The Effect of Spatial Experience on Engineering Students' Visualization Abilities

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Visualization ability was tested and compared to skills used in engineering for two introductory graphical design classes. Students were given a mental rotation task, a spatial memory span task, a verbal memory span task, a measure of controllability of visual imagery, a measure of vividness of mental imagery, and finally a survey developed to determine motivation for choice of major. We expected to find that students who performed better on the visualization tasks would have higher grades in the class. We also expected design class experience to improve students' visualization abilities. We found that spatial skills measured before training related to graphics grades.

The ability to visualize objects and situations in one's mind, and more specifically the ability to manipulate those visualizations is an important skill for those in the engineering field. It has been shown repeatedly that spatial ability is a reliable predictor of success in an engineering graphics design class (Besterfield-Sacre, Atman & Shuman, 1997; Gimmestad, 1990; Hsi, Linn & Bell, 1997). As technology provides us with ever more realistic and easier to use computer design programs, the skills and knowledge necessary for success is likely to change as well. With cooperation and support from the engineering department at Penn State Erie, the Behrend College, we studied the influence that experience with a new, advanced computer drafting program had on visualization abilities of freshman engineering and engineering technology students.

A key to success in any engineering graphics design class, by definition, is the ability to read, create, and understand orthographic and isometric drawings of a given part. An orthographic drawing is a three dimensional line representation of an object, while an isometric is a series of two dimensional drawings that include views of up to six sides of an object. These isometric and orthographic drawings are the tools used by those in the engineering field to transfer information about an object's exact shape and dimensions. The ease with which people are able to comprehend these drawings is directly related to that person's success in the graphics design class. Subsequently, it is hypothesized that the visualization skills that make such comprehension possible should prove to be important.

It has been shown that experience with visualization tasks can significantly improve an individual's ability and confidence in that area. This is particularly true for those who begin study with inferior skills (Hsi, Linn & Bell, 1997). This suggests that while a certain degree of visualization ability may be innate, performance is also dependant on experience, and therefore it is a learnable skill. This is supported by Peters, Chisolm and Laeng (1995) and by Greenfield, Brannon and Lohr (1994), who found evidence that long-term video game playing increases performance on a Paper Folding Task.

The implications of the differences between classifying performance on visualization tasks as ability or skill becomes even more important when current literature is reviewed closely. While it is true that many of these skills can be improved with practice and exposure, it is also true that there are distinct differences in ability occurring within the population. For example, sex differences have been found on a mental rotation task in children as young as primary school age, (Voyer, Voyer & Gryden, 1995; Collins & Kimura, 1997; Kerns & Berenbaum, 1991). These differences, however, are not always so well supported, as there are numerous studies where no sex difference is found at all (Voyer, 1997). It is also true that men vastly outnumber women in engineering and engineering related programs (Besterfield-Sacre, Atman & Shuman, 1997). This complicates the issue even further, because the existence of a gender difference on only one task cannot begin to account for such vast differences in choice of profession.

Our current lack of understanding about the cognitive factors involved in the skills necessary for engineering merits further research into working memory theory. The cognitive processes behind students' individual differences may be related to the visuo-spatial sketch-pad, a construct of A.D. Baddeley's theory of working memory (Baddeley, 1986). Baddeley theorized that there is a certain amount of "working memory" available with which people can actively process information. This working memory is made up of three distinct parts. The central executive is the part of the working memory that we directly control, and it helps us organize the rest of our working memory. The central executive is comparable to conscious thought, and it is responsible for decision making. It could be described as the amount of information available to a person for concentration on a task. Attached to the central executive are at least two automatic processing centers; the visuo-spatial sketch pad for mental images, and the phonological loop for speech and language perception. While these attached processing centers have some capacity to function on their own, they also draw from some of the available memory allotted to the central executive. This may help explain why we cannot concentrate on too many tasks at the same time.

Baddeley's theory, however, does not on its own explain the observed patterns of ability in engineering students. The effects of the two attached processing centers and their respective functions are usually only related to basic processing. Evidence suggests that the separable subsystems do not play a major role in more complex cognitive tasks (Shah & Miyake, 1996). What, then is their effect on a student's ability to manipulate orthographic and isometric drawings? It is not clear exactly how spatially complex these tasks are, and if they are complex, how important the simpler underlying processes might be to success. To fully understand what skills are necessary for engineering, we must observe both the overall skills present, as well as the basic processes that combine to support those skills.

