2D AND 3D FABRICATION DEVICES: CAN THEY IMPROVE SPATIAL REASONING SKILLS IN CHILDREN?

Ellen L. Zimmerman

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APPROVED:

Tandra Tyler-Wood, Major Professor
Lemoyne Dunn, Committee Member
Mickey Wircenski, Committee Member
Cathie Norris, Interim Chair of the
Department of Learning Technologies
Victor Prybutok, Interim Dean of the College
of Information and Vice Provost of
the Toulouse Graduate School

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The purpose of this study is to evaluate the potential benefit of two hours of activities involving 2D and 3D fabricators on the spatial reasoning skills of children in Grades 4 and 5, ages 9 to 10, from a private school in Southeast Texas. Can the introduction to hands-on activities with products created with these devices and learning about how these devices operate improve spatial reasoning skills? The research also evaluates the use of the Shapes Test as a valid measure of the spatial reasoning skills of children. The Cube Design and Spatial Memory subtests of the UNIT (Universal Nonverbal Intelligence Tests) were used for evaluating the spatial reasoning skills of the participants, based on their respected validity, along with a Shapes Test that is in development. Discussion regarding gender, language, and experiential theories of spatial reasoning skill development are included in the literature review.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The importance of spatial reasoning skills pervades all aspects of life. Whether you are attempting to install a car seat safely from instructions (Wegner & Girasek, 2003) or you are an architect developing new concepts as you sketch (Suwa & Tversky, 1997), you utilize the skill of spatial reasoning. One example of the importance of the ability to think spatially was exhibited by a London physicist named John Snow in 1855. Snow used spatial mapping skills to identify a contaminated water pump as the source of a cholera outbreak (1855). Spatial thinking is also very important for success in science, technology, engineering, and math (Newcombe, 2010; Titus & Horsman, 2009; Trickett & Trafton, 2007; U.S. Department of Education, 2010; Wai, Lubinski, & Benbow, 2009). There is also a continuing concern in attracting more students into science, technology, engineering, and math (STEM) careers, (Newcombe, 2010; Titus & Horsman, 2009; Tyler-Wood, Knezek, & Christensen, 2010) along with a need for activities to improve spatial reasoning skills in children so they will gain an interest in careers that engage spatial reasoning skills (Do, 2002; National Research Council, 1999).

The rest of this chapter will provide the background of this study, the statement of the problem, significance of the study, purpose of the study, research questions, research assumptions, research methods, operational definitions, limitations, and a summary.

Background of the Study

This research was conducted at a time when 2D and 3D fabrication devices were becoming much more common and less costly. The ability to create new or replacement parts at a lower cost and in lower quantities using 2D and 3D fabricators provides new options for businesses (Bull, et al., 2010). Small businesses have begun to realize the implications of the digital fabrication age and the options it affords (Blikstein, 2013; Kolarevic, 2001; Mellis, 2013). 3D fabricators can be used to create broken parts for equipment without the need to wait for an order to arrive. 3D fabricators can also be used to develop prototypes while in a design phase. There has now even been a complete car created using a 3D fabricator (Gastelu, 2014). Along with the opportunities for small businesses, education has also started to recognize the possibilities for the use of these tools in the classroom. Access was limited before based on the cost. Now, designing and fabricating 3D objects is becoming an affordable option (Bull et al., 2010; Stansell, Quintanilla, Zimmerman, & Tyler-Wood, 2015; Zimmerman, 2014).

The availability of these new tools, the start of research in support of the use of 2D and 3D fabricators in the classroom, and the potential to link existing math, science, and technology standards and increase learning outcomes through the use of digital fabrication (Bell et al., 2010; Newcombe, 2010) provides hope for new creative and engaging methods to develop spatial reasoning skills.

Statement of the Problem

The President's Council of Advisors on Science and Technology has stated, "STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security" (2010, p. vii). In order for the United States to maintain its lead among other countries, we will need to produce more students who are interested in obtaining STEM careers (Carnevale, Smith, & Melton, 2011; Newcombe, 2010; Prensky, 2001). The ability to use spatial reasoning skills can be strongly tied to the likelihood to select a career in a STEM field (Adams & Mayer, 2012; Newcombe & Frick, 2010; Titus & Horsman, 2009) and is a predictor of how well students will perform in those areas (Uttal, Miller, & Newcombe, 2013; Wai et al., 2009). Although it is clear that activities designed to develop spatial reasoning skills are beneficial to education and society (Uttal et al., 2013), a general lack of initiatives to incorporate them is not evident (President's Council of Advisors on Science and Technology, 2010).

Significance of the Study

This research was selected based on the researchers' personal opinion that there is a benefit to exposing children to activities that require spatial reasoning skills at an early age. Past experience has been that the researchers' spatial reasoning skills have been quite good and that is attributed to the childhood exposure she had helping her father work on cars and building a house. The researcher also had the opportunity and the ability to sew clothes without patterns that she learned from watching her mother sew throughout her childhood years. Without these opportunities as a child, the researcher contends that her spatial reasoning skills would not have developed to the extent that they did. The need to identify beneficial learning activities to introduce spatial thinking is important for children to develop spatial reasoning as a natural part of their way of thinking. There is an abundance of research in support of the benefits of spatial reasoning and visualization development at an early age as these skills support the development of math, design, and creativity.

The researchers' goal is to identify activities that improve spatial reasoning skills in children and to test a new tool for measuring those skills. While toddlers and preschool children show some form of mental rotation and perspective-taking skills, they undergo considerable development of those skills during this time and into middle childhood), thus supporting the need for learning that improves spatial reasoning skills as early as possible and continues through their grade school years. (Newcombe & Fricke, 2010).

The development of spatial reasoning skills can improve the interest in STEM courses by creating interest in activities and fields of study that require those skills. Teaching students to increase their spatial reasoning skills can increase the number of children interested in STEM careers and provide for the development of citizens with the skills needed to contribute to the competitiveness of our society (AAUW, 2013; National Science Board, 2010; Wai et al., 2009). There is also research support for these skills as they contribute to the creativity required for productivity in STEM fields (Trickett & Trafton, 2007; Wai et al., 2009). The identification and the encouragement of students to enter STEM fields is a national priority (National Science Board, 2010) and spatial skills are also a prediction of success in STEM fields (Harle & Towns, 2011; Liben, Kastens, & Christensen, 2011; Lubinski, 2010; Wai et al., 2009).

Purpose of the Study

The purpose of this study is to evaluate the potential benefit of two hours of activities involving 2D and 3D fabricators on the spatial reasoning skills of children in Grades 4 and 5, ages 9 to 10, from a private school in Southeast Texas. Can the introduction to hands-on activities with products created with these devices and learning about how these devices operate improve spatial reasoning skills? Past research data indicates that spatial reasoning skills can be improved with practice. (Cherney, Bersted, & Smetter, 2014; De Lisi & Wolford, 2002; Feng, Spence, & Pratt, 2008; Lord, 1985, 1987; Piburn et al., 2002; Wright, Thompson, Ganis, Newcombe, & Kosslyn, 2008). The research of Cheng and Mix (2013) found that even brief training using mental rotation puzzles with six- to eight-year-olds provided enhanced math score performance.

In order to identify activities that can improve spatial reasoning, there must be a valid tool for the measurement of the impact of these activities. While there are surveys for measuring spatial reasoning skills available, these existing instruments are primarily focused on elementary school age children. The identification of a tool with simple explanations for use with children ages 9 to 10 will allow for lessons to be developed to benefit the development of spatial reasoning skills at an early age. "Young children who are better at visualizing spatial relationships develop stronger arithmetic abilities in primary school" (Zhang, 2014). To identify activities that improve spatial reasoning skills, there must be an accurate measuring device. Part of this study was to validate the use of a new survey called the Shapes Test (Tyler-Wood, 2015).

Research Questions

The primary question posed as part of this research is "Can the spatial reasoning skills of 4th and 5th graders at a private school in Southeast Texas be improved by exposure to 2D and 3D fabricator activities ?" Access to these devices has only recently become more cost effective and widespread in education and exposure is now available to students who previously did not have this access (Bell et al., 2010).

The researchers' second question asks, "Is the Shapes Test (Tyler-Wood, 2015) a valid measure of spatial reasoning skills in children?" The expectation is that students aged 9 to 10 will have high success scores based on the fact that the purpose of the design is for use with children aged 5 to 10.

Research Assumptions

One research assumption for this study is that previously validated instruments, the Universal Nonverbal Intelligence Test (UNIT) Spatial Memory subtest and the UNIT Cube Design subtest, can provide reliable measures of a participant's spatial reasoning abilities. Another assumption is that the Shapes Test (Tyler-Wood, 2015) will be a good measure of students' spatial reasoning skills as the instrument was designed to measure student functioning in the lower realms of spatial reasoning, based on its development as an instrument for children ages 5 to 10.

Research Methods

Internal Review Board (IRB) approval (see Appendix A) was received for the research to be conducted in a face-to-face setting with student participants from a private school in Southeast Texas over a three-day period. The students were ages 9 to 12, in the fourth and fifth grades. Three researchers were involved in the face-to-face questionnaire and testing instrument delivery. Three separate tests were administered to the participants after the verification of parental consent forms.

The first step of the research was to verify the Parental Consent form (Appendix B), explain the expectations of the study to the student, and obtain self-consent for their participation (See Appendix B). If the student agreed to participate, the second step was to gather demographic information and ask for responses to three questions relative to previous experiences of the students (see Appendix C). The third step included the administration of two subtests of the UNIT and the administration of the Shapes Test (see Appendix D; Tyler-Wood, 2015). After the initial tests, students participated in 2D and 3D fabrication device activities and lessons about the devices. At the end of the activities, students were again tested on the Shapes Test (Tyler-Wood, 2015). Time did not allow for the administration of the UNIT tests again after the fabrication device lessons and activities.

The research type was quantitative based on the results of the three tests and utilized a cross-sectional design, given the limited time available for the research. According to Postlethwaite (2005), the selection of one private school is considered a case study with quantitative data that is supported with qualitative data analysis. Surveys were used to collect demographic and test score data, and questionnaires and surveys were also used to collect responses and outcomes. The results were evaluated using correlations for the UNIT Cube Design scores versus the Shapes preactivity scores and the UNIT Spatial Memory scores versus the Shapes Test (Tyler-Wood, 2015) preactivity scores. A paired T test was used to evaluate the Shapes Test (Tyler-Wood, 2015) preactivity scores versus the Shapes Test (Tyler-Wood, 2015) postactivity scores.

Definition of Terms

2D fabricator (CAM machine). These devices are also known as cutters. The devices can use blades, lasers, or water to cut through various materials (Lawrey & Scott, 2015). For the purpose of this study, a 2D fabricator refers to a device that uses blades to cut through paper and lightweight media. This term is also referred to as digital fabrication.

3D fabricator. This device allows for the creation of shapes in three dimensions (Lawrey & Scott, 2015). Media for these devices can include wood, plastics, acrylics, and even chocolate (Aaamoth, 2012). This term is also referred to as digital fabrication.

g-load. Also known as G factor. This concept is a construct used when developing IQ tests and references a more general measure of intelligence. (“G factor (psychometrics),” 2016)

Spatial reasoning skills. Spatial reasoning skills refer to the ability to "perform mentally such operations as rotation, perspective change, and so forth" (National Academies Press [multiple committees] & National Research Council, 2006).

STEM. This term stands for science, technology, engineering, and math (Newcombe, 2010). There are a variety of different terms used for the description of spatial reasoning including spatial thinking, spatial cognition, and spatial ability. These terms are interchangeable for the sake of this research.

UNIT Cube Design test. This test, developed by Bracken and McCallum in 1998, is a test that involves the presentation and reproduction of two-color, abstract, geometric designs. The Cube Design test primarily measures visual-spatial reasoning.

UNIT Spatial Memory test. This test, also developed by Bracken and McCallum in 1998, is a test where the examinee views a random pattern of dots on a 3x3 or 4x4 grid and re-creates the pattern using the appropriate color of dots. This tool is primarily a measure of short-term visual memory for abstract material.

