Spatial ability of transitioning 2D to 3D apparel design:
Applying Apparel Spatial
Visualization Test (ASVT) into virtual environment

A Thesis Submitted to
Faculty of the Graduate School at the
University of Missouri in
Partial Fulfillment of the Requirements for the Degree
of Master of Science

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JULY 2021

APPROVAL PAGE

The undersigned, appointed by the dean of the Graduate Studies, have examined the thesis entitled

SPATIAL ABILITY OF
TRANSITIONING 2D TO 3D
APPAREL DESIGN: APPLY
APPAREL SPATIAL
VISUALIZATION TEST
(ASVT) INTO A VIRTUAL
ENVIRONMENT

presented by Anna Moritz,

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ACKNOWLEDGEMENTS

First I would like to thank my committee members Dr. Ha-Brookshire and Dr. Oprean for your patience and support throughout my thesis development. I would also like to thank Dr. Youn for your guidance and unwavering support, I could not have done it without your help.

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ABSTRACT

The purpose of this was to develop a 3D Apparel Spatial Visualization Test to examine visualization skills and mental imagery in a virtual prototyping environment of students who major in textile apparel management at the college level. By examining the visualization skills and mental imagery in a virtual prototyping, this research sought to understand how 3D ASVT training could influence student's performance in a product development course. It also sought to examine how experience level (i.e., number of courses a student has taken) effects performance on 3D ASVT. Results from this study indicated there was no relationship among general spatial ability tests and the developed 3D ASVT. Generally speaking, the study found that the number of product development courses taken positively influence scores on 3D ASVT; and there was not a significant difference among number of courses taken and performance. The study also found that scores on 3D ASVT positively influence performance in product development courses.

CHAPTER I: INTRODUCTION

Chapter I contains the following sections (a) background of the study, (b) gaps in literature (c) purpose of the study, and (d) significance of the study.

Background of the Study

From concept to prototype, the capability to mentally visualize is critical to the apparel design and product development process. New channels for fashion design and product development have emerged as three-dimensional (3D) computer-aided design (CAD) software have become an important part of the design process (Papahristou & Bilalis, 2017). Through the use of 3D prototyping software, designers can create and apply their ideas in a realistic setting. The ability to design in a 3D virtual setting requires the use of mental imagery and spatial ability. Spatial ability plays a critical role in apparel design and product development education. The design process consists of many stages that require a great level of visual processing (e.g. sketching, draping, sewing, evaluating fit, patternmaking, measuring) (Ahn & Workman, 2010). Students in apparel product development and design education are often asked to effectively communicate their design process, translate work from two-dimensional (2D) ideas to three dimensional (3D) concepts, and construct garments based on those concepts. To achieve these expectations, a certain level of spatial ability is required of students.

From early stages of the design process students use spatial abilities to mentally imagine the drape of a garment on the body in order to physically sketch a two-dimensional (2D) illustration of the garment. When a sketch is created, the student then must translate the sketch into a 2D flat pattern or begin the process of translating the 2D sketch using a 3D-to-2D draping process to create a garment prototype. The prototype is then used to create 2D flat patterns for the draped design. After the 2D pattern is created, the process of construction begins. Once a

prototype is constructed, the garment is then analyzed for fit on a body form. Like many design processes, assessing garment fit is a very visual process and can lead to multiple prototypes and fit analyses.

Today's textile and apparel majors at the college level, learn the basic but necessary skills to prepare them for the apparel design and development industry. However, textile and apparel design and product development education is lacking the implementation of CAD software in the classroom. While students learn key CAD abilities using software like Adobe Illustrator and Photoshop to illustrate garments and produce technical illustrations, the use of virtual prototyping software minimally present in their education. The absences of 3D virtual software hinder student's ability to improve visualization skills and knowledge of garment construction from the beginning to end stages. While the presences of 3D virtual software can improve visualization skills and garment knowledge.