Advanced design packages have the potential to facilitate students' use of the programs themselves, and at the same time increase the students' visualization abilities. The first way it can do this is simple exposure. As we mentioned earlier, use of these mental processes can improve a student's skill, especially for those with little experience. This experience is enhanced compared to previous computer design packages such as CAD (Computer Aided Design) because it allows the user to very easily go from an orthographic to an isometric view, and back again. Also important is the fact that something changed in one view is automatically changed in all views. In the colored, solid, isometric representation, a designer can view the object from any perspective merely by dragging the mouse. Even the simple addition of color has been shown to aid in learning visualized mental rotation (Seddon & Shubber, 1985), so modern graphics packages are quite a step up from the line only drawings of previous programs. Finally, these new programs facilitate the initial learning curve by not forcing the user to choose an exact size or dimension at the initiation of a sketch. Rather, a vaguely proportional drawing can be built, and then constrained to a particular size later on.

To address these issues, we went beyond visuo-spatial skills such as those displayed with a mental rotation task. We also looked at more basic processes like visual span and verbal span to create a more complete picture of the cognitive functions involved in such a task. The study also includes questionnaire data that should give us some information about any social constructs that might effect the abilities of engineering students, or even alter the population that decides to attempt engineering as a major.

Method

Participants

The participants were 240 undergraduate students at Penn State Erie, the Behrend College. Participants received either course credit or were paid $5.00 for half-hour portions of the project. Engineering (ED&G) and engineering technology (EGT) students enrolled in a drafting class in fall semester at a small northern college comprised the experimental condition. The graphics class for the engineering technology students included more direct experience with an advanced graphics package, while the engineering students received more instruction in the theory behind the applications. Both groups, however had significant experience with graphical drawing. A control group of approximately 60 introductory psychology students were selected from the human subject pool.

Materials

Tests administered include a demographic and motivational questionnaire, a mental rotation task, a visual span task, a verbal span task, the Short Betts' Questionnaire upon Mental Imagery or QMI (Sheehan, 1967), and the Controllability of Visual Imagery Questionnaire (Gordon, 1949). At the end of the semester, subjects in the experimental condition were given orthographic and isometric drawings that they had to convert from one form to the other. Student SAT scores were requested from the registrar and obtained after receiving students' permission. Testing was done using MEL Professional version 2.0 (Psychology Software Tools, 1995). A creativity test was given to the engineering students at the beginning of the semester.

A computerized version of the 3-D mental rotation task developed by Vandenburg & Kuse (1978) was used to test spatial ability. Two shapes were presented simultaneously, and the participants were asked to decide if they were the same shape or two different shapes. There were two practice trials, and forty experimental trials. The stimuli were presented randomly between subjects.

Spatial capacity was measured with a computerized version of the task developed by Shah, Priti, Miyaki & Akira in 1996. In this task, a two dimensional letter is presented to the participant. Each letter is either mirrored or not mirrored. Each letter is also oriented in one of eight evenly spaced directions in a 360 degree circle around the letter. For each set of trials, which increases from two to six, the students must answer "normal" or "mirrored" for each letter in the set. Then, when he or she is finished with each letter in a set, he/she must point to the direction of the top of each letter in the sequence. The highest level at which a participant can consistently remember all of the orientations of a letter (three out of five trials), is that subject's spatial span. Scores on this task range from 1 to 5. As a control for the scoring method, we also collected the total number of correct trials even if there were not enough correct for a participant's span level to move up.

Participants' verbal span was tested with an adaptation of a test developed by Daneman & Carpenter (1980). Students were asked to read consecutive sentences and then to remember the last word from each sentence read. Set size in this test increased from two to six. This was scored in the same manner as the spatial capacity task.

The Randomized Short Betts' QMI was used to establish vividness of mental imagery. This test is questionnaire in form, and it simply asks the subject to rate on a seven point scale how realistically they can imagine perceiving different things. For example, a subject might be asked to imagine tasting salt, and then to report on how close his or her imagining was to the actual experience of tasting salt. The Controllability of Visual Imagery Questionnaire (CVIQ) was used to measure controllability of mental imagery. Many people are not able to control what they visualize even if the visualizations are clear. An example of how this test works is it might ask the person to picture a car wrecking, and then afterwards asks if they can picture the same car driving safely along the road, because for many people the original image persists. Both of these tests are readily available to be used for research.