Limitations

Limitations of the study include the limited amount of time available for the study involving the 4th and 5th graders at a private school in Southeast Texas, which was three days. In addition, this timeframe did not allow for complete posttest data from the participants. There also was not an opportunity to evaluate a control group versus an experimental group. The completed sample size was 12 of the 4th grade students, which is considered a case study. The limited participant number may have been an issue as potential threats to statistical conclusion validity include the selection of heterogeneous participants and low statistical power based on the low number of participants (Cook & Campbell, 1982; Creswell, 2012). The limited number of participants in this study means that the sample is not representative of the general population of fourth and fifth graders so there is not an opportunity for generalization. Interevaluator reliability may also be a factor when determining the outcomes, based on the fact that there were three evaluators engaged in the collection of data and no interrater reliability was obtained for the study.

Summary

This chapter provided you with the background of the study, the statement of the problem, the purpose of the study, research questions, research assumptions, research methods, operational definitions, and limitations. The next chapter will include a review of the literature involving spatial reasoning skills. The results of the study will be presented in Chapter 4, along with a discussion of those results. Chapter 5 will present a general summary of the study, the findings of the study, conclusions and implications of this research, including implications for the use of 2D and 3D fabricators with children, and will also include recommendations for future research.

CHAPTER 2

REVIEW OF THE LITERATURE

Now we will look at the literature as it pertains to the purpose of this study, to evaluate the potential benefit of two hours of activities involving 2D and 3D fabricators on the spatial reasoning skills of children in Grades 4 and 5, ages 9 to 10, at a private school in Southeast Texas. Spatial reasoning skills are applicable to most every aspect of life. Research has shown that spatial reasoning affects many jobs. Research by Park, Kim, and Sohn (2010) found a positive impact of 3D-simulation technology as an instructional tool for improving students' visualization in apparel design. Papert described the relationship between making and learning, as it applies to the development of visualization and spatial reasoning skills; he stated that the construction that "takes place in the head" is supported by hands-on construction and the natural development of visualization skills (1980, p. 142).

A comparison between the numbers of STEM field graduates such as science and engineering programs, compared to non-STEM-related bachelor’s degrees such as social work is an area of concern due to the projected need of STEM career job openings. Carnevale et al. explain that STEM careers are vital to “innovation, technological growth, and economic development” (2011, p. 9). The researchers further emphasize that to increase our innovative capacities; students from K-12 to postgraduate will be needed in the STEM career pipeline (Carnevale et al., 2011). Motivating younger students to consider STEM as an interest and possible career option is vital to the growth of these occupations. According to Newcombe (2010), early attention to an increase in spatial skills–like those that involve using 2D cutters–increases student achievement in math and science and helps steer students toward STEM careers. Zhang et al. (2014) stated that young children, who are better at visualization, or spatial reasoning, will do better at arithmetic in primary school.

In the early 1800s, Friedrich Froebel established what became known as kindergarten (Wellhousen & Kieff, 2001). Froebel (Wellhousen & Kieff, 2001) had innovative ideas about how children learn and the connectedness of the whole child and was holistic in his consideration of education. Frobel's kindergarten included three important parts: (a) creative play, (b) music, and (c) an appreciation of nature (Wellhousen & Kieff, 2001). Froebel's idea for creative play in education incorporated the use of blocks, making up six of 10 items that were included in the creative play category (Wellhousen & Kieff, 2001). Blocks based on his original designs are still sold today.

Piaget's theory of intelligence (Piaget, 1954) states that children progress through stages and build their learning on what they already know. This process of learning represents stepping-stones that are needed for children to learn at their current stage of development. In his research, Piaget (1954) noticed how children seemed to make the same mistakes as older individuals and envisioned a process that was common to the way most children learn. Piaget theorized that the brain developed schemas of organized data to interpret their experiences and provide a basis for further learning to take place. Piaget's work describes three kinds of structures of intelligence: behavioral schemata, as in the patterns of behavior used to respond to objects and experiences; symbolic schemata, which are internal representations of experiences; and operational schemata, referring to internal thought processes (1954). These stages change as the child learns and restructuring occurs as they form a more in-depth understanding of their experiences.

In the 1900s, Jerome Bruner (1967) developed the idea of discovery learning, as well as the term scaffolding. Bruner's theory contends that learning is an active process where learners draw on their past experiences and existing knowledge to develop new ideas and ways of thinking (1967). Bruner's use of the term scaffolding refers to the way that learners use what they already know from past experiences to make sense of new learning (1967), which is very similar to Piaget's concept that schemata change as learning takes place. Bruner (1967) stated that instructional theories should support four main aspects: (a) predisposition to learning, (b) the simplest way of presenting new information, (c) the best order of the content, and (d) the method of encouragement for positive progress or application of punishment. Some of the advantages of Bruner's learning theory are (a) the encouragement of active engagement, (b) the promotion of motivation, and (c) the development of independence and problem solving skills (1967). Bruner's learning process is an experience that is adapted to the learners at hand even when they are not all at the same stage of understanding (1967).

The digital fabrication age of the late 2000s was a continuation of previous theories based on experiential education, constructionism, and critical pedagogy (Blikstein, 2013). The theories of Froebel, Piaget, and Bruner (Froebel, 2001; Piaget, 1954; Wellhousen & Kieff, 2001) support the assumption that students can develop their spatial reasoning skills through practice. The constructivist theory encourages the ability of the learner to construct knowledge with appropriate needs-based guidance. The use of 2D and 3D fabrication devices can facilitate this theory and provide opportunities for children to build on what they already know so that they develop a deeper understanding of spatial reasoning skills, as we will continue to discuss in the next section.

Spatial Reasoning Development

We know there is variation in the spatial reasoning skills that students demonstrate (Kali & Orion, 1996; Lord, 1985; Piburn et al., 2002). So, why is this? A review of the literature provides us with several potential justifications for that answer.

Gender

Some research supports the idea that spatial reasoning skills are innate. These assumptions are often associated with gender (Berfield, Ray, & Newcombe, 1986; Hill, Corbett, & Rose, 2010; Newcombe, Bandura, & Taylor, 1983). Newcombe et al. (1983) performed two studies to identify a gender connection with spatial reasoning skills and participation in 81 "sex typed" or gender based activities.

There is an abundance of research to support the theory that men consistently perform better in skills requiring spatial abilities or mental rotation tasks (Astur, Tropp, Sava, Constable, & Marcus, 2004; Linn & Petersen, 1985; Malinowski & Gillespie, 2001; Moffat, Neal, & Witten, 1998; Vandenberg & Kuse, 1979). The theory that men perform better in spatial abilities was also shown to be the case in a study by Sorby and Baartman (2000). Sorby and Baartman (2000) administered the Purdue Spatial Visualization Test: Rotations (PSVT:R) to university engineering students and the study revealed that women were three times more likely to fail as their male counterparts.

In an effort to ascertain a justification for the difference between male and female spatial abilities, Pintzka, Evensmoen, Lehn, and Haberg (2016) experimented with 42 young women by giving testosterone or a placebo to each and found that the testosterone group had improved mental rotation abilities and performed better in the virtual environment utilized for the study, confirming that there is a relationship between testosterone and mental rotation abilities in healthy women. The Pintzka et al. (2016) study lends credence to the research findings of others in support of a gender factor in spatial reasoning skills.

Language

Language and cognitive skill research has been in existence for quite some time and connects to the development of spatial skills' research and has been found to have a strong connection to the development of math and language skills (Boroditsky, 2011; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Levinson, Kita, Haun, & Rasch, 2002). Sometimes this connection is manifested by the language we use when referencing navigational descriptors (Bergman, 2011; Boroditsky, 2011; Whorf 1956). Sapir and Lee studied how languages were varied and initiated the concept that speakers of different languages actually thought differently. Sapir and Lee felt that an individual's development of ideas and expression of the same were heavily dependent on their language (Boroditsky, 2011).

The ability to communicate terms that indicate direction and distance is one method of developing spatial understanding. Terms like up, away, and others are used from an early age to teach children direction. The Common Core Standards for children in elementary grades also includes expectations of language to facilitate spatial reasoning skills (Common Core Standards 2012). Levinson, Kita, Haun, and Rausch (2002) performed several tests aimed at an investigation of people's sense of direction. These included an investigation of gestural depictions of events and spatial orientation in various cultures (Haviland, 1993; Kita, Danziger, & Stolz, 2001; Levinson, 1996), directionality in the memory of real-life events that people have experienced (Levinson, 1997), and dead reckoning and the navigational abilities in various cultures (Levinson, 1996). Levinson also found that people who speak languages that use absolute directions, as in north, south, east, and west, are better at telling where they are as opposed to those languages that use terms relative to the individuals location like to my left or right. Levinson also explored the use of rotation of the participant in directional research (1992). Levinson's participant rotation test is different from typical forms because the individual is being rotated and not the object itself. Levinson's research supports the theory that different languages develop distinct conceptual codings connected to the verbalization of directional language (Levinson, 1992).

Li and Gleitman disagree with the idea of different languages developing distinct codings and contend that, "Linguistic systems are merely the formal and expressive medium that speakers devise to describe their mental representations" (2002, p. 290). Their research investigated the differences in spatial organization and reasoning styles of various language speakers to consider the influence that terms of spatial indications such as left or right, north or south make with regards to solving spatial reasoning or rotational problems.

The research that this researcher found most interesting, concerning language and spatial reasoning, was conducted by Johanson and Papafragou (2014). The Johanson and Papafragou findings showed that across a variety of languages, children extended the use of spatial terms consistently to explain their understanding of a spatial concept (2014). For example, in the case of their studies, English-speaking four-year-olds were able to extend the use of terminology for in, inside, or into to describe behind and under as specific terms used in the study. The children understood the spatial concept and applied the language that fit with their understanding. This spontaneous extension of spatial language use would indicate that spatial reasoning skills are not limited by the exposure to appropriate spatial terminology.

Evidence has also been found to support that early spatial abilities predict a young child's reading skills (Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Li & Gleitman, 2002). The research examined the serial search performance and spatial cueing and facilitation in 96 Italian-speaking children who were prereaders and in kindergarten. While the prereading visual spatial attention was not clearly linked to the prediction of future reading abilities, the study did establish that "independently of speech-sound perception, as well as nonalphabetic cross-modal mapping skills, visual attentional functioning predicts future reading emergence and developmental disorders" (p. 818). This connection of spatial abilities to reading skills provides the appearance that the two are dependent upon each other.

Research by Boroditsky (2011) supports the likelihood that the way we think influences the way we speak, and the way we speak influences the way that we think. Boroditsky examined how English and Mandarin speakers think about time. Two tasks utilizing temporal reasoning were compared between the English and Mandarin speakers to measure how people spatialize time in three-dimensional space. English speakers tend to use horizontal terms like front and back when talking about time while Mandarin speakers used vertical terms like up and down.

Does the way we speak or the terminology we use impact our spatial thinking? There appears to be a variety of opinions on that subject. In a case similar to: What came first—the chicken or the egg?—did the spatial skills come first looking for the language to describe what was thought or did the language come first limiting the visualization of the mind? Marzano

(1998) states that vocabulary is the very foundation of a student's knowledge base and also suggests that vocabulary is synonymous to building background knowledge.

Experiential

The use of 2D cutters in STEM career skills development is a relatively new concept (Bull et al., 2010). While there is currently limited research on the specific use of 2D and 3D fabricators for the improvement of spatial reasoning skills, there is a significant amount of research that supports the use of visual manipulation and 2D and 3D learning tools as that represented by the software and manipulation of items constructed using 2D and 3D fabrication devices. The majority of these reports also support the use of practice to improve spatial reasoning skills (Baenninger & Newcombe, 1989; National Research Council, 2006; Newell & Rosenbloom, 1981; Terlecki, Newcombe, & Little, 2008; Wallace & Hofelich, 1992; Wright et al., 2008).

Wright et al. (2008) utilized a computerized mental rotation task, mental paper-folding task, and verbal analogies tasks to evaluate 31 students' spatial reasoning skills. The research found that the participants showed improvement based on the practice. While Wright's project did not include the use of 2D and 3D fabrication devices, it did utilize software that is similar to the design software used with 3D fabricators (2008). Another aspect of the study Wright conducted was the use of the cut-and-fold products that are very like the products that are produced by a 2D cutter (2008).

