

CURRICULUM & TEACHING STUDIES | RESEARCH ARTICLE

Does technical drawing increase students' mental rotation ability?

Babalola Ogunkola and Carlos Knight

Cogent Education (2018), 5: 1489209



Received: 27 October 2017
Accepted: 12 June 2018
First Published: 20 June 2018

*Corresponding author: Babalola Ogunkola, School of Education, Faculty of Humanities & Education, The University of the West Indies, Cave Hill Campus, Bridgetown, Barbados
E-mail: babalola.ogunkola@cavehill.uwi.edu

Reviewing editor:
Timothy Joseph Lynch, Universiti Brunei Darussalam, Brunei

Additional information is available at the end of the article

CURRICULUM & TEACHING STUDIES | RESEARCH ARTICLE

Does technical drawing increase students' mental rotation ability?

Babalola Ogunkola^{1*} and Carlos Knight¹

Abstract: In this article, we examined whether technical drawing increased the mental rotation ability in 13- to 15-year-old students ($N = 201$). Students were pretested with the Mental Rotations Test. Later, a group of students was exposed to technical drawing for 10 weeks, which involved specific training with spatial activities and tasks, to increase mental rotation ability. The other group followed their normal classes. Then both groups were posttested and scores showed that the technical drawing students significantly outperformed the control group with a moderate effect size. Additional analyses revealed that the technical drawing students' scores increased from pretest to posttest, with a similar performance in the control group. But this research suggested technical drawing increased students' mental rotation ability with greater effectiveness than other subject areas that may also have broad spatial activities and tasks. Additionally, those other subjects employ classical and often static methods which may or may not provide spatial training that is either effective or efficient compared to technical drawing.

Subjects: Mathematics & Statistics; Social Sciences; Development Studies; Education; Humanities

Keywords: technical drawing; mental rotation ability; spatial ability; spatial training; secondary school

ABOUT THE AUTHORS

Babalola Ogunkola is a senior lecturer in Science Education and Evaluation, and the Director of School of Education in the Faculty of Humanities and Education at the University of the West Indies, Bridgetown, Barbados. He is a managing editor of the *Caribbean Educational Research Journal*. He has published several articles in local and international journals in the areas of evaluation of students' achievement, teaching effectiveness, and early science learning. He is also a member of professional associations such as American Educational Research Association.

Carlos Knight is a tutor in Technical and Vocational Education at the Barbados Community College, Bridgetown, Barbados. He earned his master's degree from the University of the West Indies and is now a research candidate for the PhD in education with a focus in testing and measurement. His research interests include technical and vocational education, vocational competencies and qualifications, spatial ability, and teacher training.

PUBLIC INTEREST STATEMENT

Spatial ability is important in all aspects of one's occupational, personal, and academic life. Considering what can be implied from above it would be appropriate to understand how spatial ability may be developed and improved, as it affects overall existence. To continue, the ability to mentally rotate two- and three-dimensional objects naturally occurs daily. Within technical and vocational classrooms, there is a focus on developing and increasing such components of spatial ability. Hence, technical drawing instruction can be seen as a viable way to promote students' spatial development via its specific training activities, strategies, and instruments. The aim of this study is to investigate the effect of technical drawing instruction on students' mental rotation ability. This research could advance a case for educational stakeholders to be cognizant of the educational possibilities regarding technical drawing to increase spatial cognition. Furthermore, it could improve decisions on course- and program-related policies.