The Interest In Engineering (IIE) questionnaire that was designed for this study was loosely based on previous research focused on reasons for choosing one's major. For example, we asked about the influence of the students' parents and expected pay on selection of major. The questions attempt to uncover any motivations for becoming an engineer that are not related to perceived talent at that task.

A creativity task was also administered to the engineering and engineering technology students. It was a measure that the engineering faculty had been administering in the past, and it was thought that design creativity might be related to more flexible methods of visualization. Creativity was measured by presenting the students with a drill, and with no further explanation, requesting that each student sketch as many different "holders" for the drill as he or she could think of. They were each instructed to sketch at least five holders. The definition of holder was anything that would support the weight of a drill.

Procedure

Each participant completed an informed consent form before participation in the experiment. On the first meeting of each graphics class, the students completed the Controllability of Visual Imagery Questionnaire, the Betts' Questionnaire upon Mental Imagery, the Interest In Engineering survey, and the verbal span task using computers provided in the engineering lab. The answers for the Verbal Span task were written on a paper answer sheet that was later scored by the experimenter. The creativity task was administered by the same engineering faculty member in all of the graphics classes. Within two weeks of the initial testing session, each student met in the psychology laboratory to complete the mental rotation task and the visual capacity tasks individually. During the last week of the semester, the students who completed the initial requirements took the mental rotation task a second time. The graphics students took a paper and pencil test of their isometric/orthographic drawing skills. This test was required by the engineering department but is not used in tabulating the students' grades. It was completed by 32 engineering students and 110 engineering technology students. There was a substantial amount of data lost from the engineering students, due to problems with the implementation of the computer testing. In one case, 24 subjects' data were lost due to a power failure. Most students in this section chose the paper alternative provided them instead of meeting in the lab for later testing. There was another section where 25 subjects data were lost due to a data saving error in a testing session. Due to this and normal attrition rates, engineering students who successfully completed all parts of the study were a small portion of those who began.

A group of 60 undergraduates enrolled in an introductory psychology class, matched in age and semester standing with the graphics students was used to control for the effects of the graphics class. These students also took the mental rotation task at the beginning of the semester. The second testing session occurred largely during finals, and many students failed to show up for the second part. Due to this and to many students simply having fulfilled their research requirement, only 22 of these control subjects returned with usable data.

Results

Data points from the mental rotation task that fell below 100 or above three standard deviations from the grand mean were filtered to eliminate outliers. Table 1 shows the means and deviations of the major variables are provided in the table below. They are separated into Engineering Technology, Engineering, and Control subjects.

Table 1 *Descriptive Statistics of Major Variables by Class*

	Engineering Technology			Engineer			Control		
Variable	M	SD	N	M	SD	N	M	SD	N
Imagery questionnaires									
Controllability questionnaire	2.73	.38	113	2.76	.26	64	2.68	.36	22
Betts' Questionnaire	2.11	.33	113	2.06	.40	63	1.72	.27	22
Scholastic Aptitude Test sections									
Verbal	518	74	131	534	70	64	430	66	20
Quantitative	562	64	131	548	74	64	440	50	20
Initial Mental Rotation Task									
Reaction time(msec)	4110	1262	73	4113	1242	60	1325	1755	22
Accuracy (percent)	79	12	73	69	15	60	40	11	22
Final Mental Rotation Task									
Reaction time(msec)	3994	1043	47	4001	1283	19	2502	1397	22
Accuracy (percent)	87	10	47	.77	14	19	50	12	22
Spatial Span Task									
Span	3.59	1.25	101	3.63	1.25	36	3.07	1.27	22
Total Correct	9.46	4.45	101	10.06	4.09	36	7.32	4.28	22
Verbal Span Task	3.55	.92	132	3.69	.86	35	3.36	1.07	22
Class Assessment									
Orthographic/isometric grades	89.88	9.86	110	78.00	21.04	32	na	na	na
Graphics only grades	88.23	6.12	30	83.9	11.91	30	na	na	na
Class Grades (out of a 4)	2.93	.99	129	2.83	1.08	33	na	na	na

