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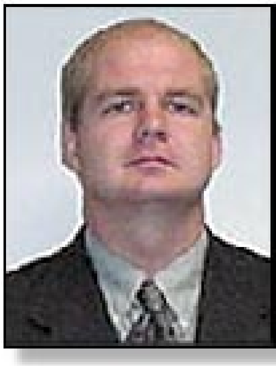

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Introduction

In industrial technology we utilize visualization in applications such as simulations, multi-media, modeling, and distance education. Each person has their own unique visualization skills. Even though we use these visualization skills continually, they have seldom been studied as a means of problem solving (Rieber, 1995).

The topics of engineering graphics and design are part of a common core of curriculum for all industrial technology and engineering programs. Spatial visualization is an established element of these topics (Miller, 1996) and is integral for success in graphics and engineering as a whole (Sorby & Baartmans, 1996). In fact, visualization skills have been found to correlate highly with successes in engineering and mathematics in general (McGee, 1979) even higher than verbal or intelligence test scores.

Computers have added a new dimension to the study of spatial visualization. The impact of high performance rendering and animation software, solid modeling packages, virtual reality, and online testing opens a number of doors for spatial visualization research and measurement. This paper will give the industrial technologist an understanding of spatial visualization fundamentals and trends as they relate to engineering graphics.

Spatial Visualization

Spatial Visualization Defined

Often the term "spatial visualization" is used interchangeably or has been combined into the broader terms of "visualization" and "spatial ability" (Braukmann, 1991). The term "spatial ability" also has many definitions which makes it difficult to be precise about its meaning (Eliot, 1983). Nonetheless, two main spatial factors consistently emerge from within the visualization discipline: spatial orientation and spatial visualization. McGee (1979, p. 893) defines spatial orientation as, "The comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented." For example, when a swimmer is diving, even though she maybe turning and twisting, she knows where the water is; a stunt pilot knows where the ground is during his maneuvers. Spatial orientation might involve the ability to predict the correct scenery given a body's movement relative to that scenery. Spatial visualization on the other hand is defined as, "the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimuli" (Mcgee, 1979, p. 893). Using these definitions, spatial visualization is the ability to manipulate an object in an imaginary 3-D space and create a representation of the object from a new viewpoint. For example, can one sketch (or close their eyes and see a picture of) the front, back, and the side of their house? Can they imagine what it would look like if they were flying over it in a small plane? Both spatial orientation and spatial visualization require some use of short-term visual memory. Spatial orientation requires only mental manipulation of a configuration in two-dimensional space while spatial visualization requires serial operations such as rotation in three-dimensional space or unfolding of flat patterns. Findings show spatial visualization has been correlated to success in mathematics while spatial orientation is more closely correlated to sense of direction and field dependence - field independence (McGee, 1979).

History of Spatial Visualization Research

Spatial visualization has been a central part of the engineering graphics curriculum for some time (Miller & Bertoline, 1991). Recent attention to spatial visualization is largely due to the vast changes in computer technology. Often when considering the history and philosophies surrounding spatial visualization, we need to look elsewhere for research. Math, science, and psychology have all contributed to spatial visualization research. More recently neuroscience has made important contributions to cognitive sciences. Early studies in the field gained knowledge on the relation of brain structure and memory from case studies of accident victims and other patients. Introduction of brain-imaging methods intensified this line of inquiry. PET research is a commonly used method where the pattern of cerebral blood flow is studied to identify patterns related to various tasks (Haberlandt, 1999). By capitalizing on neuroscience research and computing power our own discipline can further the practical aspects of spatial visualization research and application.

Eliot and Smith (1983) identified three distinct phases of the history on spatial visualization research.

> Phase One (1901-1938) dealt with an attempt by psychologists to identify a single spatial factor. Prior to this phase visual tasks were not considered an indicator of intelligence. Verbal tasks were viewed as the major indicator of intelligence. Several studies during this time led to the identification of a spatial factor that was important in determining intelligence. These studies established visualization as an important aspect of intelligence (Miller and Bertoline, 1991).

> Phase Two (1938-1961) began to identify several spatial factors and theorize how these factors varied. Two major categories of spatial factors were identified. The first dealt with the ability to recognize spatial configurations. The second included the ability to mentally manipulate those configurations. Measurement tools for the various spatial factors using pencil and paper tests were developed. It was during this time that the term spatial visualization arose.

> Phase Three (1961-1982) was an attempt to further separate the various spatial factors and establish sources of variation in them. Many studies found that age, sex, and experience were all sources of variation effecting individual differences in spatial ability.

