Assessing and Training Spatial Visualization: Free Tools from the VIZ Project

D. G. Blasko
Department of Psychology
Penn State Erie, The Behrend College, Erie, PA 16563

K. A. Holliday-Darr
Department of Mechanical Engineering Technology
Penn State Erie, The Behrend College, Erie, PA 16563

J. D. Trich Kremer, J. J. Hodge, K. M. Stranahan, K. E. Sementilli and E. Bliley
Department of Psychology
Penn State Erie, The Behrend College, Erie, PA 16563

ABSTRACT - *Spatial reasoning is a critical cognitive component of engineering graphics, and unfortunately students come into college with widely varying skills. Women and those from lower socio-economic status (SES) are more likely to have weak skills. The VIZ project is an interdisciplinary research project involving faculty and students from engineering technology and psychology. The goals of the project are to develop tools to assess and improve spatial skills. In this media showcase paper, the VIZ website http://viz.bd.psu.edu will be demonstrated and we will discuss ways to assess spatial skills and analyze data on the VIZ website for free. We will showcase a series of spatial training activities that have been shown to be helpful to students as well as enjoyable. We will also discuss some on-going research projects that suggest important issues that should be considered in the engineering graphics classroom.*

I. VIZ: History & Website

Well developed spatial thinking has been shown to be important in a wide variety of careers, especially in STEM fields such as engineering graphics (Committee on Support for Thinking Spatially, 2006). A major component of engineering graphics classes deals with the ability to mentally represent three dimensional objects and translate them to two dimensional representations. While verbal skills are a major focus of the K-12 curriculum, spatial skills, arguably the other half of sound cognitive development, are largely ignored. Poor spatial skills often leave first-year engineering students at a disadvantage that can contribute to low grades and poor retention. Therefore, it is understandable that the average incoming freshman has little knowledge of what spatial skills are and that these skills can and should be improved.

The Visualization Assessment and Training Project (VIZ) was developed at Penn State Erie starting in 1999 to test incoming engineering students on a number of potential variables that might influence success and retention in 1st year engineering courses (Blasko & Holliday-Darr, 1999) such as educational background, motivation for college, parental influence, and verbal and spatial skills. They found that math SAT scores and scores on tests of various spatial abilities such as mental rotation were the strongest predictors of first-year GPA and retention. Importantly, spatial skills predicted variance over and above that explained by math SAT scores alone. This led to the development of the VIZ website: http://viz.bd.psu.edu/viz/ (Blasko, Holliday-Darr, Mace, & Blasko Drabik, 2004).

The VIZ Website

The VIZ website allows users from anywhere to test spatial skills and receive immediate feedback on their performance. This can be extremely useful for self-assessment or for more rigorous pre and post testing to measure training effects. The tasks on the site are based on a meta-analysis of existing research on spatial cognition (Voyer, Voyer, & Bryden, 1995). The VIZ website focuses on three separable spatial components: 1) *mental rotation* (rotating blocks), the ability to manipulate three-dimensional objects in space in order to imagine them from a different perspective or orientation, 2) *spatial visualization* (paper folding), the ability to manipulate complex spatial information when several stages are required to produce the correct answer, and 3) *spatial perception* (water-level task), the ability to determine spatial relationships among objects despite distracting information.

Mental Rotation Task. (Blasko, et al, 2004). The mental rotation task was adapted from the problems used by Vandenburg and Kuse, (1978). Two block figures are shown and the participants make a same/different judgment (Figure 1). Response time and accuracy are collected for each trial. The site has 16, 32 and 48 trial versions. There are two pools of items so if a user returns to the site a different set of problems will be given.

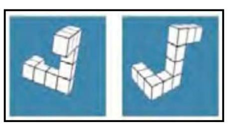

Figure 1. Sample Mental Rotation Task problem.

Paper Folding Task. Spatial Visualization (Blasko, et al, 2004, www.viz.bd.psu.ed/viz/) An object is shown folded and participants are given two unfolded figures and asked to choose which one correctly represents the object (Figure 2). This task has no time limit and contains 15 trials. Response times and accuracies are collected.

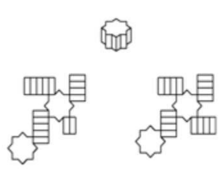

Figure 2. Sample Paper Folding problem.