Titus and Horsman (2009) conducted two evaluations of student's spatial skills based on their enrollment in a college geology course or courses. The researchers used a precourse and a postcourse survey in a quantitative and qualitative research structure to determine if spatial abilities could improve through practice in geology courses. Their research found that spatial visualization skills could be improved by incorporating frequent opportunities for visualization exercises and practice that lasted for as little as 5-10 minutes a week.

Zaretsky and Bar (2004) also found that practice with mental manipulations showed a positive improvement on intelligence scores and spatial skills. The research conducted by Zaretsky and Bar (2004) involved the use of a virtual reality setting and the game Tetris, which was invented in 1985 by Alexey Pazhitnov from Russia (Zebra Partners, 2016). Zaretsky and Bar used qualitative longitudinal research to evaluate the pre- and posttraining intelligence and spatial reasoning scores of eight pupils aged 16-17. These students included special education and regular education students for comparison. Their training sessions were held in a computer lab setting twice a week for one month, with each meeting lasting 45 minutes. At the end of the study, there was a marked gain for the special education students and a more gradual pattern of gain for the regular education students. Of significant interest in the Zaretsky and Bar (2004) study is the lack of connection to reading or math in the success of the game lending, to a true use of spatial visualization. It appears that such constructivist learning opportunities are proving to be key to the development of spatial reasoning skills and improvements in the same.

Another example of the benefits of spatial reasoning skills practice includes the work of Bethell-Fox and Shepard (1988). Bethell-Fox and Shepard studied a selection of students between the ages of 16 and 18 in the Pala Alto, California area and found evidence that individuals who practice with mental rotations develop an internal familiarity of the image that improves their ability to mentally rotate objects at a rapid rate (1988). Bethell-Fox and Shepard used a variety of spatial abilities tests for pre- and postscoring; the stimuli for the testing included several block matrix reproductions of varying difficulty over a time period of up to three hours (1988). This idea that practice using spatial activities develops spatial reasoning skills is also supported by a study by Heil, Rosler, Link, and Bajric (1989). The data revealed that the repetition of mental manipulations of various objects becomes part of a memory process that allows participants to solve the task by memory retrieval making the process faster. This concept about memory processing was supported by research from Newcombe and Huttenlocher (2000) who state that, "The fact that development of place learning continues into early childhood, with mature levels on place tasks not being seen until about 7 years of life, suggests the relevance of accumulating experience." Newcombe and Huttenlocher's research is referring to the way that place learning, or knowing where an object is placed, continues to build from about 21 months through about age seven affirming that practice does impact learning (2000).

Apparel design requires the ability to visualize clothing and how it will fit the body or object for which it is being designed. As such, spatial reasoning and visualization skills are very important to designers, in the same way they are for engineers and mathematicians (Park et al., 2010). In the field of clothing design, 3D simulation is used for prototyping patterns and the improvement of spatial reasoning skills. Park et al. (2010) used questionnaires and three different teaching techniques to evaluate visualization abilities: lecture, 3D simulation instruments, and paper patternmaking. Their research found that all three of the methods improved spatial reasoning. The emphasis was placed on the 3D simulation because of the benefit to the apparel industry by allowing fast prototyping that would speed the design process with overseas manufacturers.

The ability to use digital fabrication and “making” has been referred to as a powerful tool for education for use in the development of creativity and inventiveness, especially in design and engineering (Blikstein, 2013). Since the Massachusetts Institute of Technology developed the FabLab or Fabulous Lab kit (Gershenfield, 2012), there have been over 100 such labs established worldwide with support from the National Science Foundation. These labs provide the equipment and software needed to create 3D items. Through distance sharing of patterns and knowledge about the FabLab devices, students can experience learning that is far above any local education opportunities available to them.

Measurement of Spatial Reasoning Skills

In order to develop spatial reasoning skills in young children, validated tests are necessary that are suited to the age and understanding level of younger children aged 5 to 9. When an Internet search performed for such tests based on the phrase "validated spatial reasoning tests for children," a variety of options was found. The Spatial Intelligence Learning Center provided a listing of tests, as did a document by DeThorne and Schaefer (2004). A review of these test options revealed that most were designed to use language specific instructions or did not cover the entire age range of 5 to 9 years of age. DeThorne and Schaefer point out that "in testing applications where the level of linguistic or reading ability is not part of the construct of interest, the linguistic or reading demands of the test should be kept to the minimum necessary for the valid assessment of the intended construct" (2004, p. 82). In a past pilot study in Haiti (Zimmerman, 2014), this researcher was interested in the development of a spatial reasoning skills test that is nonverbal in nature and appropriate for children ages 5 to 10 years of age. One of the difficulties this researcher found in selecting a test for Haiti was the inability to use technology to perform a test in locations without access to electricity. Concerns like these eliminated many of the testing options that currently exist.

While the use of the UNIT test in this spatial skills case study was successful, the same test posed issues when administered in Haiti due to the difficulty level of the Cube Design test. Children in Haiti needed a much lower test floor, or simpler test items, based on their lack of understanding of the spatial skills needed to complete the test further supporting the need for a new spatial reasoning skills testing option.

UNIT

The UNIT (Bracken & McCallum, 1998) is a test used to evaluate general intelligence and cognitive abilities. The test includes six subtests—Cube Design, Spatial Memory, Symbolic Memory, Object Memory, Analogic Reasoning, and Mazes—that are all designed for use with children ages 5 years to 17 years. The purpose is to provide a test that can be utilized without language so that there is less likelihood that the score is impacted based on an issue with understanding rather than the actual ability to perform the tasks at hand. The test can be administered as a Brief Battery (Symbolic Memory and Cube Design subtests), the Standard Battery (Symbolic Memory, Spatial Memory, Cube Design, and Analogic Reasoning subtests), or the Extended Battery containing all six subtests. The UNIT (Bracken & McCallum, 1998) allows for the selection of individual subtests based on need.

Many reliability and validity tests were completed during the UNIT development. The reliability coefficients for the subtests are split-half correlations corrected by the Spearman-Brown formula (Bracken & McCallum, 1998, p. 100). The median reliability score, or degree of accuracy of the test scores, was found to be .91 across all age levels for the standardization average reliability and .96 for clinical/exceptional reliability (Bracken & McCallum, 1998). The Spatial Reasoning subtest had a .81 across all age levels, and a Standardization Average Reliability and .92 Clinical/Exceptional Reliability (Bracken & McCallum, 1998). All of the subtests meet the reliability standard of .70 or better, based on Nunnally (1978, p. 245).

Test validity was evaluated internally and externally against a number of intelligence tests (Bracken & McCallum, 1998). The outcome of the validity studies proved the UNIT to be a comparable measurement and meaningful tool for measuring intelligence (Bracken & McCallum, 1998). Advantages of the UNIT (Bracken & McCallum, 1998) over other intelligence tests include the nonverbal nature of the instructions that allow for use with English second language students or students with hearing issues. As this study only had a limited amount of time available, the brevity of the UNIT (Bracken & McCallum, 1998) test made it the best option for the measurement of two- and three-dimensional skills for this study.

Summary

The Being Fluent with Information Technology report, issued by the National Research Council in 1999, stated that technology was changing rapidly and emphasized the need for intellectual capabilities that would promote how to address unintended and unexpected problems (National Research Council, 1999). Skills are no longer the only approach to learning and there is clearly a need for higher-order thinking skills and the ability to adapt with the continuous wave of technology change. While there are varying opinions about the source of spatial reasoning skills, there appears to substantial support for the ability to learn these skills through the practice of activities that promote the use of visualization to engage and develop an interest in spatial reasoning activities (Baenninger & Newcombe, 1989; National Research

Council, 2006; Newell & Rosenbloom 1981; Terlecki, Newcombe, & Little, 2008; Wallace & Hofelich 1992; Wright et al., 2008). Piaget studied the cognitive development of children after he became interested in why children missed test questions that required logical thinking (1954). Piaget determined that children learned differently from adults and began developing a map of their learning process. Piaget concluded that children use basic building blocks that enable them to develop mental representations of the world. The map that children develop provides a way for them to build on their past learning. Piaget's cognitive learning theory supports the ability to develop spatial reasoning skills with practice based on the stages of development (1954).

CHAPTER 3

METHODS AND PROCEDURES

This chapter begins with an overview of this study, followed by descriptions of the setting, participants, protection of human subjects, methods, data collection, and timeline. The chapter will end with data analysis and a summary.

Research Design

The purpose of this study was to evaluate the ability of activities with 2D and 3D fabricators to improve the spatial reasoning skills of children in Grades 4-5 (ages 9-12) at a private school in the Southeast Texas metropolitan area. The research design was a quantitative study utilizing data collected before and after activities with 2D and 3D fabricator activities. Two of the UNIT subtests were selected to use for the study, as they are validated tests of spatial reasoning skills. With the assistance of a graphic artist, 20 items were developed for a new instrument assessing early spatial reasoning. Permission was granted to transfer the original items to Photoshop and develop a protocol to allow the administration of the instrument in a school setting for purposes of the proposed research study. The Shapes Test (Tyler-Wood, 2015) was administered before the activities with the UNIT and then again after the activities.

The research timeline included a three-day testing period to complete the on-campus testing and activities. A total of three researchers were involved in the study. These researchers were selected based on their experience with the use of 2D and 3D fabricators for the education of children. The researchers met prior to the research timeframe and discussed the outline of the survey delivery (as shown in Appendix F) and the procedures to be used when administering the tests. The three of us restated what was planned and agreed on the process. A more detailed summary of the process is included in the next section, "Setting of the Study."

The selection of fourth and fifth grade students was made due to the abundance of research indicating the importance of improvements in primary age children (Newcombe & Frick, 2010) and the desire to benchmark the administration age floor and ceiling for the Shapes Test (Tyler-Wood, 2015) for potential use with a young students.

Setting of the Study

The study was conducted at a small private school in a Southeast Texas metropolitan region over a three-day period. The research was approved for a three-day period at the school, based on the school's schedule and the availability of the students' time for the research. Two additional researchers participated in the data collection and demonstration phases. The participants were 20 fourth and 21 fifth grade students from two classrooms of each grade. The researchers were provided with two classrooms to administer the surveys where two surveyors were stationed on opposite sides in one classroom and the third was in the second classroom.

For the fabrication device activities, activities were stationed at one end of the school's gymnasium. The devices were set up on long tables with paper and media supplies needed alongside each device. This set-up allowed the students to view the equipment at eye level as fabrication was performed. While the students waited for their turn to view the fabricators and ask questions, they sat in groups of five to eight and were provided with supplies that included 2D fabricator precut houses, flowers, and cubes (depicted in Appendix E). The students were also provided with a printed map of the town of Tombstone, Arizona from the 1800s and a modern day map of the same town. The children were instructed to fold the precut houses and flowers and to select one section of a block or street to reproduce from the maps while they waited for their turn at the fabrication devices.

Participants

The participants for this study were selected from a private school in Southeast Texas. This school was chosen based on its location, the school's interest in providing the activities for their students, and the availability of time that the school could commit to the research project. There were 24 male students and 17 female students involved in the study, as shown in Table 1. The age ranges of the students in the study were from 9 years and 8 months to 12 years and 3 months of age. Table 2 represents the age in full years.

Table 1

Participant Gender Makeup

Gender	Number	Percentage
Male	24	59%
Female	17	41%
Total	41	100%

Table 2

Participant Age Makeup

Age	Number	Percentage
9 years old	5	12%
10 years old	19	46%
11 years old	15	37%
12 years old	2	5%
Total	41	100%

Of the 41 participants, there were 20 fourth grade students, 10 male and 10 female that completed all of the tests: Cube Design, Spatial Memory, and the pre/postactivities Shapes Test (Tyler-Wood, 2015) that is in development (See Table 3). Of the 41 participants, there were 21 fifth graders, 14 male and 7 female. None of the fifth grade students were able to complete either UNIT test. However, all of the fifth grade students completed the pre/post Shapes Test (Tyler-Wood, 2015; See Table 4).