Since Eliot and Smith discussed these three phases in 1983, a Phase Four may be emerging in engineering graphics. Phase Four deals with the process of establishing the effects of computer technology on spatial visualization skills and the subsequent measurement of these skills. This research began with establishing the computer as an effective 2D design tool and continues today using 3D design tools (Devon, Engel, and Foster, 1994; Jensen, 1986; Mohler, 1997; Sexton, 1992; and Sorby & Baartmans, 1996).

Factors Affecting Spatial Visualization Skills

Phase Three described by Eliot and Smith (1983) has the greatest implications for research done today. Miller (1991) does an excellent job of summarizing the various research and theories surrounding spatial visualization research, predominantly from Phase Three. Before examining the factors that affect spatial visualization, an understanding of spatial cognition is appropriate. Olson and Bialystok (1983, p.2) define spatial cognition as:

> Inner space or spatial cognition, the spatial features, properties, categories and relations in terms of which we perceive, store and remember objects, persons, events, and on the basis of which we construct explicit, lexical, geometric, cartographic, and artistic representations.

Miller (1996) states, " Spatial cognition is the underlying mental process that allows an individual to develop spatial abilities." Piaget and Inhelder (1967) identified four stages of spatial cognition based upon age. The first, *the sensomotor stage*, occurs from birth to approximately two years. The child exhibits a purely egocentric view of the world and knowledge is gained by perceptual sensation. The intuitive or *pre-operational stage* occurs from ages two to about seven. The child continues to function in an egocentric frame of reference and knowledge is gained by touch. The *concrete operational stage* occurs between ages seven through twelve. During this stage children begin to develop spatial thoughts which are independent of images but still require the actual presence of the object being manipulated. The last stage, *formal operational state*, occurs from thirteen to adulthood. Individuals can make use of infinite spatial possibilities and complex mathematical concepts.

Many psychological studies, like Miller's, identified several factors effecting spatial ability: age, experience or individual differences, and gender (Liben, 1981, McGee, 1979). Other possible factors have been proposed such as right-brain/left-brain; these effects continue to be fully explored.

Deno (1995), in a study of beginning engineering students (N=396), examined the effects of previous design and mechanical experience on the basis of spatial visualization ability of the subjects. Among male subjects Deno found non-academic activities such as model building, sketching, and assembly of parts during the high school years had the greatest positive correlation to spatial visualization. Those who were highly involved in these types of activities scored high on spatial visualization tests. Among females however, this relationship was not statistically significant. Actively playing video games was the only activity for high school-aged women that significantly improved their spatial ability skills. Boys who had played with Legos and "Lincoln Log" type toys in preschool and elementary school also scored significantly higher on spatial visualization tests. Girls had similar results from activities that were less tactile and more visual, such as educational TV during this same period. As indicated in Deno's (1995) study, a relationship has been shown to exist between gender and spatial visualization skills. Eisenburg and McGinty (1977) also found that spatial ability differences did exist between sexes but the differences depended upon the students' field of study. They concluded that women may be two to three times more likely to lag behind males in 3D spatial skills. This finding would advocate a course to address deficiencies in their backgrounds for women going into engineering or technical fields (Sorby & Baartmans, 1996).

Salthouse and Mitchell (1990) found that many of the age related effects on measures of relatively basic abilities were largely independent of the amount of relevant experience. This would indicate that a possible positive relationship between age and spatial visualization performance exists.

In engineering graphics literature, age and experience often have been found to not have a statistically significant correlation to spatial abilities even though it has been found significant in psychological research (Korosik, 1982). Gender, on the other hand, has been shown to make a difference in spatial abilities. Devon (1994) found that previous high school drafting or CAD experience had no effect on spatial visualization skills. Sexton (1992) found that neither prior experience nor attitudes were significantly correlated to scores on measures of spatial visualization. Further studies are needed to establish if the field of study, in-fact, influences the significance of these other factors.

Can Spatial Visualization Be Taught?

Several studies have claimed spatial visualization skills cannot effectively be taught through typical instructional methods (Salkind, 1976). Bertoline (1988) suggests that spatial visualization skills are developed through life experiences. He proposed that children who are exposed to appropriate learning environments would have stronger spatial visualization skills later in life.

However, an equal number of studies have found that spatial visualization can be improved through instruction (Gillespie, 1995). Sexton (1992) concluded that it is indeed possible to improve spatial visualization skills if the instruction was appropriate and the delivery time sufficiently long. A limited number of studies have shown spatial visualization can be taught in a short amount of time. Braukman (1991) was able to significantly improve spatial visualization skills during just eighteen hours of engineering graphics instruction.

