ENHANCING SPATIAL ABILITIES THROUGH EXPOSER TO COMPUTER-AID DESIGN PROGRAMS

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Spatial ability is important in the learning and understanding of mathematics and has been recognized as an indicator of mathematics achievement and STEM success. The present study aims to investigate how experiences with computer-aid design programs can enhance student's spatial ability measured by mental rotation skills. Quantitative data were collected before and after intervention using the redrawn Vandenburg and Kuse Mental Rotation Test by Peters et al. (1995). A paired sample t-test and 95% confidence intervals indicated a statistically significant difference between observed pre and post test scores. The calculated Cohen's d effect size of 0.63 indicated the CAD intervention had a positive impact on students' mental rotation skills. It can be concluded that utilizing these technologies can aid in developing and improving spatial abilities which can lead to improved mathematics achievement and STEM success.

Keywords: Spatial Thinking, STEM, Teaching Tools, Technology

Introduction and Literature Review

Improving mathematics science, technology, engineering and mathematics (STEM) success is a very relevant issues in research and education. Spatial ability has been recognized as a predictor of adult success in STEM areas across several longitudinal studies that followed a large population of both normative and intellectually gifted individuals from adolescence to adulthood (Shea, Lubinski, & Benbow, 2001; Wai, Lubinski, & Benbow, 2009). In addition, researchers have found that spatial ability provides validity to mathematical and verbal reasoning abilities yet in education there is little emphasis on the development of spatial abilities (Basham & Kotrlik, 2008). Psychologists and education researchers have been interested in the connection between spatial ability and mathematics achievement since the mid-1900's (Bishop, 1980) and prior research has supported this link (e.g. Carr et al., 2019; Casey, Nuttal, & Perzris, 1997; Ganley & Vasilyeva, 2011; Gilligan, Flouri, & Farran, 2017; Hawes, Moss, Caswell, Seo, & Ansari, 2019; Rabab'h & Veloo, 2015; Rutherford, Karamarkovick, & Lee, 2018; Verdine et al., 2014). Despite the acknowledgement and confirmation of the connections between spatial ability and STEM success, specifically mathematics achievement, there is little research on the development of spatial abilities. In the current study, researchers investigated how the implementation of computer-aided design software and 3D printing class with adolescents is associated to growth in spatial ability measured via mental rotation skills.

Mental Rotation. Spatial ability is often organized into three categories: (1) spatial perception, (2) spatial visualization, and (3) mental rotation (Linn & Peterson, 2004). All three categories are important for learning and understanding of mathematics and can improve students' problem solving and reasoning skills. In the current study mental rotation is measured as an indicator of spatial ability.

Mental rotation of objects is a fundamental spatial ability that affects several aspects of life. Mental rotation is primarily associated with the skill to mentally rotate images or objects into particular orientations. The ability to mentally rotate objects includes the visual inspection and mental simulation of the object's rotation in space (Hegarty & Waller, 2005). Mental rotation ability is important for success in several academic and career fields, especially the science, technology, engineering, and mathematics (STEM) domains (Károlyi, 2013). Mental rotation skills are utilized in performing many everyday tasks such as rearranging furniture, packing the car trunk, navigating a map, and parking a car, among many other examples academic and job tasks in non-STEM careers.

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Mental rotation is especially useful in several career areas (e.g. architecture, industrial design, engineering, sculpting, surgery, kinesiology, dentistry, and aviation). Interventions and activities that develop and improve mental rotation skills could lead to increased success in STEM and related domains. Computer-aided design (CAD) programs and 3D printing activities is an excellent way to utilize advanced technologies to develop and improve students' spatial abilities.

CAD Programs. Computer-aided design programs are utilized to create detailed three-dimensional models and two-dimensional drawings. Computer-aided design programs are most commonly used by engineers for drafting, designing, and developing diverse and complex machinery components (Sharma & Dumpala, 2015). They are also widely used by designers due to its ability to offer the creation of intricate designs (Martin & Velay, 2012) in a way that is more accessible to others. Computer-aided design programs and manufacturing tools, such as 3D printers, are ever-present in current product commercialization environment and students entering this environment need to be practiced in using such tools (Johnson & So, 2015). The utilization of CAD programs in 3D printing and design classes showed positive influences on student's mathematics skills, real-life skills, interests and motivation (Kwon, 2017). There are several types of CAD programs on the market such as *TinkerCAD*, *SketchUp*, *SolidWorks*, and *AutoCAD*, all of which are used create 2-dementional renderings of 3-dementional designs.