1. Introduction

The literature is replete with the importance of spatial ability to vocations and other cognitive areas or academic disciplines (Alias, Black, & Gray, 2002; Burton & Dowling, 2010; Cheng & Mix, 2014; Lienhard, 2000; Marunic & Glazar, 2012; Medina, Gerson, & Sorby, 1998; Serdar & Harm de Vries, 2015; Sorby, 2003). Moreover, there is an association between spatial ability and performance or interactions and success in technical drawing and several occupations that require spatial understanding (Bartholomew, 2014; Hegarty, Crookes, Dara-Abrams, & Shipley, 2010; Koch & Sanders, 2011; McCuen, 2015; Seel & Dorr, 1994). It is shown that spatial ability could be increased with training, instruction, and practice (Chowdhury, 2017; Ferrini-Mundy, 1987; Katsioloudis, Jovanovic, & Jones, 2014; Kayhan, 2005; Olkun, 2003; Samsudin, Rafi, & Hanif, 2011; Sorby, Casey, Veurink, & Dulaney, 2013; Sorby & Veurink, 2010; Stransky, Wilcox, & Dubrowski, 2010; Uttal et al., 2013; Verner & Merksamer, 2015). Similarly, spatial skills increase with vocational subjects (Baartmans & Sorby, 1996; Ben-Chaim, Lappan, & Houang, 1988). Furthermore, suitable training resources aid development of spatial abilities (Basham & Kotrlik, 2008; Cohen, Hegarty, Keehner, & Montello, 2003; Potter & van der Merwe, 2001). Other factors such as age, sex, mode of representation to include computer software and games, specific chromosome deficiency, and social context impact spatial ability development (Cherney, Bersted, & Smetter, 2014; Cohen & Hegarty, 2007; Do & Lee, 2009; Herlitz, Reuterskiold, Loven, Thilers, & Rehnman, 2013; Jacobson et al., 2010; Rafi, Samsudin, & Ismail, 2006; Safhalter, Vukman, & Glodez, 2016; Shavali, 2004; Sorby & Baartmans, 2000; Subran, 2008; Thurstone, 1948; Wong, Riggins, Harvey, Cabaral, & Simon, 2014; Wright, Thompson, Ganis, Newcombe, & Kosslyn, 2008). Even though several studies demonstrate the increase in spatial cognition with various formal and informal spatial training activities, we suggest our study is novel in this regard to a Caribbean context.

1.1. Spatial ability's importance to engineering drawing/technical drawing

Although technical drawing and engineering drawing have differences in names, Kayhan (2005) makes the link between the two, where both include visual skills, communication that is graphical, and have standard conventions and drawing rules.

Much research advanced the importance and connection between spatial abilities, technical or engineering drawing, and other vocational subjects. Students of technical and vocational programs require spatial ability to be successful (Alias et al., 2002; Bartholomew, 2014; Lienhard, 2000; Marunic & Glazar, 2012; Medina et al., 1998; Serdar & Harm de Vries, 2015). Moreover, positive effects were observed in students' learning when exposed to engineering drawing and its activities as measured by the Mental Rotations Test (MRT) (Sorby et al., 2013; Vandenberg & Kuse, 1978).

To conclude, the literature shows the importance and need of spatial ability, and training for its improvement in relation to several vocational areas. In fact, success in academic and daily life is impacted by spatial ability, where learning can be transferred to other contexts.

1.2. Can training activities develop spatial ability?

Highlighted in the literature are attempts to improve spatial ability development. However, varying opinions on interventions and degrees of success are present in the literature concerning spatial ability and training techniques. However, Clements (1998) noted that developing spatial ability in schools is not significantly successful because the common school curriculum does not cater to this ability. Uttal et al.'s (2013) meta-analysis of 206 research studies examined the malleability of spatial skills in relation to training studies. The results indicated an overall moderate effect size for training studies.

The literature linked spatial training for the improvement of spatial ability (Baldwin, 1985; Chowdhury, 2017; Samsudin et al., 2011) with suggestions that correlations occur between spatial training, improved knowledge and understanding, and improved or efficient practical skills. Kayhan (2005) examined spatial ability (spatial visualization and spatial orientation) and whether a

technical drawing course affected its development. Results indicated that the technical drawing course caused a significant increase from pretest and posttest, with a significant positive relationship to spatial ability.

Authors (Baartmans & Sorby, 1996; Ben-Chaim et al., 1988; Katsioloudis et al., 2014; Sorby & Veurink, 2010) recognized the value of preparatory lessons of graphic courses and vocational subjects to aid improving new engineering students' spatial ability. Spatial visualization ability was a significant predictor and needed for technical problem-solving success and teachers needed to instruct with activities which teach basic visualization and problem-solving skills (Alias et al., 2002; Koch & Sanders, 2011; Olkun, 2003; Verner & Merksamer, 2015). Specifically, Stransky et al. (2010) and Ferrini-Mundy (1987) suggested that spatial training can improve mental rotation where persons receiving the training outperformed those not exposed. Further, those students who had prior experiences with mental rotation significantly improved their performance. Also, it is suggested that development of spatial ability is achievable if suitable training resources are present (Basham & Kotrlik, 2008; Cohen et al., 2003; Potter & van der Merwe, 2001).

