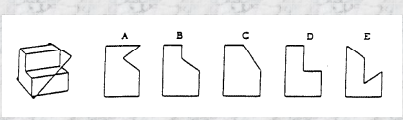
Purdue Spatial Visualization Test: Rotations (PSVT:R)



Differential Aptitude Test: Space Relations (DAT:SR)



Mental Cutting Test (MCT)



Gender Differences in Spatial Skills

- Gender differences in 3-D spatial skills, favoring males, are well-documented throughout the literature
- Theories abound to explain gender differences in spatial skills:
  - Recessive trait on the Y-chromosome
  - Hormonal
  - Environmental

Factors in the Development of Spatial Skills

- Play with construction toys
- Shop, drafting, and mechanics classes
- 3-D computer games
- Certain sports
- Mathematics skills
- Sketching
  - Most factors in developing skills have a certain degree of gender bias favoring males

Spatial Skills and Engineering Graphics

- A 1985 study at Michigan Tech determined that a student's score on the PSVT:R was the most significant predictor of success in engineering graphics
- Gender differences on PSVT:R were statistically significant

IF…..

- Spatial skills are critical to success in engineering graphics
- Graphics is one of the first "engineering" courses that students take
- Spatial skills of women lag behind those of their male counterparts

WILL….

- Women become discouraged in this introductory course at a disproportionate rate and drop out of engineering as a result?

The Michigan Tech Project: Phase 1--Initial Development

- Received funding from the NSF in 1993 to develop a course and materials for improving spatial skills
- Course topics were ordered in a manner thought to develop spatial skills
- Textbook and computer exercises written over the summer of 1993

A Course for the Development of Spatial Skills

- GN102 offered beginning in the fall of 1993
- First-year engineering students administered the PSVT:R during orientation
- 96 students failed PSVT:R with a score of 60% or lower
  - Women were around 17% of the group tested and 43% of the group failing the PSVT:R
- Random sample of 24 students selected for participation in GN102

PSVT:R Performance

	Male (n=418)	Female (n=117)
Perfect Score	42 (10.1%)	3 (2.6%)
60% or lower	50 (12.0%)	46 (39.3%)

Course Topics

- Isometric Sketching
- Orthographic Projection
- 2-D to 3-D Object Transformations
- 3-D Coordinate Systems
- Object Translations
- Object Scaling
- Object Rotations
- Object Reflections
- Cross-Sections of Solids
- Surfaces and Solids of Revolution
- Combining Objects

Course Administration

- GN102 a 3-credit course (quarter system) with two hours of lecture and one 2-hour computer lab per week
- Hand-held models used wherever possible
- Computer lab utilized I-DEAS solid modeling software

Gains in Spatial Skills

- Students were given PSVT:R as part of their final exam
  - Average pre-test score = 51.7%
  - Average post-test score = 82.0%
- Gain scores were statistically significant ($p<0.0001$)
- No gender differences in average pre-/post-test scores for GN102 students

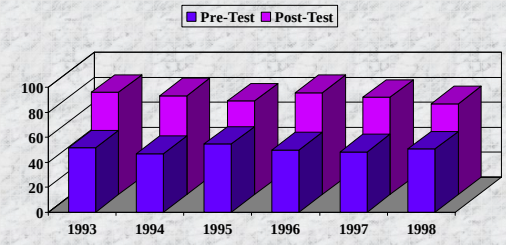
The Michigan Tech Project: Phase 2--Initial Dissemination

- A second NSF grant obtained to deliver an Undergraduate Faculty Enhancement workshop during the summer of 1994
- 24 engineering graphics educators convened for a nine-day workshop on developing spatial visualization skills
- Resource concerns prevented many participants from adopting a course such as GN102 on their home campuses

