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Using Computer-Aided Design Software and 3D Printers to Improve Spatial Visualization

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USING COMPUTER-AIDED DESIGN SOFTWARE AND 3D PRINTERS TO

improve spatial visualization

BY PETROS KATSIOLOUDIS and MILLIE JONES

BACKGROUND

Many articles have been published on the use of 3D printing technology. From prefabricated homes and outdoor structures to human organs, 3D printing technology has found a niche in many fields, but especially education (Photo 1). The education of technology and engineering students has come a long way from traditional instruction using hand drawings. Although drawings may still be a part of a student's learning, computer technology has been embraced in this field for several years. With the introduction of AutoCAD technical drawing programs and now 3D printing, learners can use 3D printed models to develop their spatial abilities in technology and engineering curricula. How does this compare to traditional hand drawings? Can students actually enhance spatial abilities more through computer drawings and 3D-printed models rather than hand drawings? Research suggests that although hand drawings are still a component of the learning process, newer technologies can now enhance a learner's ability to increase spatial ability, particularly spatial visualization.

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SPATIAL ABILITY

According to Gardner, spatial intelligence is one of the basic human intelligences: “the ability to perceive the visual-spatial world accurately and to perform transformations on those perceptions” (Lieu & Sorby, 2009, p. 3-2). Furthermore, spatial visualization is the ability “to imagine the rotation of a depicted object, the folding and unfolding of flat patterns, and the relative changes of positions of objects in space” (Miller & Bertoline, 1991, p. 9). Thurstone (1938) refers to spatial ability as a critical component of intellectual ability. Furthermore, Thurstone (1950) identified seven factors related to human intelligence, with three specifically referring to visual orientation in space:

- **S1:** “The ability to recognize the identity of an object when it is seen from different angles” (p. 518).
- **S2:** “The ability to imagine the movement or internal displacement among the parts of a configuration” (p. 518).
- **S3:** “The ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem” (p. 519).

Developed through spatial cognition, spatial ability can be described as the ability to form and retain mental representations of a given stimulus, a mental model, and may also be utilized to establish if mental manipulation is possible (Carroll, 1993; Höffler, 2010). This type of skill has been recognized as an individual ability, somewhat autonomous of general intelligence (Hoffler, 2010). The function of spatial ability relates to an individual's ability in “searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, forming mental representations of those forms, shapes, and positions, and manipulating such representations ‘mentally’” (Carroll, 1993, p. 304). According to research, it has been suggested that individuals with higher spatial

Photo 1. Many school labs in America today are equipped with 3D printers. *Credit: TCEP Lab, Old Dominion University.*

abilities have a wider range of strategies to solve spatial tasks (Gages, 1994; Orde, 1997; Pak, 2001; Lajoie, 2003).

SPATIAL VISUALIZATION

Spatial visualization is perhaps "the most [fundamental and] gratifying part of engineering graphics instruction" (Contero, Company, Saorín & Naya, 2006, p. 472). Improving technology and engineering learners' spatial skills is considered a chief component in technical education, which is typically found in the first-year technology education and industrial technology curricula as well as engineering education. It is essential that learners develop spatial skills early in technology and engineering curricula to ensure success and thus promote retention (Sorby, 2009).

According to Contero, Company, Saorín & Naya (2006), visualization skills have a learning outcome "described as the ability to picture three-dimensional shapes in the mind's eye" (p. 472). It is widely recognized that spatial visualization skills and mental rotation abilities are critical skills for technical and engineering professions. According to Norman (1994), a learner's spatial skills are the most essential and significant predictor for success in manipulating objects and interacting with computer-aided design (CAD). Recognizing the importance of spatial abilities for engineering and technology fields and the instructional tools utilized, it is important that learners with poor spatial skills improve through appropriate instructional techniques. Sorby (2012) states that "students who have the opportunity to improve their spatial visualization skills demonstrate greater self-efficacy, improved math and science grades, and are more likely to persist in engineering" (p. 1).