Water-Level Task: Spatial Perception (Blasko, et al, 2004, www.viz.bd.psu.ed/viz/) adapted from Piaget & Inhelder, (1956). Participants are asked to imagine that a bottle shown at varying orientations is half full and asked to draw a line to represent the water level (Figure 3). Response times and accuracies are collected during the eight trials task. The task has no time limit.

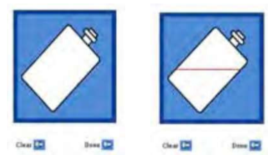

Figure 3. Sample Water Level problem.

Of the three tasks, mental rotation has been shown to have the most consistent and robust gender difference favoring men and yet this spatial component is an important skill for many Science, Technology, Engineering, and Mathematics (STEM) related occupations.

A spatial working memory task was later added to the site because working memory (the ability to hold and process information in active memory) and has been shown to be a critical component when solving cognitively demanding tasks. This task was based on work by Shah & Miyake, (1996) who suggested that spatial working memory may be different from verbal working memory. Although this claim remains controversial, what is clear is that much of the average student's trouble with the type of visualization tasks done in the engineering graphics classroom is based on difficulty maintaining the mental image as it is modified. There is evidence that working memory training may be extremely useful in improving spatial skills (Fitzhugh, S., Chein, J., Morrison, A., Newcombe, N. & Shipley, T. , 2009)

Upgrades to the VIZ site.

Although the site has been very useful to our university and others, the initial site had some drawbacks. The access database would occasionally fail to write a new record if too many users sent data at the same time. In addition, users outside the university needed to ask us to query the database if they wanted raw data and to coordinate IRBs to gain permission to use the site. The site has now been reprogrammed with a more robust SQL server platform and has macros available for download of the raw data. Our consent form allows the use of the site if one is 18 or older. For younger populations the users may need additional parental consents. On the new site we have also added a new survey, the Santa Barbara Sense of Direction Scale, (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). This may help us discover whether a fourth area of spatial thinking, wayfinding and sense of direction, is related to the more commonly studied tasks such as mental rotation.

II. VIZ: Areas of Research

The VIZ project also conducts research on spatial thinking and particularly on the factors that influence individual and group differences in performance. For example, we know from our own work and research in cognitive science that cognitive performance and the effectiveness of training efforts are influenced by many factors outside of an individual's skill level. For example if one's own stereotypes about your group "I'm a women and women aren't very good at this," are activated, it can lead to performance declines. This has been well studied in the math domain, where simply checking a box indicating one's sex as male or female before taking a test, has been shown to lead to performance declines for women (Shih, Pittinsky, & Ambady, 1999). Much less is known about the influence of stereotype threat on spatial skills, but it is one area of critical importance for teachers working with diverse populations. For example, if we try to encourage women or African Americans by talking about the importance of diversity in class we may activate unconscious stereotypes and run the risk of actually impairing performance.

Another critical area of research is the cognitive strategies that people use in spatial visualization. For example, there is some evidence that imagining yourself rotating in space around an object, viewer centered rotation, leads to better performance than imaging the object itself rotating, object centered rotation (Wraga, Creem, & Proffitt, 2000). This research suggests a useful strategy for instructors to suggest to students in the classroom.

In the last few decades technology has increasingly allowed us to peer inside the working brain to the point where "brain-based learning" has now become a new fad in education circles. Therefore, it is important to understand how the brain processes spatial information and how it changes during training. In one pilot study, the VIZ group recorded event-related brain potentials before and after brief training using the Sheryl Sorby's training workbook (Sorby, Wysocki, & Baartmans (2003). We found clear differences in the patterns of brainwaves when participant's completed mental rotation tasks after training as opposed to before training. These differences were particularly prominent in the frontal regions of the brain known to involve working memory control.

In the last 100 years the cognitive and learning sciences have accumulated a wealth of knowledge about learning, remembering, and using information, and recently pulled this information together in a way that is easy to use in the real-world contexts such as graphics engineering education. An interdisciplinary group of researchers created a guide called "25 principles to guide Pedagogy and the Design of learning environments." In the VIZ project we use these principles in our research and training projects. Because it would take an entire paper to describe these useful principles here, we will simply mention that they are available at the VIZ website and at http://psyc.memphis.edu/learning/ .