As the apparel industry's design and product development process continues to transition into a highly automated and computer aided industry, the need to prepare students for this technology driven environment is critical (Papahristou & Bilalis, 2017). Currently, there is only one developed test to measure spatial abilities specific to apparel design and product development: ASVT. The Apparel Spatial Visualization Test (ASVT) developed by Workman et al. (1999) measures spatial visualization abilities specific to apparel design in a two-dimensional environment. Although ASVT is specific to apparel design and product development, it does not examine the spatial visualization or mental imagery skills of students in a 3D prototyping environment. In fact, very few studies have examined 3D prototyping software as an effective instructional tool in apparel design and development education. Previous researchers, Park et al., (2011) is one of the few who have investigated 3D simulation technology and the effectiveness

of it as an instructional tool. Park et al., (2011) used OptiTex™, a 3D virtual prototyping software, to develop 3D simulation instruments as one of the three different methods of examining the effectiveness of 3D prototyping technology. However, a 3D spatial visualization test specific to apparel design and product development that measures the mental imagery and spatial abilities of students has yet to be developed.

Gaps in the Literature

A review of spatial ability within textile and apparel literature reveals that while the development of a 2D ASVT has added to the understanding of the importance of spatial ability in textile and apparel education, no research has developed a 3D ASVT to understand spatial ability within a virtual environment in textile and apparel education.

Purpose of the Study

Nowadays, the apparel industry has increased the need to advance the apparel industry's design and development processes by using 3D virtual garment prototyping (Papahristou & Bilalis, 2017). Because of the increase embeddedness of 3D virtual prototyping software in the apparel fashion industry, the implementation and development of a 3D CAD simulation test in the classroom would be beneficial to understand what factors can improve students virtual prototyping abilities and how instructors can better prepare students for the industry.

Furthermore, it is important to identify how students learn and understand 3D CAD technology in order to determine the best way to teach students. The purpose of this study is to develop a 3D Apparel Spatial Visualization Test to examine visualization skills and mental imagery in a virtual prototyping environment of students who major in textile apparel management at the college level. The following research questions guided this study: Will the number of courses taken positively influence 3D ASVT scores? Does a 3D apparel spatial visualization test positively

effect student's spatial performance in a design course? Will the paper folding test, mental imagery, and 3D ASVT scores have a positive relationship? Will the number of courses taken positively influence performance in PD course?

Significance of the Study

In apparel design and product development education the need to understand general spatial abilities of students has become increasingly important. Previous researchers have suggested that 3D CAD technology has positively improved student's spatial visualization skills as an effective instructional tool (Park et al., 2011). Additionally, improving student's ability to visualize 2D garments on a 3D body form. Thus, indicating that introducing 3D CAD technology in the classroom enhances spatial visualization ability and improves knowledge of garments. For example, students who are in the early stages of their college education and have minimal 3D mental imagery skills would positively benefit from the addition of 3D CAD technology. Therefore, this study aims to develop a 3D apparel visualization test that can be implemented into the classroom to enhance spatial ability specific to apparel design and product development. Findings from this study are expected to improve academic understanding of spatial visualization and mental imagery skills required for 3D virtual prototyping.

CHAPTER II: LITERATURE REVIEW

The literature review section includes the following: (a) spatial ability, (b) subdimensions of spatial ability, (c) spatial ability in apparel studies, (d) 3D design software and spatial ability in virtual environment, (e) hypothesis development and conceptual model.

Spatial Ability

Spatial ability is a complex, multifaceted concept, that many researchers have worked to decode. What constitutes spatial ability depends on the researcher. For example, previous researchers characterized spatial ability as a human's cognitive ability to visually perceive shapes, positions, and forms when mentally rotated or manipulated (Kyllonen et al, 1984). Researchers have also described it as an innate ability to visualize partially linked to general intelligence (Sorby, 1999). More recently, spatial ability has been identified as an individual ability, comprised of multiple skills, used to navigate the visual field by transforming or manipulating two-dimensional (2D) or three-dimensional (3D) objects (Suh & Cho, 2020). With its convoluted nature, spatial ability is thought to be a fundamental cognitive skill for the creative process and execution of design (Williams & Sutton, 2011). Moreover, researchers suggest the importance of cognitive spatial abilities in Science, Technology, Engineering, Arts, and Mathematics (STEAM) related professions because of the need to form visible and nonvisible ideas (Suh & Cho, 2020). STEAM related fields specific to product design and creativity use a variety of spatial components. Consisting of spatial visualization, spatial relation, mental rotation, spatial orientation, and general spatial abilities. All components that are integral to design performance. Like spatial ability, creativity is a cognitive ability important to design performance (Cho, 2016). Researchers suggest that the lack of spatial ability can result in poor spatial design performance (Liao, 2017). Those who lack the ability or

experience in spatial activities or abilities may encounter difficulties learning or performing spatial ability centered tasks.