According to several researchers, there are three major spatial elements used to test the spatial abilities of an individual—spatial relations, spatial orientation, and spatial visualization:

1. **Spatial Relations:** "The ability to imagine rotations of 2D and 3D objects as a whole body" (Martín-Dorta, Saorín, & Contero, 2008, p. 506).
2. **Spatial Orientation:** "The ability to orient oneself physically or mentally in space" (Maier, 1998, p. 71).
3. **Spatial Visualization:** The "ability to mentally manipulate, rotate, twist, and pictorially invert presented visual stimuli" (Gorska & Sorby, 2008, p. 1).

Research conducted by Katsioloudis, Jovanovic, and Jones (2014) looked at the differences in spatial visualization ability as measured through technical drawings and the impacts of model types (2D drawing and 3D drawings generated by computer as well as 3D printed objects) in industrial technology and technology education courses. The study concluded that the 3D printed model and 3D computer-generated drawing both provided statistically significant higher scores than the 2D drawing. These findings are congruent with an earlier study using a population of engineering technology students where it was found that students receiving the 3D-printed model treatment outperformed their peers who received two other models. Other research suggests instruction using computer-based 3D visualizations can provide learners with adequate classroom experiences for developing their spatial ability (Kwon, 2003; Woolf, Romoser, Bergeron & Fisher 2003). A Branoff & Dobelis (2012) study looked at the increase in 3D modeling. The two researchers asked the question as to whether or not students could still read and interpret engineering drawings. In addition, they inquired whether the ability to read these drawings related to spatial visualization ability. Branoff & Dobelis (2012) discovered that a relationship exists between reading engineering drawings and spatial visualization ability. However, few empirical studies have established the causal relationships in greater depth (Wang, Chang, & Li, 2006). Moreover, few studies have explored the effects of two-dimensional versus three-dimensional media representations on the influence of the spatial ability of undergraduate students (Wang, et al, 2006). Of the tools applied for improving spatial abilities, “sketching and drawing are…the most frequently used” (Contero et al., 2006, p. 473). According to Alias, Black, and Gray (2002), spatial visualization can be improved in engineering students through activities predominantly consisting of freehand sketching and object manipulation.

SPATIAL ABILITY USED IN ENGINEERING EDUCATION

As noted, spatial ability has been identified as having a positive correlation with learning achievements (Mayer & Sims, 1994; Mayer, Mautone, & Prothero, 2002). The use of physical object manipulations, freehand sketching on paper, and computer-aided sketching can improve the spatial ability of freshmen engineering students (Martín-Gutiérrez, Saorín, Contero, Alcañiz, Pérez-López, & Ortega, 2010). The early years of Engineering Design Graphics (EDG) (1920s-1940s) were based on the development and application of spatial ability testing in curricula. The emphasis during this time weighed heavily on using multi-view drawings to enhance a learner’s visualization ability. To date, three phases of research can be defined related to spatial ability in engineering education. First, in 1901-1938, the efforts emphasized the identification of visual tasks, and specifically, a single spatial factor. The second phase, from 1938-1961, emphasized the identification of several spatial factors: the ability to recognize spatial configurations and the ability to mentally manipulate configurations (Strong & Smith, 2001). The third phase, from 1961-1982, attempted to further isolate spatial factors, such as age, sex, and experience. As of late, a fourth phase of research may be emerging in the discipline of engineering graphics. This phase focuses on the effects of computer technology on spatial-visualization skills, as well as assessment instruments used to measure these skills (Strong & Smith, 2001). Spatial abilities, specifically visualization, play a critical role in the success of professions such as engineering, industrial and technical, mathematical, and scientific professions.