III. VIZ: Spatial Games

While one focus of the VIZ project involves creating techniques to *assess* spatial ability, the other half goes a step further and attempts to *train* those who may not have proficient spatial skills. Our results of training spatial skills as part of the EnViSIONS project with college students and high school students have been described elsewhere (e.g., Blasko, Holliday-Darr and Trich-Kremer, 2009). Here we focus on describing the spatial games that our student teams have developed and that we use as part of our training efforts and may be useful to other faculty. They use sound learning principles from cognitive science and evaluations show that participants from middle school to college have found them both useful and enjoyable. Each game was designed to be able to be played in a 30 minute time frame. Detailed lesson plans of each game can be downloaded from the VIZ website.

Time Bomb

Time Bomb is a game that is designed to train perspective taking and encourage viewer-centered rotation. Players sit around a "bomb" with four separate hubs extending from it. Each hub contains five different color wires that run across it. A player selects a card from the deck that tells them which wire to cut. The directions vary in level of difficulty, an easy example might be, "cut the red wire that is to the left of the person across from you." The higher the difficulty, the more steps the player must mentally take to find which perspective to take in order to cut the correct wire. Players receive points for correct responses but incorrect responses make the bomb more likely to explode, so the game encourages everyone to mentally try every problem.

Figure 4. Students playing Time Bomb.

Pizza Delivery

The Pizza Delivery game was designed as a method to improve spatial visualization through way finding and mental mapping. The objective of the game is to take the role of either pizza delivery driver or navigator, and work as a team to deliver all pizzas to the correct locations around the game board. The game consists of a game board which depicts a city map with numerous locations spread around the board, and also a smaller map with which the navigator directs the driver around the game board. The navigator does not see the gameboard so they must mentally remember the cars location and the driver must remember the directions and apply them to their current location. Two teams compete to see how many pizzas's they can deliver without getting lost.

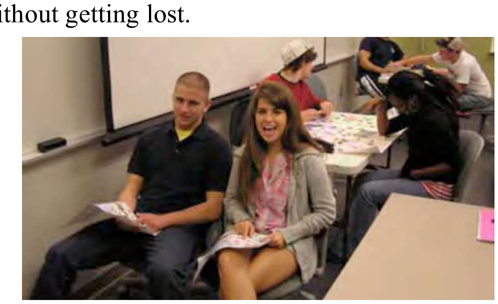

Figure 5. Students playing Pizza Delivery.

Lego Challenge

Students work in pairs and in the first part of the lesson are given Lego shapes from different perspectives which they must build as quickly as possible. They then use Lego builder® free software to rotate the example object to check their answers. Then they are given bags containing Lego pieces. The object of the game is to use all of the pieces and to build a fast but sturdy vehicle to transport their given character. Students may substitute up to four pieces from their packet with those in a large bin of parts. Each team races their car, and the one that travels the farthest without losing any pieces wins. Although Legos® are a popular toy, boys and children from middle to upper socio-economic status are much more likely to have had experience that girls or those from lower SES. Block building has been shown to improve children's understanding of structural relationships that are important to later work in mathematics. The game encourages teamwork, and develops skills in spatial visualization and design.

Figure 6. Students playing Lego Challenge.

Shapes

Spatial Shapes was modeled after the card game "spoons." The objective of Spatial Shapes is to obtain four of the same shapes in different colors. The wooden shapes are based on the Vandenburg and Kuse, (1978) shapes used in mental rotation tasks. We have versions painted the same color or different colors like suits of cards. The object is to match the shapes as they are passed from the dealer around the table as quickly as possible. When a player collects four of the same shape, they immediately grab a cube placed in the center of the table. For every team, there is one less cube than there are people. As soon as someone grabs a cube, the rest are to do the same. The person who did not get a cube does not mark their score card. The first players to spell "shapes" wins. The rapid pace encourages fast and accurate mental rotation that can be supported by actually turning the shapes.

Figure 7. Students playing Shapes.

Spatial Navigation Adventure (Wayfinding task)

Our newest game is the Spatial Navigation Adventure. Wayfinding is one's ability to navigate a particular environment by creating mental maps and making use of route information, cardinal directions and/or landmarks. Males tend to make better use of cardinal directions whereas females are more likely to utilize landmarks. The development of wayfinding skills is important not only for an individual in the real world, but may also encourage or enhance overall spatial skills. Students are divided into small teams of two or three and given a map with points of interest that represent ribbons attached to posts or trees with smaller ribbons that can be taken to accumulate points. There is one less ribbon at each point than the number of teams. Each team starts from a different place equal distance from a central compass used to orient the students.