Spatial ability is a key factor in creative design performance in 2D and 3D design applications. Thus, researchers have indicated a relationship between spatial abilities and design ability (Suh & Cho, 2020). Numerous researchers suggest that through training spatial abilities can be enhanced by using tests that challenge spatial activities but cannot improve spatial ability (Linn & Petersen, 1985). Using research developed spatial ability tools, an earlier study compared spatial abilities in participants who completed spatial training and participants who had no formal training. Results from this study confirmed the notion that prior training can enhance spatial abilities (Linn & Petersen, 1985). Also uncovering that the level of ability in spatial abilities differs among individuals. Individual differences are integral in understanding spatial ability and its complexity. Differences in abilities consist of how a person evaluates, perceives, understands and solves problems in the spatial field (Gitimu & Workman, 2007). Moreover, spatial experience influences an individual's ability to process and create with spatial activities (Khoza & Workman, 2009). Therefore, researchers developed various spatial ability tools to measure subdimensions of spatial ability from mental rotation to spatial visualization.

Sub-dimensions of spatial ability

Spatial ability encompasses numerous subconstructs varying in skills and components. Depending on the researcher, the concept of spatial ability and its subconstructs varies in definition (Suh & Cho, 2020). Each subconstruct of spatial ability, requires different skills to navigate the visual field. For example, these abilities can involve mental representation, determination of relationships and manipulation of shapes and positions. Similar to general

spatial ability, dimensions of spatial abilities depend on the researcher. Researchers have shown dimensions to include, spatial relation, spatial orientation, spatial perception, spatial reasoning, mental rotation, and spatial visualization (Linn & Petersen, 1985; Dere & Kalelioglu, 2020). Previous studies have examined specific subconstructs of spatial ability encompassing spatial relation, spatial orientation, and spatial visualization. Researchers have produced major and minor dimensions of spatial ability; however, spatial visualization, spatial orientation, and speeded rotation were said to be three major spatial abilities (Lohman, 1988).

Spatial Visualization Spatial visualization skills are considered one of the most important sub-dimensions of spatial abilities. Possessing spatial visualization skills is critical to a wide range of design centered professions and STEAM education (Workman, n.d.). This is because spatial visualization skills have an impact on STEAM education achievement and performance (Buckley et al, 2018). Researchers have identified spatial visualization as a multifaceted ability to mentally manipulate a spatial configuration and create a representation of the configuration from a new perspective (Suh & Cho, 2020). While others have determined it to be an ability involving mentally twisting, rotating, and inverting objects presented in two dimension or three dimensions (McGee, 1979). Furthermore, researchers uncovered a relationship between spatial visualization and receiving and obtaining information to understand the development of three-dimensional images (Gobert, 1999). Certain researchers suggest spatial visualization acts as a bridge from the conceptualization stage of design to the transformation of design concepts into sketches (Linn & Petersen, 1985). When using spatial visualization, other subdimensions of spatial ability like spatial perception and mental rotation may be required (Linn & Petersen,

1985). Determining spatial visualization abilities can be tested using the Paper Folding Test (PFT), the Purdue Spatial visualization Tests, Minnesota Paper Foam Board, MGMP, and others (Olkun, 2003).

The paper folding test created by Ekstrom et al., (1976) consists of mentally visualizing the outcome of folding and unfolding a configuration after a hole has been punched. Researchers created this test to measure participants varying aptitudes of spatial visualization skills. Current research results showed the paper folding test identifies how people solve problems when presented with visual information, however, it does not measure spatial visualization exclusively (Burte et al., 2019). Researchers also uncovered that the PFT does not assess individual differences in spatial abilities (Burte et al., 2019). Similar to PFT, The Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R) is intended to measure spatial visualization. Developed by Guay (1976) PSVT:R consists of 36 questions containing 2D sketches of 13 symmetrical and 17 nonsymmetrical 3-D figures. Based on previous results from PSVT:R, researchers have stated that PSVT:R is a strong measure of mental rotation specific to spatial visualization (Guay, 1976).