Table 3

UNIT Cube, Spatial, and Shapes Test Completions by Age and Gender for Fourth Grade

	Male	Female
9 years old	1	4
10 years old	9	5
11 years old	0	0
12 years old	0	1
Total	10	10

Table 4

Test Completions by Age and Gender for Fifth Grade

	UNIT Cube		UNIT Spatial		Shapes Test Pre		Shapes Test Post	
	Male	Female	Male	Female	Male	Female	Male	Female
10 years old	0	0	0	0	5	0	5	0
11 years old	0	0	0	0	8	7	8	7
12 years old	0	0	0	0	1	0	1	0
Total	0	0	0	0	14	7	14	7

This research study was a cross-sectional, case study of students at a small private school in a Southeast Texas metropolitan area conducted during May of 2015. The city demographic information showed an 85% black demographic; however, the zip code information for the area in which the private school is located had a much higher white population. The ethnic makeup of the area is 46.6% black, 34.2% white, 13.9% Hispanic, 3.4% Asian, 1.2% are two or more races, with less than .12% other (American Indian alone, Native Hawaiian and other Pacific Islander alone) (City Data, 2015). Because of the age of the students, the reliability of self-reported ethnicity information obtained was questionable and, therefore, was not collected as part of the survey. The City Data (2015) Web site states that there is a 98% urban and 2% rural population made up of 47.7% male and 52.3% female residents. In a comparison from Table 1, the participants for this research were 59% male and 41% female. The average household income in 2013 was $40,322.

The 2013 population for the specific area where the private school is located was 12,368 and the area was made up of 33 percent renters with a cost of living index of 81.5 percent. In 2013, 90.8 percent of the population residents had a high school or higher education, 27.3 percent had a bachelor's degree or higher, 7.5 percent had a graduate or professional degree, and 4.9 percent were unemployed. Students in private schools in this area represent 7.4 percent for those in Grades 1-8 (City Data, 2015). The students in the study were from two fourth and fifth grade classes at the school and were very interested in the fabrication equipment and learning about their use.

Protection of Human Subjects

Participants in the study were fourth and fifth grade students, ages 9-12, from a private school located in Southeast Texas. The research study was approved by the University of North Texas' Office of Research Integrity and Compliance. In accordance with the IRB process, a letter of approval was obtained from the school prior to beginning of the research (see Appendix A). The letter included the school's permission to work with students whose parents gave permission for their participation and provide these students with educational activities utilizing 2D and 3D fabricators as a part of the research. An explanation of the study was provided to the teachers of the potential students and included details about the activities to be provided. As included in the IRB, there was no risk associated with participation in the project. The possible benefits for the students included the opportunity to learn about new and innovative technology and the potential to develop spatial reasoning skills.

A Parental Consent form was sent home with the fourth and fifth grade students and parents were provided the opportunity to request more information. The consent form was one of the documents that was included in a packet that was approved under the requirements set by the University of North Texas' IRB (see Appendix B). The form explained the project design and that the curriculum and support for the project were provided by the University of North Texas and its Department of Learning Technologies. The request for permission to collect data was presented and the return of the signed form was stated as a requirement for the student's participation.

Of the students who had signed Parental Consent Forms, each was provided with a Student Assent Form and also individually provided with an explanation that their participation was voluntary (Appendix B). The form explained the lesson and included the statement that a student could stop participation at any time, if they chose to. The students were then asked to sign the Student Assent Form before the research began.

Research Study Instruments

The UNIT

The tasks that were included in the UNIT surveys are designed to measure the general cognitive abilities and intelligence of children and adolescents ages 5 to 17 years old. The UNIT subtests are administered individually to students and have been developed to be presented nonverbally for the benefit of those who may have difficulties with traditional tests that require verbal instructions. The test manual for this instrument, Universal Nonverbal Intelligence Test (UNIT): Examiner's Manual ([UNIT Manual], Bracken & McCollum, 1998), states that "The UNIT is intended to provide a fair assessment of intelligence for children and adolescents who have speech, language, or hearing impairment; color-vision deficiencies; different cultural or language backgrounds; and those who are verbally uncommunicative" (Bracken & McCallum, 1998, p. 1). There are two primary kinds of intelligence that the tests are designed to measure: memory and reasoning. While the test is to be delivered with nonverbal instructions, the manual encourages the creation of a "pleasant environment" (Bracken & McCallum, 1998, p. 43), in part, developed by not delivering the tests in too rigid a manner. The test manual also stressed that communication before, after, and between subtests should be used to contribute to a positive relationship with the examinee and making the setting comfortable for the participant.

The UNIT is a standardized, norm-referenced measure based on a sample of 2,100 children and adolescents that included several categories of those needing educational special services. There are six subtests and each subtest yields an age-appropriate scaled score with a mean of 10 and a standard deviation of 3. The intraindividual, or ipsative, score differences are computed with Davis's 1959 formula (Bracken & McCallum, 1998).

Figure 1. Gesture Examples from the Universal Nonverbal Intelligence Test. Permission to use a photograph of the UNIT (Universal Non-Verbal Intelligence Test) granted by Terri Cooter on February 10, 2014.

The UNIT was developed to allow for the elimination of language and the potential misunderstandings when tests are administered (Bracken & McCallum 1998). Two existing subtests of the UNIT were selected for this study based on the relationship of the skills that they measure to the intent of the research. The UNIT uses a special set of gestures that are considered to be commonly used in many countries (see Figure 1). All of the UNIT tests used in this research were administered with no verbal communication. Non-verbal communication removed the potential error from communication issues or misunderstandings of interpretation. Examples of gestures that are used during administration of the UNIT include head shaking, open-handed shrugging, palm rolling, pointing, hand waving, stop signaling, and thumbs up. The G and secondary abilities that each measure are shown in Appendix G. Detailed descriptions of these abilities can be found in Table 7.3 of the Bracken and McCallum UNIT Manual (1998).

The reliability coefficients of the UNIT Subtest Scaled Scores and Scale Standard Scores by Age are shown in Table 5. Nunnally (1978, p. 245) recommends that all instruments used in basic research have a reliability of .70 or higher. All scores for the UNIT fit those criteria, with only one approaching .70—at .74 for seven-year-olds on the Spatial Memory subtest. Concurrent validity studies (Bell, 2013; Brown, Sherbenou, & Johnsen, 1990; Kaufman, 1994; Kaufman & Kaufman, 1990) show good correlation in the mid-to-high 80s (Bracken & McCallum, 1998; Fives & Flanagan, 2002).

Table 5

UNT Reliability Coefficients – UNIT Cube Design and Spatial Memory Tests

Subtest/ Scale	Age in Years 5	6	7	8	9	10	11	12	13	14	15	16/17	Standardization Average Reliability	Clinical/ Exceptional Reliability
Cube Design	.84	.86	.81	.90	.88	.91	.92	.94	.94	.93	.94	.95	.91	.96
Spatial Memory	.80	.81	.74	.82	.80	.81	.80	.82	.81	.83	.80	.84	.81	.92

Note. N = 175 for each age group. [a]The reliability coefficients for the subtests are split-half correlations corrected by the Spearman-Brown formula. The reliability coefficients for the scales were calculated with the formula for the reliability for linear combinations (Nunnally, 1978).

The subtests selected for this research are both part of the nonsymbolic quotient and are said to require less internal verbal mediation based on the abstract and figural nature of the tasks involved. As such, these subtests are not particularly related to language. Table 6 shows the difference between single subtests and the level of statistical significance. Several studies have been found to support the validity of the UNIT (Bell, McConnell, Lassiter, & Mathews 2013; Borghese, 2009; Borghese & Gronau, 2005; Bracken & McCallum, 1998; Farrell & Phelps, 2000; Maller & French, 2004).

Table 6

Differences Between Single Subtest and Level of Statistical Significance

	Subtest Variability Within Scales		
Scale Subtest	.10	.05	.01
Nonsymbolic-Cube Design	2.03	2.28	2.80
Nonsymbolic-Spatial Memory	2.35	2.64	3.24

A demographic survey component was completed by the researcher during a face-to-face interview with each student prior to the start of the tests. The questions included gender, grade, age, and the questions shown in Appendix C. The purpose of the qualitative questions was to help explain the results of the quantitative research. While Creswell (2003) defines qualitative research as the open-ended collection of data for the primary intent of the development of themes from the data, Strauss and Corbin state that qualitative data can be used to clarify quantitative findings (1990). The quantitative data appears to show a correlation between the scores and the prior skills of the students and that data was collected to be used in further research.

Cube Design

The Cube Design subtest of the UNIT "involves the presentation and direct reproduction of two-color, abstract, geometric designs" (Bracken & McCallum, 1998, p. 3) and is intended to measure reasoning abilities. The Cube Design subtest of the UNIT is similar to the Wechsler Scales (Wechsler, 1991) and uses a scaled score subtest metric of M = 10 and SD = 3. The administration of the Cube Design test requires one of two wire-bound books from the UNIT kit, the UNIT Manual, a laminated guide showing the gestures, a laminated response mat, and a set of nine cubes (Bracken & McCallum, 1998). The 11-inch by 8½-inch white laminated mat contains a black diagonal line about one third down the page on the left just to the right of the middle and toward the bottom of the page. There are nine one-inch cubes—each with two solid white sides, two solid green sides going around the cube, and half green and half white triangle shapes on opposite sides of the cube. The blocks are placed to one side of the paper.

Participants are shown several demonstration items and samples. The participants are then shown a test layout to recreate what they see. Students may view the image for as long as they are working but the time limit for each item is 120 seconds. If the first two or three items in a row after the demonstration sample are not successfully completed within the 120 seconds each, the test is discontinued.

The reliability coefficients are split-half coefficients corrected with the Spearman-Brown formula and averaged across all ages with Fisher's z transformation resulting in .91 for the Cube Design test. Test-retest stability coefficients are corrected for the variability of scores on the first testing and showed a .85 result. As stated in the UNIT Manual (Bracken & McCallum 1998, p. 216), the correlates of the Cube Design subtest are:

> Performance on the Cube Design subtest may predict the examinee's mechanical or graphic (e.g., artistic, drafting, geometry) competence; ability to divide aspects of problems into discrete parts for examination and recombination to provide a viable solution; tenacity in complex future problem-solving situations; reaction to activities that have deadlines or specific time limits; flexibility in evaluating and modifying solution strategies; and ability to orient in and around his or her environment (e.g., reading maps, following spatial directions).

Hence, the measurement of the ability to perform tasks requiring spatial reasoning skills can be validated by the Cube Design subtest.

Spatial Memory

The Spatial Memory subtest is used as a "measure of short-term visual memory for abstract material" (Bracken & McCallum, 1998, p. 3) and was chosen based on the ability to evaluate the two dimensional abilities of the participants. The Spatial Memory subtest uses a black 3 X 3 grid pattern on one side of a white, flat 8½-inch by 11-inch piece of laminated paper, with a black 4 X 4 grid pattern on the back side of the same paper. There are eight black circle spots and eight green circle spots that are used for the test. Students are shown an image with a layout of black and green spots for a maximum of five seconds and then are expected to create the image on their own grid. The student participants can take as long as needed but can only view the image for a maximum of five seconds. If participants do not complete the first two or three items in a row correctly, the test is discontinued per the manual administration guidelines.

The reliability coefficients are split-half coefficients corrected with the Spearman-Brown formula and averaged across all ages with Fisher's z transformation resulting in .81 for the Spatial Memory test. Test-retest stability coefficients were corrected for the variability of scores on the first testing and showed a .68 result.

As stated in the UNIT Manual (Bracken & McCallum 1998, p. 216), the correlates of the Spatial Memory subtest are:

> Performance on the Spatial Memory subtest may predict such future behaviors as the examinee's ability to view the totality and central nature of problems; attend to, process, and recall visual details (e.g., editing, photography, chess); remember the crux of information, rather than the sequence in which the information was presented; concentrate on a problem until the problem is well understood; disassemble and reassemble objects (e.g. motors, computers) by memory; and sensitivity and awareness

to minor changes in the environment (e.g., noting the addition or subtraction of important elements.).