The Michigan Tech Project: Phase 3--Maintenance

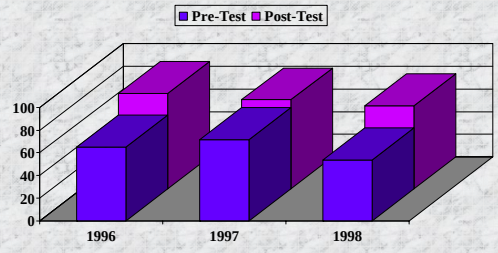
- GN102 offered each fall quarter
- Engineering students were administered PSVT:R during orientation
  - People who failed encouraged to enroll in GN102
- Students administered PSVT:R as part of their final exam
- Beginning in 1996, the DAT:SR and MCT were given as pre-/post-tests

PSVT:R Test Results



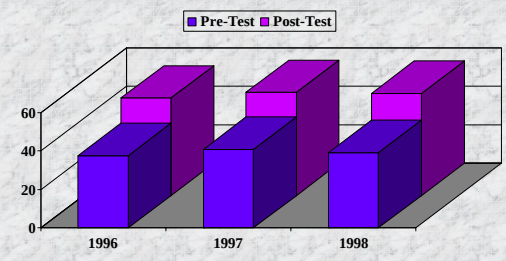
Gains statistically significant

DAT:SR Test Results



Gains statistically significant

MCT Test Results

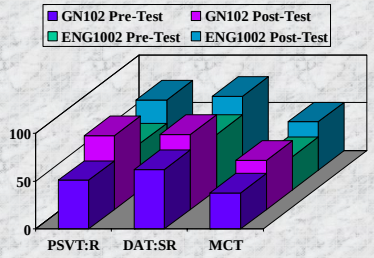


Gains statistically significant

The Michigan Tech Project: Phase 4--Multimedia Software

- Additional NSF funding received in 1998 to develop multimedia software and a workbook for enhancing spatial skills
- Nine modules developed over a two-year period
- Students rated the software favorably
- Course modified in fall 2000 to be nearly "self-paced"

Fall 2000 Pre-/Post-Test Results



The Michigan Tech Project: Phase 5--Long Term Assessment

- Total of 536 students failed the PSVT:R during freshman orientation from 1993-98
- Transcripts analyzed during January 2000
  - Students who enrolled in GN102 (n=175) were "Experimental Group" (EG)
  - Students who did not enroll in GN102 (n=361) were "Comparison Group" (CG)

Long-Term Data Obtained

- Grades in subsequent graphics courses
- Grades in first calculus course
- Attrition from Michigan Tech
- Attrition from the College of Engineering
- Gender differences in data were also investigated

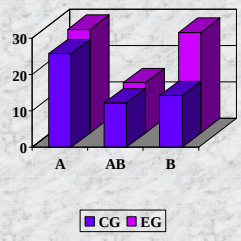
Average GPA in Subsequent Graphics Courses

- Females
  - CG=2.71 (n=148)
  - EG=3.02 (n=116)
- Difference statistically significant ($p<0.02$)
- Males
  - CG=2.55 (n=274)
  - EG=2.87 (n=2.87
- Difference statistically significant ($p<0.005$)

Male-Female differences within groups not significant

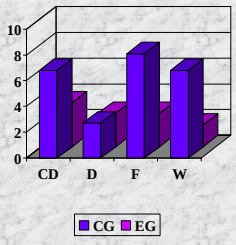
Female graphics grades of A, AB, or B

- 69.8% of the graphics grades received by women in the EG were B or higher compared to 52.0% for the women in the CG
- The difference was statistically significant ($p=0.0038$)



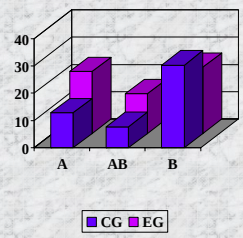
Female graphics grades of CD, D, F, or W

- 10.3% of graphics grades received by women in the EG were CD or lower compared to 24.3% of the grades for women in the CG
- The difference was statistically significant ($p=0.0036$)



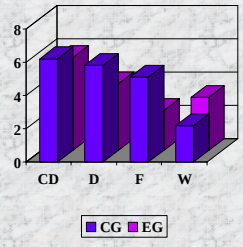
Male graphics grades of A, AB, or B

- 61.3% of the graphics grades received by males in the EG were B or higher compared to 50.7% for the men in the CG
- The difference was statistically significant (p=0.05)