In summary, technical drawing involves several of the concepts utilized within studies from the literature. Although technical drawing is not specifically named in the literature, there is a suggestion that training activities may lead to the development of spatial ability, but it is not always transparent. The spatial ability and technical/engineering drawing training association within the literature has been established. However, activities, instruments, and strategies all have impacted the degree of how spatial ability could be developed or increased. Finally, one may conclude that spatial training in the form of technical drawing would increase students' spatial ability.

1.3. Impact of other factors affecting spatial ability development

In concurrence with spatial development, several researchers have investigated the effects of spatial training in regard to age, mode of representation, and computer technologies on the development of spatial ability. For instance, Thurstone (1948) claimed that after age of 14 spatial ability growth would become stationary, although some growth occurs through the twenties. Safhalter et al. (2016) observed the effects of age and sex (11 to 15 years) on 196 non-randomly selected secondary school students' spatial reasoning development. It was concluded that students' spatial reasoning increased because of the spatial training, but age and sex had no effect.

Subran (2008) examined technical and vocational secondary school students' performance on spatial tasks with regard to the impact of three modes of representation. Results point to the mode significantly influenced the learning environment and not necessarily the specific type of spatial training.

Much research has focused on computer technologies and software to enhance spatial abilities through classroom activities. Improvement in engineering students' spatial ability skills could be had with Computer Aided Drawing and Design (CADD) software (Sorby & Baartmans, 2000). However, studies offered no significant difference in students' scores when CADD and other computer technologies were used (Godfrey, 1999; Rafi et al., 2006; Shavaliar, 2004). However, there was significant interaction between the students' spatial experience level and the method of instructions used which suggested effectiveness of the training method could be dependent on their level of spatial experience.

Further research (Do & Lee, 2009) endeavored that spatial ability can be enhanced by video games while sex differences in mental rotation performance can be reduced (Cherney et al., 2014) but Cohen and Hegarty (2007) advocated controlling computer animations of three-dimensional objects, but with only some persons and Wright et al. (2008) have shown persistent training and practice with manipulatives could result in significant positive spatial performance improvement.

Wong et al. (2014) and Jacobson et al. (2010) investigated children with a deficiency in a specific chromosome to determine the effect on their processing of spatiotemporal information. When this

specific chromosome was absent, processing of spatiotemporal information was diminished and weakness occurred in spatial/visual memory.

Herlitz et al. (2013) examined 187 students for the effect of sex hormones, age, and development at puberty on their cognition regarding mental rotations. There was no relationship between mental performance and hormones or between sex hormones, age, development at puberty, and students' mental sex differences.

All of these studies allowed for exploration of factors which may impact how spatial ability or cognition increases and develops. Several studies have exhausted the investigation of instructional strategies and technological novelties, video games, and social setting and experiences. Furthermore, biological factors were explored which ranged from sex differences to the presence or absence of hormones.

2. Methods

2.1. Participants

There were 201 children involved in the study ($M_{age} = 14.2$, range = 13.1–15.3). Children at this age range were selected because of their first introduction to formal spatial training via a technical drawing course. Moreover, previous research recognized this age range as being optimum for spatial development, and the training for such (Kayhan, 2005; Safhalter et al., 2016; Thurstone, 1948). Participants were intact groupings allocated to an experimental group exposed to a technical drawing course ($n = 90$), and the control group that was not exposed ($n = 111$). Students were selected from government secondary schools, in Barbados and are largely black from a varied social hierarchy. In the experimental group, there were 4 girls and 86 boys and in the control group 45 girls and 66 boys.

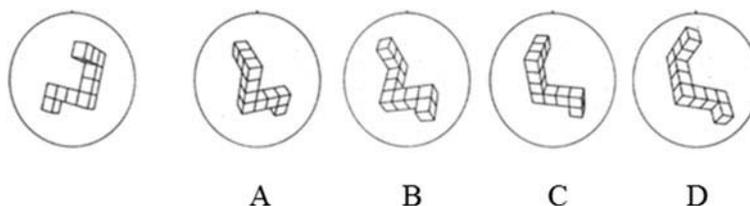
2.2. Materials and procedure

A spatial pretest was completed by students, within the first week of a 14-week term. Technical drawing instruction 120-min sessions occurred weekly for 10 weeks, and the posttest administered a week later.