At the present time the whole question of whether spatial visualization can be taught remains unanswered. As shown, there are many contradicting beliefs and research studies. Most professionals in engineering graphics have come to an acceptance that spatial visualization skills can be improved through experience, which tends to contradict the findings on many psychological studies. What type of experience and the length of the experience have yet to be firmly established.

Current Research

The human/computer interface continues to present opportunities for expanding spatial visualization research. "New human/computer interfaces should not only use graphics to display icons, images, and menus, but also maps, sequences, and animation to aid the user in knowing where he or she is and knowing how to get to the next desired step" (Norman, 2000). The mainstream usage of technologies such as simulation, animation, and virtual reality raises many questions. By using the previously mentioned technologies, can spatial visualization be significantly improved? If in fact improvements are significant, are they significantly different from traditional methods for improving spatial visualization. Does one need a certain level of spatial visualization ability to effectively use these technologies?

With the advent of large computer databases and menu hierarchies, spatial visualization ability has also become important in terms of navigation within the realm of computers and computer applications (Alonso, 1998). The human/computer interface has a direct relationship to the stress placed on the user's cognitive ability. Several studies have found technical aptitudes such as spatial visualization are significant factors in predicting human/computer interaction performance (Stanney, 1998). Cognitive stress is reduced if a user can easily perceive an interface, comprehend its functions, and solve problems based on an understanding of how something works (Norman, 2000). Yet the effects on spatial ability that result from simulations are unknown, as are the influences of virtual reality, and/or solid modeling software. For example, the creation of 2-D orthographic projections which once required a significant amount of spatial visualization ability might now require relatively little spatial visualization skill due to 3-D constraint-based modeling techniques.

The integration of virtual reality technology into existing CAD/CAM environments is now being used to improve quality and shorten design-to-manufacture cycle times (Steffan, 2000). Adapting current technical knowledge of spatial ability into the realm of virtual environments has just begun, while the application of virtual environments into "real world" practice is well underway.

Conclusions

Spatial visualization or the ability to perform complex mental manipulation of objects has been established as a predictor of success in several technology related disciplines. The value of this ability and changes in technology warrant attentiveness to teaching, history, and trends related to spatial visualization. Several factors including age, gender, individual differences, and experiences impact spatial visualization ability. Of these factors, experiences of sufficient length and type improve spatial visualization and may compensate for deficiencies caused by age, gender, or lack of the proper previous experiences.

As in the studies of Deno (1995), the right tactile and visual stimuli improve spatial visualization ability. Because the strength of the impact is often gender specific care must be taken in the selection of activities designed to improve spatial visualization. Traditional introductory engineering graphics design courses often utilize orthographic projection, missing line, sectioning, auxiliary view, descriptive geometry, and instrument drawing for the purpose of improving visualization skills. More recently some of these traditional topics are being reduced or eliminated in favor of 3D solid modeling, and the integration of design activities into the curriculum (Buchal, 2001).

A foundational knowledge of visualization research exists. The research of McGee (1979) and those similar are dated only by time and are still considered the basis for much of today's spatial visualization research. This knowledge will be greatly affected by emerging computer technologies. Application of established research knowledge to emerging technologies will ensure ample research opportunities for the Industrial Technologist into the foreseeable future.

Recommendations

Ever-changing technology looks to increase the breadth and complexity of spatial visualization issues as they relate to engineering graphics for some time to come. This may be why Bertoline (1991) and others promote a separate visualization discipline to deal with these issues. The commonality of engineering graphics with industrial technology and engineering programs presents an opportunity for our disciplines to attempt to answer some of the many questions related to spatial visualization. The author suggests the following research to deal with the issues surrounding spatial visualization:

Many of the studies discussed thus far are of limited size and scope. Variances in testing methods further strain the validity of these studies. The development of a generally accepted and computerized spatial visualization test must occur. Several hundred tests of spatial ability are in existence; adapting one or more of these tests to an online format would allow for the collection of large amounts of test data. Furthermore, computerized testing when combined with Virtual Reality Modeling Language (VRML) or similar technologies provides additional opportunities for testing using three-dimensional objects.

Animation, parametric solid modeling, and virtual reality technologies are all readily accessible for use in the classroom. Studies are needed to compare the variations between these technologies, from the impact of design using parametric solid modeling to rotating a 3D solid model using VRML. Variations within a particular technology must also be examined. Applying textures, colors, or lighting to a 3D model may significantly impact spatial ability.

Keeping up with changes in engineering graphics software is in itself a substantial task without considering the impact on more obscure but critical skills such as spatial ability. Multiple research opportunities have emerged as a result of new technologies and should be exploited. The application of previous and current multi-disciplinary research in combination with emerging technologies in our own discipline should act as the basis for further study.

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