These are relevant skills to the use of spatial reasoning.

Shapes Test

The Shapes Test (Tyler-Wood, 2015) began as a project to further develop a test that could be used as a tool to measure spatial reasoning skills for children younger than nine years old. The need for a test to use with younger children was evident when this researcher worked on a pilot study in Haiti (Zimmerman, 2014). This researcher was provided with rough images from a test that was still in the design phase. This researcher re-created the 20 images using Photoshop CS6 and developed a table structure for the answer sheet. Three additional shape examples and selections were created in addition to the 20 items for use during the introduction and explanation of what was expected prior to the actual survey items. These shape examples were laminated and wire-bound for re-use with each student. The 20 questions were produced in a grid format with the stimulus image in the far left box and the selection items to the right as shown in the sample item in Figure 2. This researcher then created instructions to allow for a nonverbal delivery as used in other tests such as the UNIT Manual (Bracken & McCallum, 1998) and the Naglieri Nonverbal Achievement Test (1997). While the demonstration items were presented with the reusable laminated document, the 20 actual items were presented to the students on paper so that they could circle their choices.

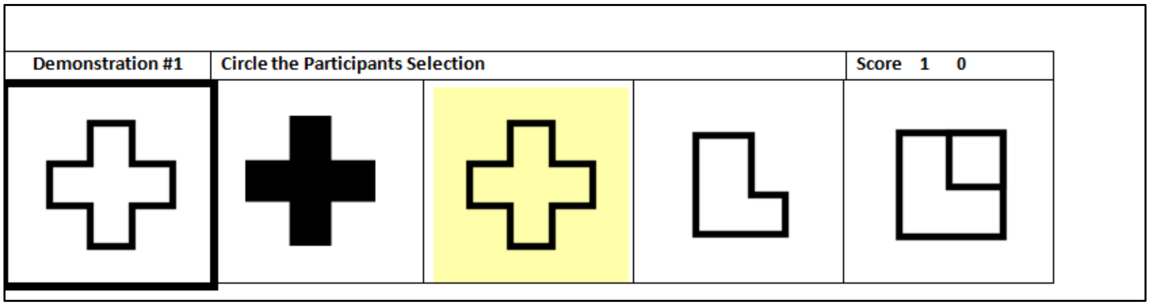


Figure 2. Sample Shapes Test Demonstration Item.

At the start of the test administration, the researcher pointed with the writing instrument to the demonstration item and then handed the device to the student with an open palm and a head nod to indicate that it was time for them to respond. Most students immediately understood what they were to do. If there was any confusion, the researcher explained that the expectation was for the student to circle the image that went with the demonstration image in the first column. Participants were given as much time as needed to complete the survey.

Research Method

This research was a quantitative pre- and posttest designed study. The data was collected from three tests: the UNIT Cube Design subtest (Bracken & McCallum, 1998), UNIT Spatial Memory subtest (Bracken & McCallum, 1998), and the Shapes Test (Tyler-Wood, 2015). The Shapes Test (Tyler-Wood, 2015) is a product that is still in the development phase. Paired T-tests and correlations were used to determine if there was a relationship between the UNIT Spatial reasoning test and the Shapes Test (Tyler-Wood, 2015) scores, between the UNIT Cube Design test and the Shapes Test (Tyler-Wood, 2015), and finally, between the Shapes Test

(Tyler-Wood, 2015) preactivity score and the Shapes Test (Tyler-Wood, 2015) postactivity test score.

Data Collection

The purpose of the data collection for this research study was to determine if there was an increase in spatial reasoning skills after two hours of activities with 2D and 3D fabricators and to determine if the Shapes Test (Tyler-Wood, 2015) is a valid measure of spatial reasoning skills. A sampling of fourth and fifth grade students was selected to participate in the study. Part of the justification for this age group is the fact that the Shapes Test (Tyler-Wood, 2015) was designed to be used for younger students and my pilot study with students in Haiti proved to me that there needed to be another testing tool developed for use with students who have communication difficulties (Zimmerman, 2014). The data collection for all of the tests in my research involved the administration of the tests at a small private school in Southeast Texas.

Day 1 started with the researchers verifying Informed Consent Forms (Appendix B) for all students and explaining the research to the students to collect Student Assent Forms (Appendix B) to participate in the research. The next step was to collect the responses to the self-developed questionnaire, which included demographic information along with three questions regarding previous experiences with musical instruments, reading music, and playing with building toys (Appendix C). The third step was to administer two of the UNIT subtests, the Cube Design and Spatial Memory test, and the Shapes Test (Tyler-Wood, 2015) to all students who had approval to participate in the study and completed the Student Assent form.

The pretesting concluded at about noon on the second day of the research. For two and one half hours, the researchers introduced the students to activities utilizing the 2D and 3D cutters and took small groups of about five to eight students up to the devices to watch them work and explain the basics of the devices. The students were provided with precut 2D fabrication products and created houses, boxes, and three-dimensional flowers (Appendix E) while they waited their turn to see the equipment in action.

On day three, the researchers performed posttests of the Shapes Test (Tyler-Wood, 2015) on all students and did not have time to perform any posttests of the UNIT. The survey data was then manually entered into Statistical Package for Social Sciences to be analyzed for descriptive statistics.

Timeline

The timeline for the research was three days. Day one was used for the verification of Parental Consent form, the explanation and acquisition of the Student Assent form, and the administration of the majority of the pretests. Day 2 included the finishing of the pretests and the 2D and 3D activities lesson. Day 3 involved the completion of as many posttests as possible.

Data Analysis

The primary scales used in the UNIT material are Memory and Reasoning and the secondary scales are symbolic and nonsymbolic. Based on Bracken and McCallum (1998, p. 13) reasoning abilities have been considered a cornerstone of intelligence (Binet & Simon, 1905/1916; Carroll, 1993; Jensen, 1980, 1984; Thurstone, 1938) and the most effective measures of intelligence are those measures that include broad-reasoning.

The participants' chronological ages were calculated to represent a years and months age for use in the UNIT scoring process. Next, the subtest scores were reviewed. For each correct answer on the Spatial Memory test, the participant received one point. For the Cube

Design subtest, the score was calculated using a combination of the score and the bonus points, when applicable. Raw scores for the tests were converted to scaled scores using the conversion data in the UNIT Manual and shown in Appendix H (Bracken & McCallum, 1998).

Summary

The first research question for this study was, "Can spatial reasoning skills be improved by exposure to 2D and 3D fabricator activities?" For this question, the researcher started with a scatter plot to identify how strong the relationship was between the two variables for the Cube Design preactivity scores and the Shapes Test preactivity scores, along with the comparison of the Spatial Memory test scores preactivity to the Shapes Test (Tyler-Wood, 2015) preactivity scores. This analysis also identified whether there was an increasing or decreasing relationship. The next step was to use correlation coefficients to identify the degree of association between the two variables. Pearson's coefficient was evaluated as a measure of the degree that the relationship formed a straight link.

The second research question asks, "Is the Shapes Test (Tyler-Wood, 2015) a valid measure of spatial reasoning skills in children?" For this question, a paired-samples T-test was performed to compare the means of the data between the Shapes Test preactivity scores and the Shapes Test (Tyler-Wood, 2015) postactivity scores.

CHAPTER 4

RESULTS

Can spatial reasoning skills of students in a private school in Southeast Texas be improved by exposure to 2D and 3D fabricator activities and is the Shapes Test (Tyler-Wood, 2015) a valid measure of spatial reasoning skills in children? These are the questions being evaluated. This chapter will include the test results based on the analysis of the data that was collected for the Cube Design, Spatial Memory, and Shapes Test, the assumptions that were included in the research, and a summary.

UNIT Test Results

According to Bracken's 1987 standards, the UNIT subtests and scales show consistent reliability across sex, race, and ethnicity, and also meet reliability standards. Based on the UNIT Manual, the Cube Design score is the most stable of the subtests with regards to test/retest scores and the Spatial Memory test has the smallest mean gains from test to re-test. The Cube Design and Spatial Memory tests both meet or exceed Kaufman's criterion as good g measures, $\geq .70$ (1994). Because the timeframe for the research was limited, postactivity scores are not available for the Cube Design and Spatial Memory tests. The research data included in this study provides comparisons of the preactivity scores for the UNIT subtests to the preactivity scores of the Shapes Test (Tyler-Wood, 2015) using correlations and a comparison of the Shapes Test (Tyler-Wood, 2015), and preactivity to the Shapes Test (Tyler-Wood, 2015) to the postactivity using paired T-tests. Interesting to note is the fact that an initial scatter plot of the UNIT Cube Design test as correlated to the UNIT Spatial Memory appeared to have a very weak relationship (Figure 3). This weak relationship may be based on the fact that the interpretation of the Spatial Memory test at the subtest level is to be made more cautiously because it is the most "g-loaded" of the UNIT subtests meaning that it shows the most common variance of 60% with regards to the other tests in the battery as shown in Table 7. The measure of g-load is interpreted based on a factor pattern coefficient of .70 or greater (defined as a good measure of g), coefficients from .50 to .69 define fair, and coefficients less than .50 are usually considered poor (Kaufman, 1994). The spatial Memory test has a g-load of .77 while the g-load for the Cube Design test is .73.

Table 7

UNIT Subtest g-Loadings and Common, Specific, and Error Variance Components

	Loading	Common Variance %	Specific Variance %	Error Variance %
Cube Design	.77	54	37	9
Spatial Memory	.73	60	21	19

Note. A principal components analysis of the standardization data was used to partition variance components. The g-loadings are factor pattern coefficients for the first unrotated factor for the Extended Battery.

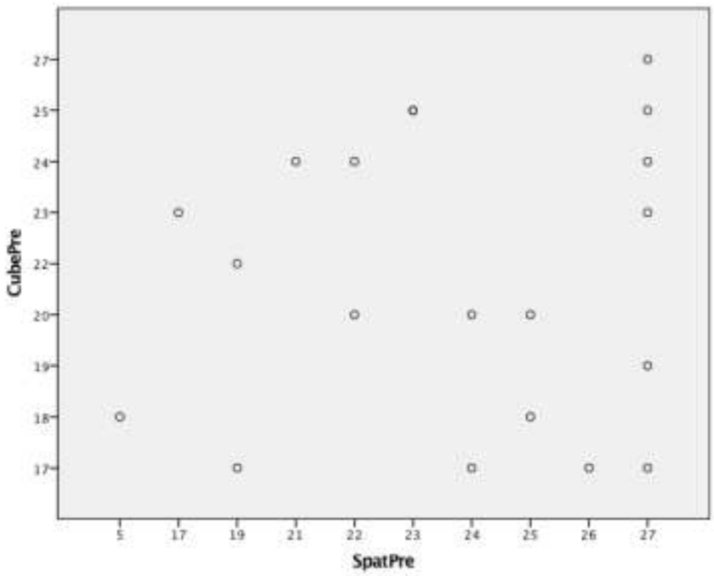


Figure 3. Scatterplot Graph of the Cube Design and Spatial Memory Preactivity Scores.

Cube Design Subtest

The first step in the analysis of the Cube Design subtest was to construct a scatterplot of the data for the comparison of the Cube Design and Shapes Test (Tyler-Wood, 2015) preactivity data, as shown in Figure 4. If the outliers are removed, there appears to be a positive correlation in the results.

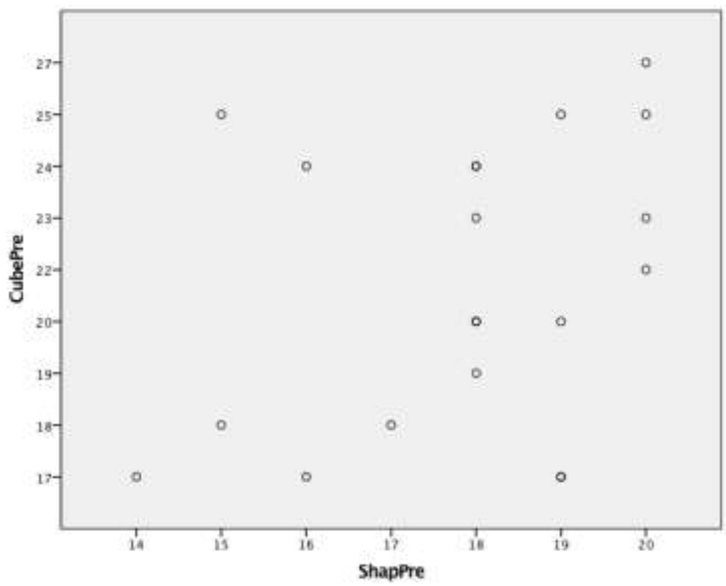


Figure 4. Scatterplot Graph of the Cube Design and Shapes Test Preactivity Scores.