Technical drawing students received activities involving namely mental rotation (see Figure 1) and other spatial concepts such as isometric and orthographic drawings. The technical drawing teachers would have involved activities and tasks drawn in two- and three-dimensional objects, which were viewed from different directions. Within instruction to students, activities and tasks were presented in various modes (chalkboard, computer, manipulatives, and paper). Students not exposed to the technical drawing course followed their normal classes, which involve subject areas (woodwork, metalwork, technology education, to mention a few) that may exposed them to broad spatial activities and tasks.

The spatial test used was a modified version of the paper and pencil MRT (Vandenberg & Kuse, 1978; see Figure 1). The modified 15-min MRT was comprised of 10 dichotomously scored items, which were similar to some used in the technical drawing sessions. Responding to items occurred

Figure 1. MRT item example (Vandenberg & Kuse, 1978).



by shading two letters from the four on an answer sheet representing their choice of figures that is similar to the criterion figure. The MRT measured whether the technical drawing course aid with increasing or developing of students' mental rotation ability. The Kuder–Richardson 20 (KR20) estimate of reliability coefficients was 0.83.

3. Results

The one-way analysis of covariance was performed in order to determine whether the technical drawing increased or developed students' mental rotation ability. Also, whether students exposed to the technical drawing course were significantly different than students not exposed. The MRT posttest scores were used as the dependent measure and pretest scores as a covariate. Moreover, effect size was estimated using partial eta squared (η^2_p), because it is appropriate to use with analyses of variance and hence covariance. So Cohen's (1988) guidelines were used where small effect is 0.01, moderate effect is 0.06, and large effect is 0.14 (Cohen, 1988; Pallant, 2005). The analysis indicated a statistically significant difference between groups with a moderate effect size, $F(1, 198) = 16.92, p < 0.0005, \eta^2_p = 0.08$. Also the technical drawing students ($M = 4.81, SD = 1.04$) outperformed the control group ($M = 4.18, SD = 0.83$). These results suggest that the technical drawing increased or developed the students' mental rotation ability.

In order to comprehend the impact of technical drawing on students' MRT scores, a paired *t*-test was performed. Effect sizes were manually calculated and estimated using eta squared (η^2), because it is appropriate to use with analyses of paired *t*-test. Therefore, Cohen's (1988) guidelines were used, where small effect is 0.01, moderate effect is 0.06, and large effect is 0.14 (Cohen, 1988; Pallant, 2005). The analysis revealed there was a significant increase in technical drawing students' MRT scores from pretest ($M = 3.14, SD = 1.09$) to posttest [$M = 4.81, SD = 1.04, t(89) = 15.72, p < 0.0005$], with a large effect size indicated by the eta squared statistic (0.74). Similarly, the control group significantly increased their MRT scores from pretest ($M = 2.78, SD = 1.07$) to posttest [$M = 4.18, SD = 0.83, t(110) = 12.58, p < 0.0005$], with a large effect size indicated by the eta squared statistic (0.59).

4. Discussion

Several studies have illustrated that spatial abilities can be increased or developed via various spatial training activities or tasks (Cheng & Mix, 2014; Katsiouloudis et al., 2014; Safhalter et al., 2016; Sorby et al., 2013). Our study is novel as it shows the effect of technical drawing on Barbadian secondary school students' mental rotation ability. In addition, our study is the only of its kind in the Caribbean and Barbados. It was revealed that the 10 weeks of the technical drawing course, involving various spatial activities and tasks, significantly increased students' mental rotation ability. We added a contribution to knowledge as did previous studies that established associations between spatial training activities and tasks, and spatial abilities namely mental rotation.