Spatial Mental Imagery Spatial mental imagery is the ability to “see with the mind’s eye” when seeing an object or scene mentally (Wimmer et al., 2015). Generally, surveys and questionnaires are used to measure mental imagery, however, using this form of measurement provides multiple limitations and accuracy of measurement. To measure spatial mental imagery, Campos (2009) developed a new test based on the visualization fact of mental imagery; the Measure of the Ability to Form Spatial Mental Imagery (MASMI). This test involves the unfolding of a cube with different signs on each side where the participant has to mentally visualize the cube folded together (Campos, 2009). Spatial relation is said to be one of

the two most often measured and used subdimensions of spatial ability with spatial visualization being the most used (Hoffler, 2010). Similar to general spatial ability, what constitutes spatial relation depends on the researcher. Researchers have defined spatial relation as the ability to engage rapidly and accurately to analyze a pair of stimuli in a mental rotation process (Ekstrom et al., 1976). While other researchers have found it to involve mental manipulation of object and the relationship to other objects (Pellegrino et al., 1984). Spatial relation is also said to be a subdimension of mental rotation with mental rotation being a subdimension of spatial ability (Carroll, 1993). Furthermore, in a study attempting to identify commonalities and differences among three facets of spatial ability researchers Miyake et al., (2001) established a correlation between spatial visualization and spatial relation. Spatial relation and spatial visualization both require a certain level of spatial memory, the ability to imagine an object, and the ability to temporarily store information (Hoffler, 2010; Miyake et al., 2001). Although these are two seemingly different facets of spatial ability, results have indicated that there are no substantial differences between the two abilities.

Measurements of spatial relation include a Card Rotations Test and A Cube Comparisons Tests.

The card rotations test developed by Thurstone and Thurstone (1941) is intended to measure spatial relations by requiring the participant to identify 2D rotated versions of a set of presented figures. Similar to research conducted on other sub-dimensions of spatial ability, results from this study failed to find evidence indicating a significant difference from spatial visualization. Using the cube comparison test developed by Pellegrino et al., (1984) participants are presented six cubes with printed objects on each surface and then asked to assess whether the cubes are the same or not. Spatial orientations the ability to understand and comprehend the

arrangement of elements within a visual stimuli pattern remaining unconfused by changing orientations (Lohman, 1979). It is also said to measure the ability to form an awareness and imagine an objects orientation (McGee, 1979). Like spatial relation, spatial orientation is hard separate from other facets of spatial ability. Carroll (1993) could not find evident that establishes differences between spatial orientation and spatial visualization. This is because tests of spatial orientation are intended to measure spatial orientation often involve mental rotation and the imagining of stimuli rather than challenging orientation of oneself (Kozhevnikov & Hegarty, 2001). Spatial orientation can be measured using the Spatial

Orientation Test (SOT) and the Spatial Orientation Skills Test (SOST).

The Spatial Orientation Test developed by Guilford and Zimmerman (1948) consists of a series of questions containing different views of landscapes from the viewpoint of a boat to determine how the position of the boat has changed from the different viewpoints. Previous researchers tested the validity of SOT and discovered that SOT does not measure difference factors than the spatial visualization Test (Lohman, 1979). Developed by Campos and

Campos-Juanatey (2019) the Spatial Orientation consists of 30 questions with two different maps per question; one map is positioned at 0° (the model map) and the other are maps have been amplified and rotated in other varying positions. The test requires participants to navigate their way around the model map with a reference point of “you are here” to end up at a specific end point by using reference the point (Campos & Campos-Juanatey, 2019). Results from this study indicated that SOST is a good instrument for measuring spatial orientation.