A bivariate Pearson Correlation was performed next using SPSS to determine if the two variables were linearly related to each other. Table 8 reflects the findings. Table 9 shows the Pearson's coefficient was .349, based on a sample size of 20, indicating a moderate strong, increasing correlation (Frankel, Wallen, & Hyun, 2012).

Table 8

Cube Design and Shapes Test Preactivity Results

	Mean	Std. Deviation	N
CubePre	21.25	3.307	20
ShapPre	17.85	1.814	20

Note. Std. = Standard

Table 9

Cube Design and Shapes Test Preactivity Correlation Results

		CubePre	ShapPre
CubePre	Pearson Correlation	1	.349
	Sig. (2-tailed)		.132
	N	20	20
ShapPre	Pearson Correlation	.349	1
	Sig. (2-tailed)	.132	
	N	20	20

Note. Sig. = Significance.

The confidence interval of the correlation between the Cube Design preactivity test and the Shapes Test (Tyler-Wood, 2015) preactivity scores reflect a 95% confidence interval for the difference of -1.917 to 4.883, meaning that there is a 95% likelihood that the mean has been determined precisely (IBM Corporation, 2015).

Of the 20 participants who completed the Cube Design subtest, 10 have an age equivalent score above their actual participation age, leaving 10 with age equivalents below their age at the time of their participation (See Appendix I).

Spatial Memory Subtest

The scatter plot for the Spatial Memory subtest and the Shapes Test (Tyler-Wood, 2015) preactivity are shown in Figure 5. The scatter pattern is very widespread and seems to show a positive trend. As previously mentioned, interpretation of the Spatial Memory test at the subtest level is to be made more cautiously because it is the most "g-loaded" of the UNIT subtests, meaning that it shows the most common variance of 60% with regards to the other tests in the battery. This is interpreted to mean that the Spatial Memory test does not have the ability to provide a general measure of intelligence as well as the other subtests.

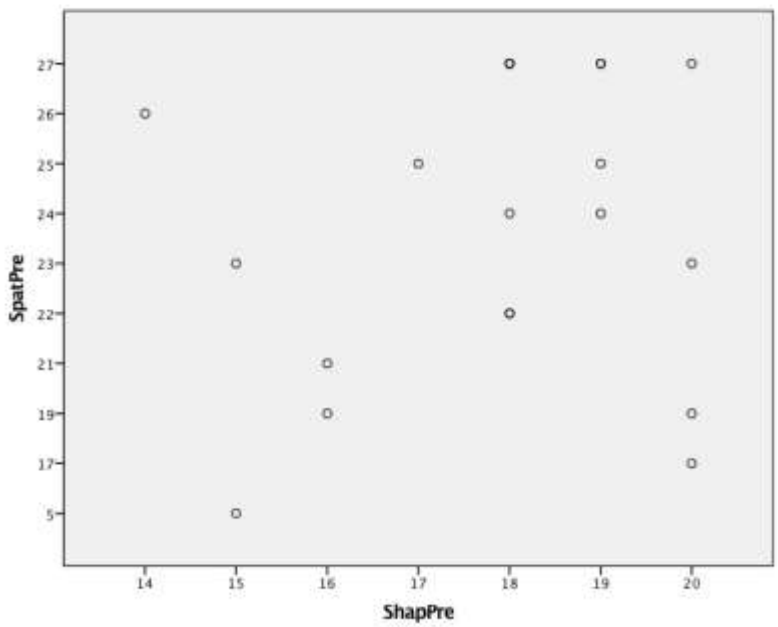


Figure 5. Scatterplot Graph of the Spatial Memory and Shapes Test Preactivity Scores.

A bivariate Pearson Correlation was run next using SPSS to determine if these two variables were linearly related to each other. Table 10 and 11 reflect the findings. Table 11 reflects the Pearson's coefficient as .282 based on a sample size of 20, indicating a small or weak correlation (Frankel et al., 2012).

Table 10

Correlation Results – Spatial Memory and Shapes Test Preactivity Scores

	Mean	Standard Deviation	N
SpatPre	22.85	5.194	20
ShapPre	17.85	1.814	20

Table 11

Correlation Results for 2-Tailed – Spatial Memory and Shapes Test Preactivity Scores

		SpatPre	ShapPre
SpatPre	Pearson Correlation	1	.282
	Sig. (2-tailed)		.228
	N	20	20
ShapPre	Pearson Correlation	.282	1
	Sig. (2-tailed)	.228	
	N	20	20

On the Spatial Memory subtest, all 20 participants scored above their age as of the time of their participation in the research (shown in Appendix I). Eight participants scored at the ceiling of the test. Appendix I reflects the score distribution by age for each fourth-grade participant.

Based on the preactivity scores for the Spatial Memory subtest, the research participants displayed very good performance, as indicated in Appendix J. When the subtest scores are evaluated to interpret the Full Scale Intelligence Quotient, the results show that five of the participants were categorized as Very Superior, 11 as Superior, 1 as High Average, and 3 as Average, providing an FSIQ range of 106 to 132.

Shapes Test Results

A paired-samples T-test was run for the comparison of the Shapes Test (Tyler-Wood, 2015) preactivity scores to the Shapes Test (Tyler-Wood, 2015) postactivity scores (See Table 15). The results from the paired samples statistical analysis, shown in Tables 12, 13, and 14, show a significance of .131, which is not considered significant. On average, Shapes postactivity scores were 6 points higher than the Shapes preactivity scores.

Based on the Shapes Test scores, there was an increase of approximately 6 points in the spatial reasoning skills of the participants after the 2D and 3D fabricator activities. However, the Paired Samples T-test results reflect a t statistic of -1.58 and p-value (Sig. 2-tailed) of .131, which does not show significance. Because this number is greater than .05, the results conclude that there is no statistically significant difference between the two test score results. The differences between condition means are likely due to chance and not due to the activities. The lower and the upper limits of the 95% confidence interval means that we can be 95% confident that the population mean difference between the preactivity scores and the postactivity scores is between -1.395 and .195 points. The simplified explanation is that there were students whose score increased and students whose scores decreased and there is not enough evidence to support that the increases were due to the intervention. While there appears to be an increase in scores, we cannot confirm significance based on this study.

Table 12

Paired Samples Statistics for Shape Test Preactivity and Postactivity Scores

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ShapPre	17.85	20	1.814	.406
	ShapPost	18.45	20	1.395	.312

Note. Std. = Standard

Table 13

Level of Significance for Shapes Test Preactivity and Postactivity Scores

		N	Correlation[a]	Sig.
Pair 1	ShapPre & ShapPost	20	.465	.039

Note. Sig = Significance. [a]There is a correlation defined as moderately high based on Fraenkel, Wallen, & Hyun, 2012.

Table 14

Paired Samples Difference for the Shape Test Preactivity and Postactivity Scores

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1								
ShapPre - ShapPost	-.600	1.698	.380	-1.395	.195	-1.580	19	.131

Note. Std. = Standard; Sig. = Significance. Effect size = 20.

The Shapes Test (Tyler-Wood, 2015) preactivity scores revealed that 5 out of 20 students (25%) made a score on the low end of the range of 14-16, as broken out in Table 15.

Fifteen of the 20 students (75%) had scores from 17-20. The postactivities Shapes Test (Tyler-Wood, 2015) scores reflect two students (10%) with scores in the 14-16 range and 18 students (90%) with scores of 17-20. This means that there was an overall increase of 6-points for the scores on the Shapes Test (Tyler-Wood, 2015) after the 2D and 3D fabricator activities and a 15% increase in the higher scores of 17-20. There were eight students whose scores challenged the ceiling on the pretest and their scores were removed from the data so the percentage totals do not reflect 100 percent. A paired t-test of the remaining 12 students' scores reflects a t statistic of -2.028 and p-value (Sig. 2-tailed) of .067. If we use a one-tailed result based on the fact that we are only interested in increases in scores, we get a significance of .0335.

With a correlation of .465 for the Shapes Test (Tyler-Wood, 2015) pre- and posttest score results, there is a strong possibility of significance based on the correlation to the UNIT tests, which are heavily validated tests.

Table 15

Distribution of Scores for Pre and Postactivity Shapes Tests

Shapes Test Score	Shapes Test Preactivity Number of Students	% of Total Scores	Shapes Test Postactivity Number of Students	% of Total Scores
14	1	5	0	0
15	2	10	1	5
16	2	10	1	5
17	1	5	3	15

(*table continues*)

Table 15 (*continued*).

Shapes Test Score	Shapes Test Preactivity Number of Students	% of Total Scores	Shapes Test Postactivity Number of Students	% of Total Scores
18	6	30	2	10
19	4	20	9	45
20	4	20	4	20
Totals	20	100	20	100

A review of the pre/post Shapes Test (Tyler-Wood, 2015) results for all 41 fourth and fifth grade students who completed both tests indicate higher scores for 21 of the 41 students, the same score for 16 of the 41, and 4 students had lower scores on the posttest. While this is not a direct verification that the activities were the justification for the increase, there is an indication that the activities did have an impact on the improvement of spatial reasoning skills.

Discussion of the Results

The purpose of this study was to evaluate the use of 2D and 3D fabrication devices as a means of increasing spatial reasoning skills and to evaluate the use of the Shapes Test (Tyler-Wood, 2015) as a measurement tool for spatial reasoning skills in children. The expected outcome was to see an increase in the spatial reasoning skills of the children in this study after two hours of activities with 2D and 3D fabrication activities. A review of the literature provided evidence to support the improvement of spatial reasoning with practice. Titus and Horsman (2009) found that "spatial visualization skills can be improved by participation in a geology course and by frequent opportunities for visualization practice lasting only 5-10 minutes per week."

Bracken and McCallum's (1984) evaluation of the ceilings of the UNIT subtests used in this research found that the average raw score for the ceiling of the subtests, at the highest age evaluated, was found to be 18.00 representing a 99^{th} percentile, meaning that there are sufficient difficult items to determine a difference between average performance and above-average performers. The data supports that the average subtest ceiling provides substantial and sufficient ceilings for all six subtests. The abbreviated battery of tests for the UNIT have very good or excellent subtest floors and are suited for assessing the functioning of participants over the entire age range, with the exception of the lowest end of the age ranges where caution is advised when determining delayed development. With the justification of the ceiling for the UNIT tests, an implication can be made that the Shapes Test (Tyler-Wood, 2015) that is in development can be re-evaluated for use with students younger than 9 years of age, based on the fact that many of the students in the study scored at the ceiling or maximum score for this test. Because of this high scores achieved by the participants in this study, it may be beneficial to use the Shapes Test with younger children or that more challenging problems should be added to increase the ceiling of the test scores.

Upon review of the data for the Shapes Test (Tyler-Wood, 2015), it was noted that if the scores of the students who challenged the ceiling on the pretest scores were removed from the data, as previously presented in Table 15, and the data was recalculated, the findings would show significance. This new data is represented in Table 16. The posthoc paired samples t-test analysis resulted in a two-tailed significance of .0625 or a one-tailed significance of .031 (as shown in Table 17). This represents a gain in the posttest scores.

Table 16

Distribution of Scores for 4th Grade Pre- and Postactivity

Shapes Tests with Pretest Scores Challenging the Ceiling Removed

Shapes Test Score	Shapes Test Preactivity Number of Students	% of Total Scores	Shapes Test Postactivity Number of Students	% of Total Scores
14	1	8	0	0
15	2	17	1	8
16	2	17	1	8
17	1	8	3	15
18	6	50	2	69
Totals	12	100	12	100

The Paired Samples T-test results reflect a t statistic of -2.433 and p-value (Sig. 2-tailed) of .067. Based on the consideration that we are only interested in an increase in scores, the one-tailed result is .0334 as show in Table 17. This amount is less than .05 concluding that there is a statistically significant difference between the two test score results. The differences between condition means are likely due to the activities.