Cheng and Mix (2014) discussed their interest on the effects different types of spatial training would produce. Our technical drawing training activities and tasks within the study were similarly aligned with other spatial ability development studies. However, mental rotation ability was increased in both control and experimental groups, which was contrary to Cheng and Mix's (2014) study. An increase in the mental rotation ability in the control group may have occurred due to subject areas that involved some broad spatial training activities, tasks, and suitable resources (Bartmans & Sorby, 1996; Basham & Kotrlik, 2008; Ben-Chaim et al., 1988; Cohen et al., 2003; Potter & van der Merwe, 2001). Although both groups' mental rotation ability increased, the technical drawing students outperformed those not exposed suggesting technical drawing had greater effectiveness in increasing the students' mental rotation ability than other subject areas. Another inference is that the activities and tasks within technical drawing instruction were more specific to spatial training than to the other subject areas. Furthermore, technical drawing as a novel instructional method would produce higher reliability regarding students' spatial training, as it consistently provides spatial training activities. Other subject areas may vary the quantity and specificity of

spatial training opportunities. In other words, these subjects employ classical and often static methods which may or may not provide spatial training that is either effective or efficient compared to technical drawing. Then, technical drawing should be elite when considering spatial training and increasing students' mental rotation ability.

Greater research is required for the development of spatial cognition regarding technical drawing and the effects of related factors such as modes of representation, length and type of training, and students' age and gender. Nevertheless, our findings are significant as it establishes technical drawing can aid in the increase of spatial cognition in the form of mental rotation ability. Hence, a case could be advanced to educational stakeholders who should be cognizant of the educational possibilities regarding the use of technical drawing to increase spatial cognition.

Acknowledgements

The authors want to thank the students and teachers who participated in this research. Finally, they also thank the reviewers for their comments that improved this manuscript.

Funding

The authors received no direct funding for this research.

Author details

Babalola Ogunkola¹
E-mail: babalola.ogunkola@cavehill.uwi.edu
Carlos Knight¹
E-mail: carlosknight307@hotmail.com

¹ School of Education, Faculty of Humanities and Education, The University of the West Indies, Cave Hill Campus, Bridgetown, Barbados.

Cover Image

Source: Carlos Knight.

Citation information

Cite this article as: Does technical drawing increase students' mental rotation ability?, Babalola Ogunkola & Carlos Knight, *Cogent Education* (2018), 5: 1489209.

References

- Alias, M., Black, T. R., & Gray, D. E. (2002). Effect of instruction on spatial visualization ability in civil engineering students. *International Education Journal*, 3(1), 1–12. Retrieved from http://eprints.uthm.edu.my/1815/1/EFFECT_OF_INSTRUCTION_ON_SPATIAL_MAIZAM_ALIAS.pdf
- Baartmans, B. G., & Sorby, S. A. (1996). Making connections: Spatial skills and engineering drawings. *The Mathematics Teacher*, 89(4), 348.
- Baldwin, S. L. (1985). Instruction in spatial skills and its effect on math achievement in the intermediate grades. *Dissertation Abstracts International*, 46, 595A.
- Bartholomew, S. (2014). Why we cannot afford to lose CTE in schools. *International Journal of Vocational and Technical Education*, 6(2), 7–12. Retrieved from <https://doi.org/10.5897/IJVT2014.0149>
- Basham, K. L., & Kotrlík, J. W. (2008). The effects of 3-dimensional CADD modeling on the development of the spatial ability of technology education students. *Journal of Technology Education*, 20(1), 32–47. doi:10.21061/jte.v20i1.a.3
- Ben-Chaim, D., Lappan, G., & Houang, R. T. (1988). The effect of instruction on spatial visualization skills of middle school boys and girls. *American Educational Research Journal*, 25(1), 51–71. doi:10.3102/00028312025001051
- Burton, L. J., & Dowling, D. G. (2010, July). *The effects of gender on the success of a cohort of engineering students*. Paper presented at the Engineering Education Conference, Birmingham, United Kingdom.
- Cheng, Y., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition & Development*, 15(1), 2–11. doi:10.1080/15248372.2012.725186
- Cherney, D. I., Bersted, K., & Smetter, J. (2014). Training spatial skills in men and women. *Perceptual & Motor Skills*, 119(1), 82–99. doi:10.2466/23.25.PMS.119c12z0
- Chowdhury, M. A. (2017). Gifted education in the enabling sciences with a particular emphases on chemistry. *Malaysian Online Journal of Educational Sciences*, 5(2), 35–48.
- Clements, D. (1998, February). *Young children and technology*. Paper presented at the Forum on Early Childhood Science, Mathematics, and Technology Education, Washington, DC.
- Cohen, C. A., & Hegarty, M. (2007). Sources of difficulty in imagining cross sections of 3D objects. In D. S. McNamara & J. G. Trafton (Eds.), *Proceedings of the Twenty-Ninth Annual Conference of the Cognitive Science Society* (pp. 179–184). Austin TX: Cognitive Science Society. 10.1016/J.JHSB.2006.11.013
- Cohen, C. A., Hegarty, M., Keehner, M., & Montello, D. R. (2003). Spatial abilities in the representation of cross sections. In *Proceedings of the 25th annual meeting of the Cognitive Science Society*, Erlbaum, Mahwah.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.
- Do, T. V., & Lee, J. W. (2009, July). A multiple-level 3D-LEGO game in augmented reality for improving spatial ability. In *International Conference on Human-Computer Interaction* (pp. 296–303). Berlin, Heidelberg: Springer. 10.1177/1753193409354523
- Ferrini-Mundy, J. (1987). Spatial training for calculus students: Sex differences in achievement and in visualization ability. *Journal for Research in Mathematics Education*, 18(2), 126–140. doi:10.2307/749247
- Godfrey, G. S. (1999). Three-dimensional visualization using solid-model methods: A comparative study of engineering and technology students. *Dissertation Abstracts International*, 60, 4390.
- Hegarty, M., Crookes, R. D., Dara-Abrams, D., & Shipley, T. F. (2010, August). Do all science disciplines rely on spatial abilities? Preliminary evidence from self-report questionnaires. In C. Holscher, T. F. Shipley, M. Olivetti Belardinelli, J. Bateman, & N. S. Newcombe. (Eds.), *Lecture Notes in Computer Science: Vol. 6222. International Conference on Spatial Cognition* (pp. 85–94). Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-642-14749-4
- Herlitz, A., Reuterskiöld, L., Loven, J., Thilers, P. P., & Rehnman, J. (2013). Cognitive sex differences are not magnified as a function of age, sex hormones, or puberty development during early adolescence.