CAD and Mental Rotation. Spatial ability and mental rotation in children are often neglected in early education but can be promoted through experiences with three-dimensional modeling programs (Matthews & Geist, 2002). Students' mental rotation has been identified as a predictor of success in STEM domains and computer-aided design (CAD) programs have overcome barriers to spatial expression (Chang, 2014) that has been an essential tool in engineering education (Chester, 2007). Mental rotation skills could be developed and improved through the use of certain technologies (e.g. CAD software and 3D printing) which can lead to improved mathematics achievement and STEM success.

Methodology

In the present study a quasi-experimental study was conducted to explore the relationship between the utilization of CAD programs and students' mental rotation skills. To determine how the implication and use of CAD programs in a classroom influenced student's mental rotation skills, data were collected during a week-long CAD intervention. The current study was guided by the following research question: How will student's mental rotation skills be influenced after experiences and utilizing computer-aid design programs in a 3D printing class?

Participants. The sample was comprised of 1 middle school student and 24 high school students who attended a one-week STEM summer camp at a research-intensive university. The ethnic backgrounds of the sample included 15 Caucasians (60%), 7 Hispanics (28%), 1 African Americans (4%), and 2 whom did not disclose ethnicity (8%). The sample is comparable to the United States population with a noted difference that African Americans were slightly underrepresented in the sample. The sample included 5 females (20%) and 20 males (80%), females were underrepresented in the sample regardless of the level of comparison.

Instrument. The *Mental Rotations Test* was used to assess participants mental rotation skills (Peters et al., 1995) and adaptation of the original paper and pencil *Mental Rotations Test* by Vandenberg and Kuse (1978). The test contained 24 items with five 3D drawings of cubical figures per item. Each item contained one target figure on the left and four answer choices on the right. The participants were to identify which two of the answer choices were identical to the target but rotated along the y axis. The two other answers were mirror-images of the target and thus could not become identical to the target by rotation. The test was given in two parts, the participants were given three minutes to complete the first 12 questions, a two-minute break, and three minutes to complete the remaining 12 questions. Two undergraduate students recorded participants answers into an excel spreadsheet which was then checked by a senior doctoral student. Recorded answers were then scored by the instructor. One point was given for each correct answer, and one point is subtracted for each incorrect answer yielding a maximum of 48 points. The internal consistency for this sample was measured using Cronbach's (1951) alpha coefficient; score reliability was high with a 0.84 for the pre-test and 0.89 for post-test. All participants were tested both before and after the intervention at the same time by the same test administrator and instructions.

CAD Programs Used for Instruction. In the present study two different 3D CAD programs (TinkerCAD and SketchUp) were introduced and utilized. These two CAD programs were chosen because they both are available free TinkerCAD, owned by Autodesk, is a free, online 3D modeling program that runs in a web browser and is known for its simple interface and ease of use. TinkerCAD allows users to start their designs with 3D geometric primitives (Avila & Bailey, 2016) that can be combined and manipulated. Geometric primitives are basic geometric shapes (e.g. sphere, cube, cylinder, pyramid) that can be assembled with others to construct more complex shapes (Boubekeur, Kaiser, & Ybanez Zepeda, 2019). Starting with these basic 3D shapes provides a much simpler mode to create complex shapes and objects. TinkerCAD provides an easy, early training ground to introduce solid modeling and 3D printing to a younger or less experienced students.