Ribbons indicated on the map represent 1, 2, or 3 points depending on their distance from the start compass so the team must quickly orient and plot a strategy. The team that accumulates the most points and returns to the starting location within 30 minutes wins. Students are encouraged to use cardinal directions and map the two dimensional map to the 3-dimensional world. Their mental maps can be tested after the game by asking them to draw their routes.

Figure 8. Students playing Spatial Navigation Adventure.

Spatial Jeopardy

Spatial jeopardy is the ideal "wrap-up" game as it combines all of the spatial skills previously mentioned (e.g. mental rotation, spatial visualization, spatial perception, and spatial working memory). The game was modeled after the television show *Jeopardy*, however it includes categories analogous to topics covered in a spatial training course such as mental rotation, coded plans, and paper folding. Students are broken into teams and those who accumulate the most points in the different categories win.

Figure 9. Students playing Spatial Jeopardy.

IV. VIZ: Game Evaluations

The VIZ games have been developed over a number of years and each time they are used we make small changes to improve their effectiveness. We also modify them slightly for the age group and time frame we have available. Although we obviously cannot claim that playing one 30 minute game significantly increases spatial performance we can say that including the games as a standalone outreach activity or as part of a training course, can help students understand what spatial thinking entails and its real life applications while they have fun. We also hope that they will understand the importance of exposing their children, both male and female to a variety of spatial activities.

Our evaluations consistently show that the games are very enjoyable**.** Table 1 shows the data from a 2009 four week summer spatial training program with high school students between their junior and senior years (MCE/WISE, Minority College Experience, Women In Science and Engineering). On a four point scale from 1 strongly disagree to 4 strongly agree, the means for" enjoyed the activity" were all well above 3 (agree). The mean rating for "beneficial to my understanding/learning of the material," were still good although they were slightly lower than the enjoyment ratings.

In the four week program we had time to play only 4 games, so Table 2 also shows the ratings for a Fall 2008 college sample who were taking a 1 credit supplemental spatial visualization class and played Shapes, Time Bomb and Pizza Delivery. Those students also found the games enjoyable and beneficial although the ratings were somewhat lower than the summer program.

Table 1. Means and standard deviations for ratings of Lego Challenge, Shapes, Spatial Navigation Adventure, and Spatial Jeopardy (high school).

Enjoyable	Mean	Std. Dev.
Lego Challenge	3.45	.69
Shapes	3.45	.69
Spatial Navigation Adventure	3.70	.48
Spatial Jeopardy	3.80	.42
Beneficial		
Lego Challenge	3.18	.87
Shapes	3.09	.70
Spatial Navigation Adventure	3.70	.99
Spatial Jeopardy	3.44	.53

Table 2. Means and standard deviations for ratings of Shapes, Time Bomb and Pizza Delivery (college).

Supplemental Class Activity Ratings		
Enjoyable	Mean	Std. Dev.
Shapes (3D)	3.42	.41
Time Bomb	3.54	.28
Pizza Delivery	3.30	.52
Beneficial		
Shapes (3D)	3.25	.45
Time Bomb	3.14	.38
Pizza Delivery	3.00	.58

V. Discussion.

The VIZ project continues to work to develop ways to assess and improve spatial thinking with the VIZ web site, research activities, and the development of hands-on activities for teachers from K-12 to college. Our goal is to make these materials available to anyone who is interested free of charge. The VIZ website continues to be improved and with a new more robust server, five spatial measures and easy data download it is accessible to anyone with a PC, internet connection and the appropriate plugins. Directions are available for using the site and for setting up a class affiliation at www.viz.bd.psu.edu/viz

We are also happy to share the results of our research and are interested in collaborations with others interested in understanding the factors that can influence spatial performance in an out of the classroom. Posted on our website are links to a number of helpful materials including the 25 learning principles discussed in this article and a link to the Spatial Intelligence and Learning Center sponsored by the National Science Foundation (http://www.spatialintelligence.org/) There you can find others interested in spatial learning, tests and measures, and an extensive bibliography of helpful articles

The materials that our interdisciplinary undergraduate teams have developed will be posted to the VIZ website as they are formatted as easy to use lesson plans with learning objectives, materials, directions and assessment strategies. We also invite the submission of new lesson plans for spatial activities that we will be happy to post to the VIZ website.

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