- Developmental Neuropsychology*, 38(3), 167–179. doi:10.1080/87565641.2012.759580
- Jacobson, C., Shearer, J., Habel, A., Kane, F., Tsakanikos, E., & Kravariti, E. (2010). Core neuropsychological characteristics of children and adolescents with 22q11.2 deletion. *Journal of Intellectual Disability Research*, 54(8), 701–713. doi:10.1111/j.1365-2788.2010.01298.x
- Katsioloudis, P., Jovanovic, V., & Jones, M. (2014). A comparative analysis of spatial visualization ability and drafting models for industrial and technology education students. *Journal of Technology Education*, 26, 88–101. doi:10.21061/jte.v26i1.a.6
- Kayhan, E. B. (2005). *Investigation of high school students' spatial ability* (Master's thesis). Retrieved from <https://etd.lib.metu.edu.tr/upload/12605771/index.pdf>
- Koch, D., & Sanders, M. (2011). The effects of solid modeling and visualization on technical problem solving. *Journal of Technology Education*, 22(2), 3–21.
- Lienhard, J. H. (2000). *The engine of our ingenuity: An engineer looks at technology and culture*. NY: Oxford University Press.
- Marunic, G., & Glazar, V. (2012). Spatial ability through engineering graphics education. *International Journal of Technology and Design Education*, 23, 703–715. doi:10.1007/s10798-012-9211-y
- McCuen, T. (2015). *Investigating the predictors of spatial skills essential for construction science student success in the digital age* (Doctoral dissertation). University of Oklahoma. Retrieved from https://shareok.org/bitstream/handle/11244/23330/2015_McCuen_Tamera_Dissertation.pdf;sequence=2
- Medina, A. C., Gerson, H. B., & Sorby, S. A. (1998). *Identifying gender differences in the 3-d visualization skills of engineering students in Brazil and in the United States* (Research Report No. 143). Retrieved from <https://eric.ed.gov/?id=ED443729>
- Olkun, S. (2003, April). Making connections: Improving spatial abilities with engineering drawing activities. *International Journal of Mathematics Teaching and Learning*, 1–10. doi:10.1501/0003624
- Pallant, J. (2005). *SPSS survival manual: A step by step guide to using SPSS for windows (version 12)*. New South Wales, Australia: Allen & Unwin.
- Potter, C., & van der Merwe, E. (2001, August). Spatial ability, visual imagery and academic performance in engineering graphics. In *International Conference on Engineering Education*, Oslo, Norway.
- Rafi, A., Samsudin, K. A., & Ismail, A. (2006). On improving spatial ability through computer-mediated engineering drawing instruction. *Journal of Educational Technology and Society*, 9(3), 149–159.
- Safhalter, A., Vukman, K. B., & Glodez, S. (2016). The effect of 3D-modeling training on students' spatial reasoning relative to gender and grade. *Journal of Educational Computing Research*, 54(3), 395–406. doi:10.1177/0735633115620430
- Samsudin, K. A., Rafi, A., & Hanif, A. S. (2011). Training in mental rotation and spatial visualization and its impact on orthographic drawing performance. *Educational Technology & Society*, 14(1), 179–186.
- Seel, N. M., & Dorr, G. (1994). The supplantation of mental images through graphics: Instructional effects on spatial visualization skills of adults. In W. Y. Schnotz & R. W. Kulhavy (Eds.), *Comprehension of graphics* (pp. 271–290). Amsterdam: Elsevier Science B.V.
- Serdar, T., & Harm de Vries, P. E. R. (2015, June). *Enhancing spatial visualization skills in engineering drawing course*. Paper presented at the meeting of American Society for Engineering Education, Seattle, WA.