Table 17

Level of Significance for Shapes Test Preactivity and

Postactivity Scores with Ceiling Challenges Removed

		N	Correlation[a]	Sig.
Pair 1	ShapPre & ShapPost	12	.147	.034

Note. Sig = Significance. [a]There is a medium or moderate correlation based on Fraenkel, Wallen, & Hyun, 2012.

Summary

Chapter 4 presented an analysis of the data collected and associated test results for the Cube Design, Spatial Memory, and Shapes Test. This chapter also included assumptions that were included in the research. Chapter 5 will include a summary of the research study, conclusions inferred, and recommendations for further research based on the research question.

CHAPTER 5

PURPOSE OF THE STUDY

This chapter includes a summary, conclusions, and recommendations for further research based on the research questions: "Can the spatial reasoning skills of 4th and 5th graders at a private school in Southeast Texas be improved by exposure to 2D and 3D fabricator activities?" and "Is the Shapes Test (Tyler-Wood, 2015) a valid measure of spatial reasoning skills in children?"

Study Summary

Based on the correlation of the Cube Design scores to the Shapes Test preactivity scores, there is a medium or moderate positive correlation. The Spatial Memory scores compared to the Shapes Test preactivity scores show a small or weak positive correlation. If these results are considered together, there appears to be confirmation that these tests do correlate to the Shapes Test scores.

The paired T-tests to compare the scores from the preactivity Shapes Test to the postactivity score for this test, there is no significant evidence ($t = -1.580$, $p = .131$) to support the fact that the Shapes Test can be used to measure spatial reasoning skills based on a confidence level of 95% at the difference of -1.395 and .195.

In reviewing the number of participants who scored at the ceiling of the Shapes Test, it can be ascertained that the Shapes Test may not be difficult enough for students aged 9-12. While the validity of the test was not confirmed, it does appear that the instrument may be more appropriate for children younger than those included in the study. In future iterations of this test, the developer may want to increase the difficulty of the items to allow for the needed range of performance capabilities or the test should be utilized with a younger age group.

Conclusions

There is a clear need for spatial reasoning skills to succeed in STEM-related careers (Newcombe, 2010; Titus & Horsman, 2009; Trickett & Trafton, 2007; U.S. Department of Education, 2010; Wai et al., 2009), along with a need for society to develop individuals to fill other types of jobs that require spatial reasoning skills (National Research Council, 2006; National Science Board, 2010). Research has shown various activities that can improve spatial reasoning skills in students (Baenninger & Newcombe, 1989; National Research Council, 2006; Newell & Rosenbloom, 1981; Sorby & Baartman, 2000; Terlecki, Newcombe & Little, 2008; Wallace & Hofelich, 1992; Wright et al., 2008). Practice using 2D and 3D fabricators is an excellent opportunity for students to gain spatial reasoning skills, and entertaining learning experiences can be designed that also promote self-motivated learning in individuals, which has been shown to create the best atmosphere for development (Malone, 1981). In a study with collectable card games, Malone (1981) found that there are three aspects to a game that motivate players: fantasy, challenge, and curiosity. These same aspects can be found when utilizing 2D and 3D fabricators. An enjoyment of learning can encourage the further development of creativity and exploration related to the development of spatial reasoning skills.

While the t-test to compare the pre/posttest scores for the Shapes Test did not show significance in the measurement of spatial reasoning skills, it is still too early to say that it cannot be used for younger children. This study involved three researchers and interevaluator reliability may have been a factor in those findings.

Recommendations for Future Research

Future research is needed to provide additional information regarding the correlation of the Shapes Test (Tyler-Wood, 2015) to the UNIT and to additional tests of spatial reasoning skills for confirmation of this test's ability to measure spatial reasoning skills. Research that includes children ages 5-10 can benefit the evaluation of the Shapes Test (Tyler-Wood, 2015) as an appropriate level of challenge for students of this age. There is also a benefit to additional research using between-group comparisons with a control group that does not actually receive the fabrication activities, an experimental group that does receive the activities, and a comparison group that is provided a modified version of the activities (Creswell, 2012).

Additional research into the identification of more exact explanations for the development of, or lack of development of, spatial reasoning skills can benefit the improvement of spatial reasoning skills in children. Areas of consideration include the relationship of language acquisition to spatial and reasoning skills, the impact of exposure to certain toys on spatial skills development and learning in children, and possibly, the relationship of jobs and tasks children are familiar with, or exposed to, that may impact their likelihood to develop skills based on those experiences or knowledge. The qualitative data that was collected as part of this study provide insight into the possibility of a connection between certain activities and the acquisition of spatial reasoning skills, as found by Newcombe et al. (1983) and leaves opportunities for further research regarding the connection of 2D and 3D activities on spatial reasoning skill development.

During the literature review and evaluation of the opinions regarding the source of spatial reasoning skills, it was apparent that most previous research has only focused on one aspect at a time; gender, language, and experiential. This researcher sees a benefit additional research that evaluates spatial reasoning development based on a combination of factors and the impact that each can contribute.

APPENDIX A

UNT NOTICE OF IRB APPROVAL TO BEGIN RESEARCH

UNT

A green light to greatness.

THE OFFICE OF RESEARCH INTEGRITY AND COMPLIANCE

April 23, 2015

Supervising Investigator: [redacted]
Student Investigator: [redacted]
Department of Learning Technologies
University of North Texas

Re: Human Subjects Application No. 15136

Dear [redacted]

As permitted by federal law and regulations governing the use of human subjects in research projects (45 CFR 46), the UNT Institutional Review Board has reviewed your proposed project titled "The Impact of Digital Fabrication on Spatial Reasoning Skills" The risks inherent in this research are minimal, and the potential benefits to the subject outweigh those risks. The submitted protocol is hereby approved for the use of human subjects in this study. **Federal Policy 45 CFR 46.109(e) stipulates that IRB approval is for one year only, April 23, 2015 to April 22, 2016.**

Enclosed is the consent document with stamped IRB approval. Please copy and **use this form only** for your study subjects.

It is your responsibility according to U.S. Department of Health and Human Services regulation to submit annual and terminal progress reports to the IRB for this project. The IRB must also review this project prior to any modifications. **If continuing review is not granted before April 22, 2016, IRB approval of this research expires on that date.**

Please contact Shelia Bourns, Research Compliance Analyst at extension 4643 if you wish to make changes or need additional information.

Sincerely,

Chad R. Trulson, Ph.D.
Professor
Department of Criminal Justice
Chair, Institutional Review Board

CT/sb

UNIVERSITY OF NORTH TEXAS
1155 Union Circle #310979 Denton, Texas 76203-5017
940.369.4643 940.369.7486 fax www.research.unt.edu

APPENDIX B

INFORMED CONSENT DOCUMENTS

University of North Texas Institutional Review Board

Informed Consent Form

Before agreeing to your child's participation in this research study, it is important that you read and understand the following explanation of the purpose, benefits and risks of the study and how it will be conducted.

Title of Study: The Impact of Digital Fabrication on Spatial Reasoning Skills

Investigator: [redacted] University of North Texas (UNT) Department of Learning Technologies.

Purpose of the Study: You are being asked to allow your child to participate in a research study which involves completing assessments about spatial reasoning skills. This research will provide data on the effectiveness of digital fabrication for improving knowledge about spatial reasoning skills and abilities and interest in science, technology, engineering, and math (STEM).

Study Procedures: Your child will be asked to complete a series of questionnaires, instruments and surveys concerning spatial reasoning skills that will take about 30 minutes of your child's time prior to participating in the unit of instruction and 30 minutes after participating in the unit. The actual activities are expected to take from 2-4 hours. The curriculum taught in this study will be taught to all students in participating classrooms. The curriculum is part of the general curriculum. The data collected through the project will be used by teachers to determine the effectiveness of the curriculum. You have the right to withdraw consent for the use of your student's data throughout the project. Since the project is part of the general curriculum, students will not have an option to opt out of the day-to-day curriculum activities and assessment.

Foreseeable Risks: There are no foreseeable risks involved in this study.

Benefits to the Subjects or Others: We expect the project to benefit your child by providing an opportunity to learn new and innovative material related to an emerging STEM field, digital fabrication. Digital fabrication is defined as computer-aided processes that manipulate material through subtractive or additive methods. These processes can be broken down into two groups: computer numerical control (CNC) processes and rapid prototyping (RP) processes. The fundamental difference between these two is that the CNC processes create objects by removing material (subtractive) while RP processes create objects by building it up layer-by-layer (additive). A few examples of CNC processes are milling, water jet cutting, and laser cutting. RP processes include three-dimensional printing, stereo-lithography, and fused-deposition modeling. These skills potentially help to develop spatial reasoning abilities in individuals.

Compensation for Participants: None

Procedures for Maintaining Confidentiality of Research Records: Data from this study will be coded so that no study participant can be identified. Information obtained from this study will be secured in the IITTL data repository system in the Department of Learning Technologies. No identifying information will appear in any reports or articles generated through the study.

Questions about the Study: If you have any questions about the study, you may contact [redacted].

Review for the Protection of Participants: This research study has been reviewed and approved by the UNT Institutional Review Board (IRB). The UNT IRB can be contacted at (940) 565-3940 with any questions regarding the rights of research subjects.

Research Participants' Rights: Your signature below indicates that you have read or have had read to you all of the above and that you confirm all of the following:

- [redacted] and/or her designee has explained the study to you and answered all of your questions. You have been told the possible benefits and the potential risks and/or discomforts of the study.
- You understand that you do not have to allow your child to take part in this study, and your refusal to allow your child to participate or your decision to withdraw him/her from the study will involve no penalty or loss of rights or benefits. The study personnel may choose to stop your child's participation at any time.
- You understand why the study is being conducted and how it will be performed.
- You understand your rights as the parent/guardian of a research participant and you voluntarily consent to your child's participation in this study.
- You have been told you will receive a copy of this form.

____
Printed Name of Student

____
Printed Name of Parent or Guardian

______________________________ ____________
Signature of Parent or Guardian Date

APPROVED BY THE UNT IRB 4/23/15 TO 4/22/16

For the Investigator or Designee: I certify that I have reviewed the contents of this form with the parent or guardian signing above. I have explained the possible benefits and the potential risks and/or discomforts of the study. It is my opinion that the parent or guardian understood the explanation.

_________________________________ ____________

Signature of Investigator or Designee Date

APPROVED BY THE UNT IRB
FROM 4/23/15 TO 4/22/16

Student Assent Form

You are being asked to be part of a research project being done by the University of North Texas, Department of Learning Technologies.

This study involves taking surveys and answering questions about digital fabrication lessons you take part in while at school.

You will be asked to participate in a lesson where you get to use the computer to help make 2 and 3 dimensional objects as part of a lesson. You will also be asked to take some surveys and answer questions that will take about one hour of the allocated time.

If you decide to be part of this study, please remember you can stop participating any time you want to.

If you would like to be part of this study, please sign your name below.

____
Printed Name of Student

APPROVED BY THE UNT IRB
4/23/15 TO 4/22/16

________________________ ____________
Signature of Student Date

________________________ ____________
Signature of Investigator Date

Office of Research Services
University of North Texas
Last Updated: December 12, 2014

Page 4 of 4

APPENDIX C

SAMPLE OF SURVEY QUESTIONNAIRE

The Shapes Test Instructions and Data Collection Form

Participant Name: ____ Sex: M F

Examiner: ____

School/Agency: [redacted] ______________

Grade Placement: ____________________________

	YEAR	MONTH	DAY
Testing Date	2015	05	
Birth Date			
Age			

Have you ever played a musical instrument?	Yes No	Instrument:
Can you read music?	Yes No	
Have you ever played with Legos, Lincoln logs, blocks, or similar toys that build things?	Yes No	Toy(s):

Overview of Survey

The examiner should be sitting with the participant where there is a flat surface and as little distraction as possible. The examiner will first administer the demonstration items and then begin the actual survey response items after it is determined that the participant understands the expectations.