Spatial ability in Apparel Studies

Similar to apparel design and product development, interior design is another field where spatial ability skills are essential. Interior design involves the use of two-dimensional and three-dimensional drawing formats, including planning, elevation, and physical models (Suh & Cho, 2020). Researchers Suh and Cho (2020) examined the relationship between students' performance in interior design and spatial abilities while also examining gender differences. The purpose of this study was to gain a better understanding of facets of spatial ability and its relationship to design performance. Using general spatial ability tests and the Architecture and Interior design domain-specific Spatial Ability Test (AISAT), they measured student proficiency in 2D-to-3D visualization. Central to this study, Suh and Cho (2020) concentrated on spatial visualization, mental rotation, and general spatial abilities. Results indicated that general spatial ability is not crucial to performance in interior design, however, spatial visualization is important to interior design performance (Suh & Cho, 2020).

In spatial ability specific to apparel design and product development research has discussed influences of training, influence of cultural difference, strategies and tools used for problem solving. Furthermore, researchers have analyzed the effects of technology on training and relationships of domain specific spatial ability and general spatial ability; however, the apparel design field was missing a test to measure abilities specific to apparel. Through the development of a test specific to measuring apparel design spatial abilities (ASVT), Workman et al., (1999) found that the development of this test can be implemented as a method of training to improve spatial abilities. Additionally, Workman and Lee (2005) wanted to examine how culture and training effects individual's spatial performance tasks using two different measurements; Apparel Spatial Visualization Test and the Paper Folding Test. Individuals are influenced the

environmental factors that surround them (e.g., Cultural influences and training) (Workman & Lee, 2005). They discovered that when students received training in classes their scores improved on both Apparel Spatial Visualization Test (ASVT) and the Paper Folding Test (PFT). Results from this study also showed a difference in aptitude on the PFT due to exposure from a particular culture (Workman & Lee, 2005). Following, Workman and Khoza (2009) examined the effect of an individual's environmental factors in relation to learning style and spatial performance. Culture may influence an individual's learning style and skills. For this study, the Apparel Spatial Visualization Test (ASVT) was used to measure spatial tasks and a Perceptual Modality Preference survey was used to measure learning styles. Workman and Khoza (2009) found performance of spatial ability is affected by culture rather than training.

Examining training, Workman and Caldwell (2007) found there to be a significant improvement in spatial visualization abilities among students who received indirect training. Gitimu and Workman (2007) found that strategy choices determined performance of ASVT. While Gitimu and Workman (2008) also found individual differences in strategy usage to problem solve spatial tasks. By investigating information processing on apparel related spatial performance, using ASVT and Strategical Information Processing style (SIPS), Gitimu et al. (2005) found that performance was influenced by training and not SIPS. Ahn and Workman (2011) questioned whether estimating and measuring full-scales lines can be improved through training by developing the Estimate of Linear Measurements of Full-Scale Lines (ELMFSL). Results from this study suggest that training contributes to improved estimation of and measurement of full-scale lines, however, the study also revealed some students lack the ability to estimate and measure (Ahn & Workman, 2011). Unlike previous research, Park et al. (2010) analyzed the effectiveness of technology specifically, 3D simulation technology, as a training for

improving spatial ability. Results suggest positive outcomes for improving spatial ability using 3D technology. While also suggesting visualization of 2D patterns for apparel design and product development were improved by teaching methods (Park et al, 2010).

Table 1. *Previous Apparel Spatial Ability Studies*

Author	Title	Purpose	Test	Results
Workman et al., (1999)	Development of a test to measure spatial abilities associated with apparel design and product development	Develop a test that measures spatial skills relative to product development and apparel design	ASVT DATSR	The ASVT measures spatial skills specific to apparel design and product development – not significantly correlate with DATSR
Gitimu & Workman (2007)	Influence of strategy choice on spatial performance in apparel design	To understand individual differences in processing of spatial information	ASVT USQ	Individuals use multiple strategies to accomplish most cognitive tasks
Ahn & Workman (2010)	Spatial visualization skills of apparel industry professionals	To examine spatial visualization skills and leisure activities of apparel industry professionals	PFT ASVT	
Gitimu et al., (2005)	Influences of training and strategical information processing style on spatial performance in apparel design	To contribute to a better understanding of individual differences in processing of spatial information	ASVT SIPS	There is a significant difference in performance on the ASVT between students with more training and those with less training in apparel design.