- Shavaliar, M. (2004). The effects of CAD-like software on the spatial ability of middle school students. *Journal of Educational Computing Research*, 31(1), 37–49. doi:10.2190/X8BU-WJGY-DVRU-WE2L
- Sorby, S., & Veurink, N. (2010, June). *Are the visualization skills of first year engineering students changing?* Paper presented at 2010 Annual Conference & Exposition, Louisville, Kentucky.
- Sorby, S. A. (2003). *Introduction to 3D spatial visualization: An active approach*. NY: Thomson Delmar Learning.
- Sorby, S. A., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education*, 89(3), 301–307. doi:10.1002/jee.2000.89.issue-3
- Sorby, S. A., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences*, 26, 20–29. doi:10.1016/j.lindif.2013.03.010
- Stransky, D., Wilcox, L. M., & Dubrowski, A. (2010). Mental rotation: Cross-task training and generalization. *Journal of Experimental Psychology. Applied*, 16(4), 349–360. doi:10.1037/a0021702
- Subran, D. (2008). *The impact of modes of representation on technical and vocational students' performance of spatial tasks* (Unpublished doctoral dissertation). University of the West Indies, Trinidad.
- Thurstone, L. L. (1948). Psychological implications of factor analysis. *American Psychologist*, 3(9), 402–408.
- Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A., Warren, C., & Newcombe, N. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139(2), 352–402. doi:10.1037/a0028446
- Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations: Group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, 47(2), 599–604. doi:10.2466/pms.1978.47.2.599
- Verner, I., & Merksamer, A. (2015). Digital design and 3D printing in technology teacher education. *Procedia CIRP*, 36(2015), 182–186. doi:10.1016/j.procir.2015.08.041
- Wong, L. M., Riggins, T., Harvey, D., Cabaral, M., & Simon, T. J. (2014). Children with chromosome 22q11.2 deletion syndrome exhibit impaired spatial working memory. *American Journal on Intellectual and Developmental Disabilities*, 119(2), 115–132. doi:10.1352/1944-7558-119.2.115
- Wright, R., Thompson, W. L., Ganis, G., Newcombe, N. S., & Kosslyn, S. M. (2008). Training generalized spatial skills. *Psychonomic Bulletin & Review*, 15(4), 763–771. doi:10.3758/PBR.15.4.763



© 2018 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:

Share — copy and redistribute the material in any medium or format.

Adapt — remix, transform, and build upon the material for any purpose, even commercially.

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:

Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.

You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.



Cogent Education (ISSN: 2331-186X) is published by Cogent OA, part of Taylor & Francis Group.

Publishing with Cogent OA ensures:

- Immediate, universal access to your article on publication
- High visibility and discoverability via the Cogent OA website as well as Taylor & Francis Online
- Download and citation statistics for your article
- Rapid online publication
- Input from, and dialog with, expert editors and editorial boards
- Retention of full copyright of your article
- Guaranteed legacy preservation of your article
- Discounts and waivers for authors in developing regions

Submit your manuscript to a Cogent OA journal at www.CogentOA.com