Researchers in engineering education, the U.S. Department of Labor, as well as major industry representatives have called for the improvement of spatial visualization ability in engineering and technology students (Ferguson, Ball, McDaniel, & Anderson, 2008). “Improving the spatial-visualization ability of engineering and technology students is a challenge for educational researchers” (Ferguson, Ball, McDaniel, & Anderson, 2008, p. 2). Although research has suggested “that spatial visualization ability can be improved through instructional methods,” there is no “clear consensus on what combination and duration of instructional methods is most beneficial for improving spatial visualization ability” (Ferguson et al., 2008, p. 2). According to Contero et al. (2006), in order to shift from a teacher-centered to a student-centered education paradigm model, there must be a critical analysis of the various engineering courses included in curricula. Furthermore, “teachers of `engineering graphics' should put the emphasis in spatial reasoning, since we do consider it to be a core competence for future engineers” (Contero et al., 2006, p. 471).

STATIC VS. DYNAMIC MODELS

The benefit of using static (Photo 2) versus dynamic visualizations (Photo 3) is a debated one. Few studies have explored the usefulness of static visualizations to those of dynamic visualizations (e.g., videos or animations), and the current state of the literature remains somewhat unclear (Kuhl, Sheither, Gerjets, & Edelman, 2011). A lengthy debate about the opportunities for using animation in learning and instruction has been ongoing over the past decade. More specifically, it has been indicated that dynamic visualizations often provide no advantages over static visualizations (Malone & Lepper, 1987). If advantages had been identified, it was due to the fact that more information was available in the animated than in the static version. Given this outcome, the focus turned to the question of when dynamic displays are more applicable in learning than static ones (Hegarty, 2004).