Workman & Lee (2005)	A cross-cultural comparison of the apparel spatial visualization test and paper folding test	Examine the effects of culture and training on performance of spatial tasks by using ASVT and PFT to students from two cultures at the beg. And end of the semester classes in apparel design	ASVT PFT	Students improved significantly on both the Paper Folding Test and ASVT as a result of training received in their classes
Workman & Zhang (1999)	Relationship of general and apparel spatial visualization ability	Determine if apparel spatial visualization ability as measured by ASVT is correlated with general spatial visualization ability as measured by SDT and if both abilities are related to level of training	ASVT Surface development test SDT	Spatial visualization abilities are related to level of training and that the ASVT measure spatial ability specific to apparel
Workman & Khoza (2009)	Effects of culture and training on perceptual learning style and spatial task performance in apparel design	Examine the effects of culture and training on preferred perceptual learning style and performance of spatial tasks in apparel design	ASVT Perceptual Modality Preference Survey (PMPS)	Preferred perceptual learning style was affected by culture, training, and culture of participants.
Workman & Caldwell (2007)	Effects of training in apparel design and product development on spatial visualization skills	Examine the effects of indirect training provided by apparel design and product development courses on spatial visualization skills	ASVT PFT	Results support the viability of indirect training provided in courses as a means to improve spatial visualization skills.

Gitimu & Caldwell (2008)	Identification of strategies used for solving items on the apparel spatial visualization test	To identify, categorize, and verify strategies that students use to solve items on the ASVT	ASVT Use of Strategy Questionnaire (USQ)	Different individuals use different strategies to solve the same spatial cognitive task
Workman & Ahn (2011)	Linear Measurement and Linear Measurement Estimation Skills in Apparel Design	to develop and critically evaluate instruments to assess estimation and measurement skills and to use the instruments to investigate several research questions.	Physical measurement test ELMFSL Estimate of linear measurements of full-scale lines	Training provided in apparel design classes appeared to contribute to spatial skills
Kamis et al., (2015)	Spatial Visualization ability among apparel design students	To identify the spatial visualization ability among apparel design students	ASVT USQ	The results showed that various combinations of strategies used to answer each item in ASVT
Park et al., (2011)	3D simulation technology as an effective instructional tool for enhancing spatial visualization skills in apparel design	To evaluate the 3D simulation technology as an innovative instructional tool in apparel design education.		3D simulation technology has a positive potential as an efficient instructional tool for improving student's visualization skills

3D Design Software and Spatial Ability in Virtual Environment

Spatial skills are integral in the ability to mentally picture three-dimensional (3D) shapes (Martin-Gutiérrez et al, 2010). Furthermore, spatial skills are a key factor in creative performance and conceptual design (Chang, 2014). In the field of engineering, the development of spatial skills is directly linked to the success of professional work and academic performance (Martin-Gutiérrez et al., 2010). Previous researchers have established the use of training as a method to improve. Three-dimensional computer-assisted drawing

(3DCAD) applications have been tested by researchers to determine if these applications can improve spatial ability. Moreover, Chang (2014) discovered a positive effect on creativity and spatial comprehension when using CAD software. Results from this study, indicated that CAD is an effective tool for greatly increasing creative performance and spatial skills of students (Chang, 2014). Students with better capabilities of spatial skills performed better than those who lack spatial ability skills. Furthermore, a significant difference in the ability of the subconstructs of spatial ability was found among students (Chang, 2014). Similar to Chang, Martín-Dorta et al (2008) examined spatial ability specific to the field of engineering. The authors developed a remedial course to improve engineering students' spatial abilities using 3D CAD modeling (Martín-Dorta et al., 2008). Results indicated that a remedial course proved effective in improving and gaining spatial ability skills. Further, Onyancha et al. (2009) investigated targeted training and CAD software as an effective way for improving spatial abilities. Mechanical Engineering students enrolled in an entry level CAD course were divided into three groups based on their spatial ability level (e.g., Low group, Intermediate group, and High group) (Onyancha et al., 2009). Students in the low group received target training, students in the intermediate group