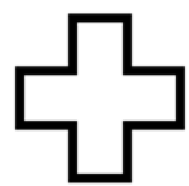
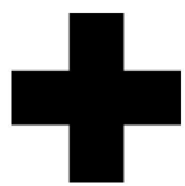
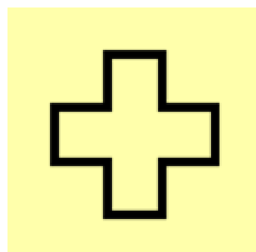
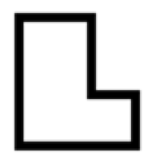
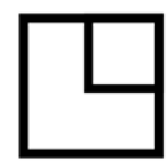
For the actual survey response items, the examiner will provide the participant with the document to mark their answer selections. The participant will use a writing utensil to circle their matching shape selection. NOTE: The survey is designed to be usable without the need of an interpreter when there is a language barrier.

APPENDIX D

SAMPLE OF SHAPES TEST DEMONSTRATION ITEMS

Part 1 Instruction – Sample Demonstration Items

Sample Demonstration Item #1 – Set the Demonstration Card for Item 1 on the flat surface in front of the participant. Point to the first demonstration image and then the image of the correct answer on the card. Point to the correct answer. Shake your head to indicate "yes" pointing from the stimulus image and then the matching image to indicate that it is the right answer. Be sure to mark their selection on the answer form. (The highlighted image is the correct answer.)

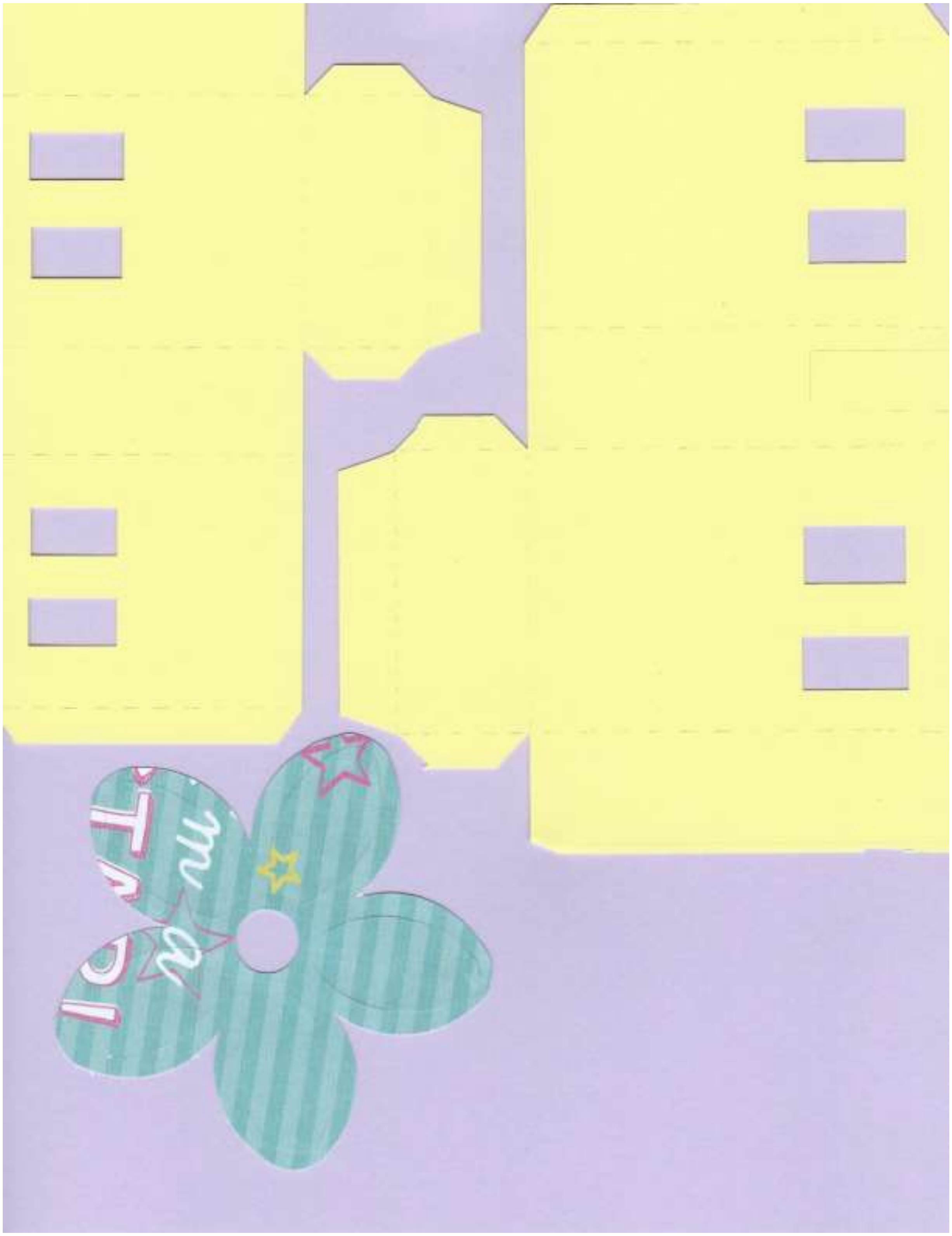
Demonstration #1	Circle the Participants Selection			Score 1 0
				

Sample Demonstration Item #2 - Set the demonstration card for Item 2 on the flat surface in front of the participant. Point to the demonstration image and then wave your hand with the palm up to the answer choices to indicate that it is the participants turn to point to the answer.

- If they select the correct answer, shake your head to indicate "yes" pointing from the demonstration image #2 and then to the matching response image to indicate that it is the right answer. You may continue with the actual items at this point.
- If they select an incorrect image, shake your head "no" and wave your hand, palm up, again to indicate another try. If the participant now makes the correct choice, continue with the survey. If they do not, discontinue participation.

APPENDIX E

SHAPES TEST ACTIVITY EXAMPLES



APPENDIX F

SCRIPT OUTLINE FOR RESEARCH PROJECT

Script Outline for Research Project
The Impact of Digital Fabrication on Spatial Reasoning Skills
IRB #15136

When will the interview take place: During the first morning of the research project prior to the activities and on the second day after the activities have taken place.
Where will the interview take place: The student Interview will take place in a classroom without distractions.
SCRIPT
Hello. You will be doing some activities using 2D and 3D fabricators during today and tomorrow. Do you know what those are? You may know them as a device that is used for scrapbooking and a device that can create shapes using plastic or other material. An example is when you take a flat pattern of a cube and fold it to make a box. You are being asked to participate in a research study which involves completing assessments, similar to a test with no right or wrong answers, about spatial reasoning skills. These "tests" will help us decide if digital fabrication improves your abilities and interest in science, technology, engineering, and math and if you understand the idea 3 dimensional objects.

Do you agree to participating in the project? [If the student agrees, they will sign the consent form and the script continues.]

The first test I would like you to do include two activities. Are you ready?
[The test criteria and testing instructions begin at this point. The UNIT spatial reasoning and Cube Design sections will be completed.]

The next test I would like you to participate in is a shapes test. Are you ready?
[The test criteria and testing instructions begin at this point. The Shapes test will be completed.]

There is one more test. Are you ready?
[The test criteria and testing instructions begin at this point. The Weshler Preschool and Primary Scale of Intelligence test will be completed.]

AFTER THE 2D and 3D ACTIVITIES
Hello. Do you remember the tests that we did before the project? I would like you to participate in those again now so we can tell if participating in the project improved your ability to see things differently. Are you ready?
[The same tests as prior to the project will be administered again and the student will be thanked for their participation.]

APPENDIX G

PRIMARY AND SECONDARY ABILITIES ASSESSED BY THE UNIT SUBTESTS

Underlying Abilities	Cube Design	Spatial Memory
Abstract Thinking	P	
Analysis	P	
Attention to Detail	P	P
Concentration		P
Evaluation	P	
Holistic Processing	P	
Nonsymbolic Mediation	P	P
Nonverbal Reasoning	P	
Perception of Abstract Stimuli	P	P
Perceptual Organization	P	P
Reasoning	P	
Reproduction of a Model	P	
Simultaneous Processing	P	P
Spatial Orientation	P	P
Synthesis	P	
Three-Dimensional Representation	P	
Visual-Motor Integration	P	S
Visual Short-Term Memory		P
Working Under Time Constraints	S	

Note. P = Primary; S = Secondary.

APPENDIX H

UNIT SCALED SCORE DIFFERENCE AND STATISTICAL SIGNIFICANCE FOR FOURTH GRADE

Participant	Cube Design Scaled Score	Spatial Memory Scaled Score	Difference	Normative Frequency of the Difference
1	11	19	-8	1.3
2	12	19	-7	2.9
3	9	18	-9	.7
4	12	18	-6	11.8
5	12	19	-7	2.9
6	12	19	-7	2.9
7	10	12	-2	61.9
8	11	19	-8	1.3
9	12	19	-7	2.9
10	8	2	6	6.3
11	9	19	-10	.2
12	11	18	-7	2.9
13	8	19	-11	.1
14	8	14	-6	6.3
15	12	19	-7	2.9
16	8	15	-7	2.9
17	9	19	-10	.2
18	8	19	-11	.1
19	8	19	-11	.1
20	11	16	-5	11.8
21	10	14	-4	22.1

APPENDIX I

UNIT SUBTEST RAW SCORES AND AGE EQUIVALENTS FOR FOURTH GRADE

Participant	Participant Age in Years	Participant Age in Months	Cube Design Subtest Raw Score	Cube Design Test Age Equivalent of Unit Subtest	Spatial Memory Subtest Raw Score	Spatial Memory Test Age Equivalent of Unit Subtest
1	10	4	19	8:6	27	17:10
2	10	3	20	9:6	25	17:10
3	9	8	24	11:6	22	17:10
4	9	10	25	11:10	27	17:10
5	10	4	24	11:6	27	17:10
6	10	8	23	10:6	17	12:6
7	9	10	23	10:6	27	17:10
8	9	9	25	11:10	23	17:10
9	10	6	18	8:6	25	17:10
10	10	7	20	9:6	24	17:10
11	10	1	25	11:10	23	17:10
12	10	9	18	8:6	25	17:10
13	10	9	17	8:6	19	16:6
14	10	10	27	12:10	27	17:10
15	12	3	20	9:6	22	17:10
16	9	11	17	8:6	24	17:10
17	10	8	17	8:6	27	17:10
18	10	0	17	8:6	26	17:10
19	10	6	24	11:6	21	17:10
20	10	0	22	10:6	19	16:6

APPENDIX J

UNIT STATISTICAL SIGNIFICANCE AND PERCENTILE RANKS

FOR FOURTH GRADE PARTICIPANTS

Participant	Cube Design Scaled Score	Spatial Memory Scaled Score	Cube + Spatial Scores Nonsymbolic Scaled Score	Significance	Percentile Rank
1	11	19	30	> .01 Sig	Superior
2	12	19	31	> .01 Sig	Superior
3	9	18	27	> .01 Sig	Superior
4	12	18	30	> .01 Sig	Very Superior
5	12	19	31	> .01 Sig	Very Superior
6	12	19	31	Not Sig	Average
7	10	12	22	> .01 Sig	Superior
8	11	19	30	> .01 Sig	Very Superior
9	12	19	31	> .01 Sig	Superior
10	8	2	10	> .01 Sig	Superior
11	9	19	28	> .01 Sig	Superior
12	11	18	29	> .01 Sig	Superior
13	8	19	27	> .01 Sig	Average
14	8	14	22	> .01 Sig	Very Superior
15	12	19	31	> .01 Sig	Average
16	8	15	23	> .01 Sig	Superior
17	9	19	28	> .01 Sig	Superior
18	8	19	27	> .01 Sig	Superior
19	8	19	27	> .01 Sig	Superior
20	11	16	27	Not Sig	High Average
21	10	14	24	> .01 Sig	Superior

Note. Sig = Significance.

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