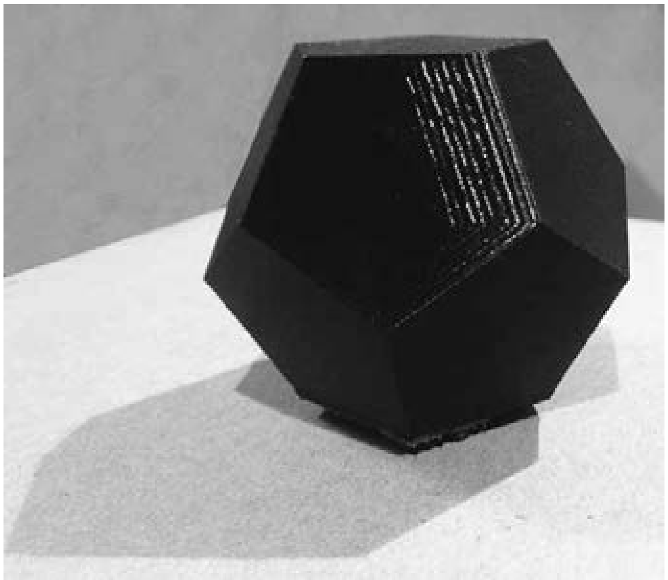

Photo 2 (above). Static 3D printed Octahedron. *Credit: Author.*

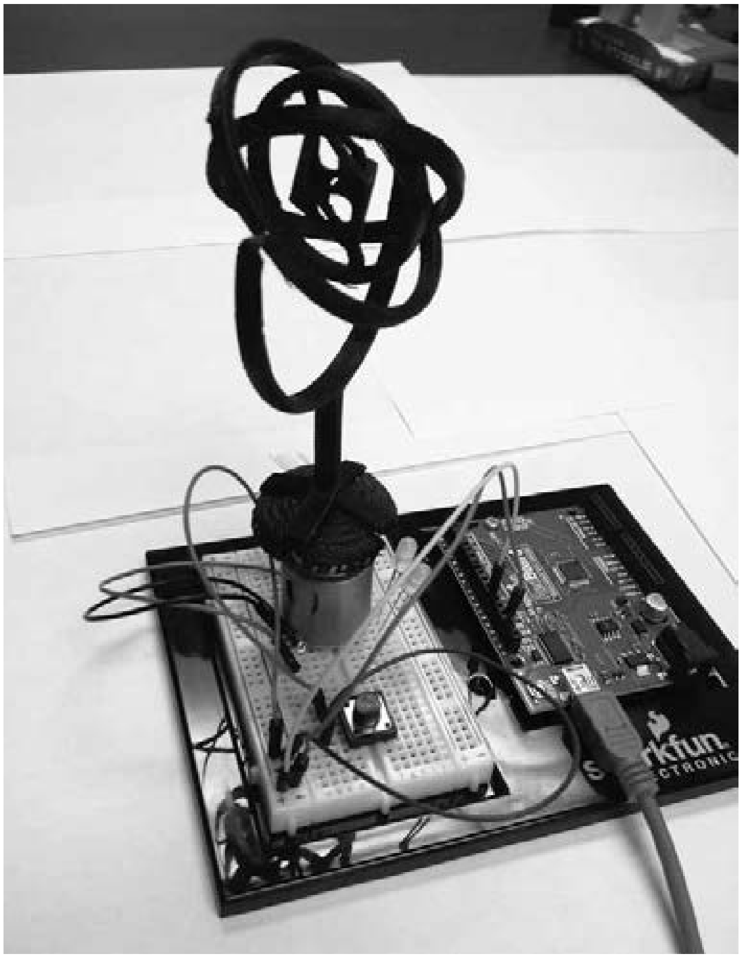

Photo 3 (right). Dynamic 3D printed Dodecahedron. *Credit: Author.*

DYNAMIC VISUALIZATIONS FOR DIFFERENT DISCIPLINES

Dynamic visualizations and 3D animations are assumed to offer an environment that assists in changes and improvements in a student's incomplete mental model (Wu & Shah, 2004). The introduction of computer-based design tools (CAD) and dynamic visuals are used in place of, or in addition to, static visuals today. Static and dynamic representations require different cognitive demands for learners when creating a mental representation (Lewalter, 2003). However, it remains controversial whether or not 3D models or dynamic visualizations actually enhance the learning process (Huk, 2006; Lewalter, 2003). While some researchers have indicated the possibility of dynamic visualizations in learning and improving spatial ability, there have been no definitive outcomes suggesting spatial ability may actually act as an enhancer, especially in learners with low spatial ability (Höffler, 2010; Huk, 2006; Hegarty and Kriz, 2008; Mayer and Sims, 1994). Höffler (2010) suggests dynamic visualizations have "a compensating effect for low spatial ability learners" (p. 266). Furthermore, Hegarty & Kriz (2008) suggest animations may act as a "cognitive prosthetic" for those learners possessing low spatial ability. Hays (1996) found a statistically significant interaction of spatial ability with learners possessing low spatial ability. In this study, the learners receiving animation made greater gains than those receiving no animations.

The world of technology has a great deal to offer education. With the introduction of computer modeling programs and 3D printing, the possibilities are endless. The focus of Science, Technology, Engineering, and Mathematics (STEM) in education from K-12 through college and beyond has stimulated the growth in using technology in many fields including many disciplines in education.

CLASSROOM ACTIVITIES

Many activities can be designed and used to help students understand the capabilities of 3D printers and to enhance their spatial visualization abilities through the process. One is to have students reverse-engineer a device, identify potential flaws, and, with the help of computer design software, redesign specific components that can be 3D printed (Photo 4). It is crucial, however, that the activity doesn't end at this point. Upon 3D printing, students need to test the new part and, if it doesn't provide better results than the existing one, to repeat the process for several rounds.

Photo 4. The gear that was redesigned and rebuilt using CAD and 3D printing technology to perform with higher efficiency. *Credit: Author.*

Activities such as the one described above are easy to correlate with the technological literacy standards first created by the International Technology Education Association (ITEA/ITEEA) in 2000. See Table 1 for correlations with the *STL* standards.

The evolution of 3D printers has opened many doors for the educators of the 21st century. Today, instead of just visualizing an object, students have the opportunity to design, build, and test any idea. However, it is crucial for teachers to realize that 3D printers are only a tool that can enhance learning experience and not something that can replace it. In many schools today, the administration will furnish labs with the latest technology but often without the support of appropriate curriculum and professional development. Such efforts are destined to fail, as technology rapidly changes and current curriculum without updates becomes irrelevant; therefore, teachers without the latest resources cannot be successful.