The first set of analysis focused on the relationship between the major variables for the engineering students. A series of Pearson R correlations is shown in Table 2. Mean accuracy on the initial mental rotation task correlates significantly with grades in the graphics portion of the class. Accuracy also correlates with visual span and quantitative SAT's, but not with verbal span, suggesting that they are not related functions. Reaction time on the mental rotation task correlates negatively with total correct on the spatial span task and with scores on orthographic/isometric drawings. These correlations show that spatial span might be able to predict performance on this area of engineering. The orthographic/isometric drawing scores also correlate with the quantitative SAT's. Graphics grades in turn correlate with both isometric/orthographic drawings and with accuracy on the mental rotation task. Graphics grades are an important part of the grading system in a graphics class, so everything that effects performance on the graphical portion of the class also effects the overall grade.

Table 2. *Correlations of Major Visualization Variables*

Subscale	2	3	4	5	6	7	8	9	10	11	12	
Engineering Technology												
1. CVIQ	.40*	.09	-.03	-.07	.06	.01	.08	.20*	.02	.21	.08	.
2. Betts' QMI		-.06	-.09	-.03	.04	.10	.13	.14	-.10	.03	.10	

3. Verbal SAT	.39**	-.08	-.05	-.03	.02	.21**	-.02	.02	.10
4. Quantitative SAT		-.02	.28**	.16	.23**	.05	.17*	.09	.26**
5. Initial MRT RT			.15	-.12	-.17*	-.06	-.31**	.13	-.05
6. Initial MRT AC				.23**	.31**	.17	.15	.40*	.19
7. Spatial Span					.86**	.14	-.01	-.01	-.00
8. Spatial total						.12	.02	-.03	.04
9. Verbal Span							-.18*	.11	-.11
10. Ortho/Iso								.54**	.51**
11. Graphics grades									.86**
12. Class grades									

A paired samples t-test was used to compare scores on the mental rotation task recorded at the beginning and the end of the semester. We expected to find that students in the engineering graphics class improved more over the course of the semester than would the control subjects. Engineering technology students improved significantly in accuracy for the task $t(46) = 4.7$, $p<.01$. There was no significant difference for reaction time found $t(46) = 1.86$, $p>.05$. Engineering students showed improvement in reaction time $t(15) = 2.32$, $p<.05$, however they did not change significantly in accuracy $t(15) = .93$, $p>.05$. The control population improved significantly in accuracy $t(21) = 4.69$, $p<.01$, but the also took significantly longer, $t(21) = 2.1$, $p<.05$.

There were no significant differences in visualization scores between those who dropped or failed the classes and those who completed them.

Discussion

The results of this study support our hypothesis that some improvement in visualization ability took place over the course of the semester for engineering students. On the mental rotation task, EGT students improved in accuracy, ED&G students improved in reaction time, and the control group showed an accuracy - speed trade off. While this trade off makes it difficult to make any strong claims about the meaning of the results, we can say that of the three samples, only the control group did not show clear, statistical improvement.

The correlations suggest that visualization ability is indeed important to success in a graphics course. Reaction time on the initial mental rotation task significantly predicted performance on an orthographic and isometric drawing test administered at the end of the semester. In lieu of the learning that we have already shown to have taken place, this is quite a powerful finding. Even after an entire semester of exposure to spatial manipulation, the students who entered the class showing a aptitude left with better skills at creating these drawings. Secondly, students' ability to create and interpret these drawings was significantly correlated with their final grade in the class, even though these particular drawings were not part of their grades. This shows the importance of this skill, and subsequently the importance of the ability for engineering students to mentally manipulate visual information. These results are also supported by the correlation of graphics grades with the initial mental rotation task and with final grades in the class. The graphics portion of the class grade included both students' ability to use an advanced graphical design package to create a part, and their ability to read the kind of drawings used at the end of the semester. While the graphics grade / final grade correlation is obvious, these data still serve to support the rest of the study.

These results show that visualization ability does have a strong effect on performance in an engineering class. Not only do those who enter with better visualization skill perform better overall, but students' spatial skills improve during the course of the class. It remains to be seen whether or not improving those initial scores can improve students' grades. Further research in the area should investigate the performance differences between those students who are given spatial instruction outside of the classroom, and those who are not.

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Acknowledgements

This project was funded by a grant from the Penn State Undergraduate Research Awards, and from the Schools of Humanities and Social Sciences and Engineering and Engineering Technology.