Male graphics grades of CD, D, F, or W

- 15.3% of the graphics grades received by males in the EG were CD or lower compared to 19.3% for men in the CG
- The difference was not statistically significant



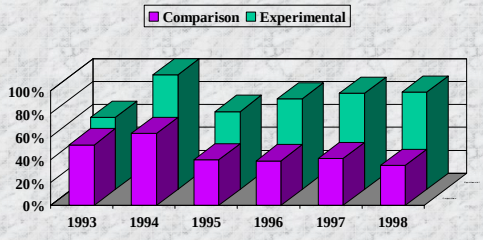
Average GPA in first calculus course

- Females
  - CG=2.47 (n=139)
  - EG=2.39 (n=86)
- Difference not significant
- Males
  - CG=2.16 (n=161)
  - EG=2.38 (n=75)
- Difference not significant

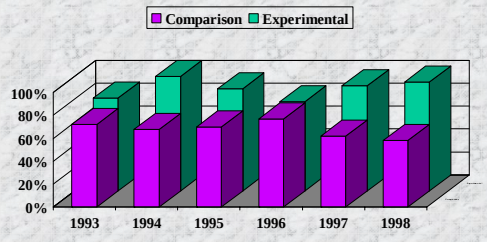
•Male-Female difference in EG not significant

•Male-Female difference in CG significant (p<0.025)

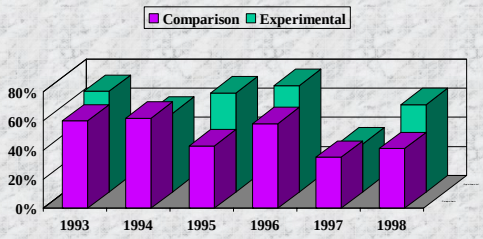
Retention of Female Students in Engineering



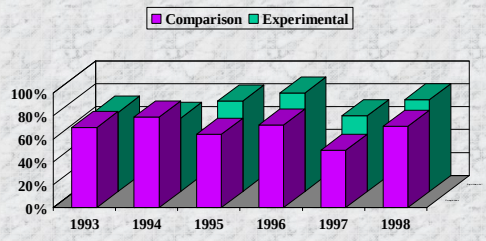
Overall Retention of Female Students at Michigan Tech



Retention of Male Students in Engineering



Overall Retention of Male Students at Michigan Tech



Raw Retention Data

Comparison Group Male n=200	Comparison Group Female n=161		Experimental Group Male n=85	Experimental Group Female n=90
62 (31.0%)	51 (31.7%)	Not Retained	21 (24.7%)	10 (11.1%)
34 (17.0%)	33 (20.5%)	Retained at MTU, not COE	12 (14.1%)	11 (12.2%)
104 (52.0%)	77 (47.8%)	Retained in COE	52 (61.2%)	69 (76.7%)

Differences in Retention Rates

- Differences between the retention rates for male students in the comparison and experimental groups were not significant
- Differences between the retention rates for female students in the comparison and experimental groups were significant ($p<0.0002$)
  - Both overall and within engineering

For students who were not retained:

- Men in the CG were just as likely to do poorly in calculus (45.9%) as were men in the EG (42.8%)
- Men in the CG were more likely to do poorly in graphics (37.9%) than were men in the EG (15.8%) ($p=0.0734$)

For students who were not retained: (continued)

- Women in the CG were more likely to do poorly in graphics (40.7%) than were women in the EG (10%) ($p=0.0768$)
- Women in the EG were more likely to do poorly in calculus (80%) than were the women in the CG (29.1%) ($p=0.0456$)

Conclusions

- Engineering has many “Gateway” courses
  - Typically thought of as Calculus, Physics, and Chemistry
- For women, and for some men, Engineering Graphics may be another Gateway course
- By developing and implementing a course to improve spatial skills we have positively impacted the performance and retention of engineering students, particularly women