SketchUp, owned by Trimble Inc., is a 3D modeling computer program used for a variety of applications including but not limited to architectural, interior design, mechanical engineering, and video game design. SketchUp starts with 2D geometric primitives (e.g. point, line, plane, circle) and allows users to push or pull them into 3D objects (Avila & Bailey, 2016). SketchUp provides a platform for users to sketch and create 3D designs with much more creativity, precision, detail, and complexity than TinkerCAD. SketchUp could be considered an intermediate to advanced CAD program but is still user friendly and accessible. Several SketchUp packages are offered at different price points but a free web-based version is now available. The free version was used in the present study.

Intervention

During a one-week STEM summer camp participants were randomly assigned and placed in a 3D printing class. The class met for one and a half hours each day for one-week: Monday through Friday. The class was instructed and facilitated by a third year female Mathematics Education PhD student who had previous training in 3D printing and Sketch-Up. She also had two years of experience (two projects per school year) utilizing a 3D printer, TinkerCAD, and Sketch-Up in high school Geometry classes (on level and pre-AP). On the first day participants took the pre-test and listened to an introduction to 3D printing, the engineer design process, and were given guidelines for the first project *Make your own Trophy* (see Table 10. They created TinkerCAD accounts, explored the software, and created their trophy. Day two the instructor introduced SketchUp and guided participants through how to use the available tools. They then received three open-ended final projects to choose from.

Table 1: Project descriptions

Project Title	Description
Make your own trophy	Create an award for yourself to receive at the end of the camp that is less than 5"x5"x5", has your name, and consist of at least 10 shapes.
Fusion of Art and Function	Design and create something that is both fun/interesting to look at and is functional.

Project Title	Description
Historical Structure	Choose and replicate any historical structure of your choice.
Product Prototype	Invent the next big thing; design and create a prototype of a brand-new product.

For the final project participants were given the option to work in TinkerCAD or SketchUp; which required participants to self-assess their skill level and choose a platform for which they were comfortable using. It was unknown to the instructor what prior knowledge, skills, and/or experiences participants would have entering the class, therefore a beginner program and an intermediate/advanced program were offered so participants of various skill levels would remain actively engaged by attempting to avoid disengagement caused by frustration, boredom of a steep learning curve of the CAD program. Only two participants chose to work in SketchUp. Day three and four were project workdays where the participants worked independently on their final projects. During this independent work time their trophies were being printed and participants were taken in small groups to the 3D printer room to see them in action. The instructor provided them with additional information about the printer and printing procedures then answered any questions they had. On the fifth day participants finished their final project and shared their design.

Data Analyses

Quantitative data were collected pre and post intervention to assess participants mental rotation skills using the Mental Rotations Test - Form A (Peters et al., 1995). First, data were analyzed using a paired sample *t*-test to investigate the statistical differences between mental rotation skills before and after the intervention. Prior to conducting the paired sample *t*-test, Q-Q plots and box plots of the pre-test and post-test scores were analyzed to assess score distribution and check for outliers. Second, to provide a visual representation of the results, 95% confidence intervals (CIs) for the pre and post test scores were examined. The 95% CI indicates that if the study was conducted an infinite number of times, the calculated point estimate would be captured 95% of the time. Using 95% CIs provides a visual depiction of the preciseness of the estimate and a direct comparison model for other similar studies (Thompson, 2002). Finally, Cohen's *d* effect size estimates were computed to quantify the magnitude of the difference between pre and post test scores. Due to the small sample size of the present study *t*-test results may be skewed therefore effect size is more suitable for the given data. Effect size indices are valuable in quantifying the effectiveness of an intervention because they are unitless, making them comparable across studies, and do not depend on sample size (Sullivan & Feinn, 2012). Reporting effect size is an important practice in order to report and interpret results in a trustworthy way that is usable for scholars and practitioners (Thompson, 1999a). In addition, reporting effect sizes, even for results that are not statistically significant, aids in compelling researcher to think meta-analytically and provides grist to possible future meta-analyses (Cumming & Finch, 2001; Thompson, 1999b; Thompson, 2001). Statistical package SPSS 25 was used in the aforementioned data analyses.

Overall, the results indicated that mental rotation skills, as measured by the instrument, were improved by the CAD intervention. No class time was spent on reviewing mental rotations or practicing with similar diagrams. Therefore, direct instruction in the concept is not a potential threat to validity.

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