Table 1. Correlation With *Standards for Technological Literacy*

The Nature of Technology	Technology and Society	Design
Standard 1: Students will develop an understanding of the characteristics and scope of technology.	**Standard 4:** Students will develop an understanding of the cultural, social, economic, and political effects of technology.	**Standard 8:** Students will develop an understanding of the attributes of design.
Standard 2: Students will develop an understanding of the core concepts of technology.	**Standard 5:** Students will develop an understanding of the effects of technology on the environment.	**Standard 9:** Students will develop an understanding of engineering design.
Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.	**Standard 6:** Students will develop an understanding of the role of society in the development and use of technology.	**Standard 10:** Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
	Standard 7: Students will develop an understanding of the influence of technology on history.	

Note. Adapted from the International Technology Education Association (ITEA/ITEEA). (2000/2002/2007). *Standards for Technological Literacy: Content for the Study of Technology.* Reston, VA: Author.

REFERENCES

Alias, M., Black, T. R., & Gray, D. E. (2002). Effect of instructions on spatial visualization ability in civil engineering students. *International Educational Journal, 3*(1), 1-12. Retrieved from www.iejcomparative.org/data/volumes/v3n1.pdf

Branoff, T. J. & Dobelis, M. (2012). The relationship between spatial visualization ability and students' ability to model 3D objects from engineering assembly drawings. *Engineering Design Graphics Journal, 76*(3), 37-43.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies.* New York: Cambridge University Press.

Contero, M., Company, P., Saorín, J. L., & Naya, F. (2006). Learning support tools for developing spatial abilities in engineering design. *International Journal of Engineering Education, 22*(3), 470-477.

Ferguson, C., Ball, A., McDaniel, W., & Anderson, R. (2008). *A comparison of instructional methods for improving the spatial-visualization ability of freshman technology seminar students.* Paper presented at the 2008 IAJC-IJME International Conference, Nashville, TN. Retrieved from http://ijme.us/cd_08/PDF/37_IT305.pdf

Gages, T. T. (1994). *The interrelationship among spatial ability, strategy used, and learning style for visualization problems.* (Doctoral dissertation). The Ohio State University.

Gorska, R. & Sorby, S. (2008). *Testing instruments for the assessment of 3-D spatial skills.* Paper presented at the ASEE Annual Conference, Pittsburgh, PA.

Hays, T. A. (1996). Spatial abilities and the effects of computer animation on short-term and long-term comprehension. *Journal of Educational Computing Research 14*(2), 139-155.

Hegarty, M. (2004). Dynamic visualizations and learning: Getting to the difficult questions. *Learning and Instruction, 14*, 343-351.

Hegarty, M. & Kriz, S. (2008). Effects of knowledge and spatial ability on learning from animation. In R. Lowe & W. Schnotz (Eds.), *Learning with animation: Research implications for design* (pp. 3-29). Cambridge, England: Cambridge University Press.

Höffler, T. N. (2010). Spatial ability: Its influence on learning with visualizations—a Meta-analytic review. *Educational Psychology Review 22*, 245-269.

Huk, T. (2006). Who benefits from learning with 3D models? The case of spatial ability. *Journal of Computer-Assisted Learning, 22*, 392-404.

International Technology Education Association (ITEA/ITEEA). (2000/2002/2007). *Standards for technological literacy: Content for the study of technology.* Reston, VA: Author.

Katsioloudis, P. J., Jovanovic, V., & Jones, M.V. (2014). A comparative analysis of spatial visualization ability and drafting models for industrial and technology education students. *Journal of Technology Education, 26*(1), 88-101.

Kuhl, T., Scheiter, K., Gerjets, P., & Edelmann, J. (2011). The influence of text modality on learning with static and dynamic visualizations. *Computers in Human Behavior, 27*, 29-35.

Kwon, O. N. (2003). Fostering spatial visualization ability through web-based virtual-reality program and paper-based program. *Lecture notes in computer science, 2713*, 701–706. doi:10.1007/3-540-45036-X_78.

Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction, 13*, 177-189.

Lajoie, S. P. (2003). Individual differences in spatial ability: Developing technologies to increase strategy awareness and skills. *Educational Psychologist, 38*(2), 115-125.

Lieu, D. K. & Sorby, S. A. (2009). *Visualization, modeling, and graphics for engineering design.* Clifton Park, NY: Delmar, Cengage Learning.

Maier, P. H. (1998). Spatial geometry and spatial ability: How to make solid geometry solid? In E. Osnabrück, K. Cohors-Fresenborg, G. Reiss, G. Toener, & H. Weigand (Eds.), *Selected papers from the annual conference of didactics of mathematics 1996* (pp. 63–75). Munich, Germany: Gesellschaft für Didaktik der Mathematik (GDM).

Malone, T. & Lepper. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R. Snow & M. J. Farr (Eds.) *Aptitude, learning, and instruction, Volume 3: Conative and affective process analyses*, (pp. 223-53). Hillsdale, NJ.

Martín-Dorta, N., Saorín, J. L., & Contero, M. (2008). Development of a fast remedial course to improve the spatial abilities of engineering students. *Journal of Engineering Education, 97*(4), 505–513. doi:10.1002/j.2168-9830.2008.tb00996.x.

Martín-Gutiérrez, J., Saorín, J. L., Contero, M., Alcañiz, M., Pérez-López, D.C., & Ortega, M. (2010). Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics, 34*, 77-91.

Mayer, R. E., Mautone, P., & Proterho, W. (2002). Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology, 86*, 389-401.

Mayer, R. E. & Sims, V. K. (1994). For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Journal of Educational Psychology, 82*, 715-26.

Miller, C. L. & Bertoline, G.R. (1991). Spatial visualization research and theories: Their importance in the development of an engineering and technical design graphics curriculum model. *Engineering Design Graphics Journal, 55*(3), 5-14.

Norman, K. L. (1994). Spatial visualization—A gateway to computer-based technology. *Journal of Special Education Technology, 12*(3), 195-206.

Orde, B. J. (1997). *Drawing as visual-perceptual and spatial ability training.* Presentation at the 1997 National Convention of the Association for Educational Communications and Technology, Albuquerque, NM.

Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education, 31*(3), 459–480. doi:10.1080/09500690802595839

Sorby, S. A. (2012). *ENGAGE strategy research brief: Spatial visualization skills.* Retrieved from www.wskc.org/documents/281621/307749/ENGAGE+Brief+-+Spatial+Skills.pdf/200fbd8f-41b2-47c3-b9dd-c53eaefdcac0?version=1.0

Strong, S. & Smith, R. A. (2001). Spatial visualization: Fundamentals and trends in engineering graphics. *Journal of Industrial Technology 18*(1), 1-6.

Thurstone, L. L. (1938). *Primary mental abilities. Psychometrika monograph no. 1.* Chicago, IL: University of Chicago Press.

Thurstone, L. L. (1950). Some primary abilities in visual thinking. *Proceedings of the American Philosophical Society, 94*(6), 517–521. Retrieved from www.jstor.org/stable/3143593

Wang, H-C., Chang, C-Y., & Li, T-Y. (2006). The comparative efficacy of 2D- versus 3D-based media design influencing spatial visualization skills. *Computers in Human Behavior, 23*(4), 1943-1957. doi:10.1016/j.chb.2006.02.004

Woolf, B., Romoser, M., Bergeron, D., & Fisher, D. (2003, July). Tutoring 3-dimensional visual skills: Dynamic adaptation to cognitive level. In *Proceedings of the 11th International Conference on Artificial Intelligence in Education*, Sydney, Australia.

Wu, H. K. & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education, 88*, 465-92.

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AD INDEX

Ball State University	**C2**
The Chicago School of Professional Psychology	**3**
CNC/Mastercam	**C4**
Goodheart-Willcox Publisher	**37**
Kelvin	**36**
L J Create	**3**
North Carolina State University	**37**
Tormach, LLC	**37**
U.S. Super STEM Competition	**20**

***C = cover**