(experimental group) were offered training but did not have to opt in, and students in the high group (control group) did not receive any training (Onyancha et al., 2009). Results from this study indicated that students who receive targeted training enhanced their spatial ability skills while students who did not receive any training did not improve their spatial ability (Onyancha et al., 2009). Continuing to measure engineering students' spatial skills, János & Gyula (2019) sought to examine students' learning and understandings of 3D technology and their capability. To do so, János & Gyula (2019) developed the CAD 3D course measuring students' abilities at the beginning of the semester and again at the end. Similar to past studies, results from this study suggest that 3D CAD courses improve spatial skills of students. Results also suggest that CAD modeling bridges a gap for students who have poor spatial ability skills (János & Gyula, 2019)

With similar objectives to János and Gyula, Pittalis et al. (2007) examined a library of 3D software applications and its influence in the development and improvement of spatial ability among students. However, this study focused specifically on testing elementary or lower secondary mathematics student's spatial ability skills (Pittalis et al., 2007). Using four different software applications enabled Pittalis et al. (2007) the ability to observe student's ability to construct, manipulate, study, and promote their visualization skills. The results from this study identified a positive relation between students' spatial ability and their performance in the various academics (e.g., engineering, mathematics, architecture studies). Results also suggest software applications increase a student's ability to understand spatial thinking and visualization (Pittalis et al., 2007). Likewise, Dere & Kalelioglu (2020) investigated spatial abilities of secondary school students using a web-based 3D design environment. Using a mixed methods approach, this study applied three tests to measure different subdimensions of spatial ability in sixth grade students and understand what contributions to the creation of 3D design (Dere & Kalelioglu, 2020). Results from this study indicate a significant improvement in

both the student's ability to mentally visualize and manipulate spatial objects. The results from this study also suggest a virtual environment to be more effective than the traditional classroom environment (Dere & Kalelioglu, 2020). Adopting a Conceive Design Implement and Operate (CDIO) teaching strategy, Haung and Lin (2016) explored how 3D modeling technologies impact on spatial ability skills of college students in non-design related departments. CDIO integrated with 3D modeling technologies combines both thinking and practice. Combining both CDIO and 3D modeling technology and materials, this study investigated differences among learners and the improvement of various spatial ability subdimensions (Haung & Lin, 2016). In this study, students were tasked with the challenge of developing a product concept and completing a 3D modeling to produce a final product (Haung & Lin, 2016). From this study indicated that 3D modeling technologies integrated with CDIO resulted in students developing and improving sub-dimensional skills of spatial ability and learning outcomes. This study also provided new approaches to teaching 3D modeling technologies (Haung & Lin, 2016).

In the field of apparel design, Park et al. (2010) conducted an analysis to explore 3D simulation technology as an effective tool for enhancing spatial visualization skills. This study examined apparel product development and design college majors varying in experience level and spatial ability. Using three different instructional methods (e.g., 3D simulation, conventional lectures, and patternmaking practices) results showed that students' abilities to mentally visualize flat pattern on a body were greatly improved (Park et al., 2010). Results also indicated the effectiveness of 3D technology as an effective tool for improving spatial abilities when combined with traditional lecture and patterning making practice. Further, students from the

study reported positive benefits of 3D CAD technology on spatial visualization ability and its potential to be used as an instructional method (Park et al., 2010).

Hypotheses Development

The Apparel Spatial Visualization Test has contributed to the understanding of individual differences in processing of spatial information, learning style, cultural influences, and performance for apparel design and product development students. Currently, the use of 3D CAD technology has become an increasingly important in apparel design and product development related majors and within the industry. While the ASVT test measures apparel spatial visualization abilities of individuals in a 2D environment it is lacking the ability to measure apparel spatial ability in a 3D environment. The understanding of spatial visualization ability performance specific to apparel design and product development using a 3D virtual environment becomes increasingly important as the industry seeks individuals with 3D CAD experience. This study aims to fill the current gap by developing and implementing a 3D virtual prototyping Apparel Spatial Visualization Test using a 3D CAD software; CLO3D. The goal of this study is to understand how a 3D Apparel Spatial Visualization Test when applied in a classroom setting may enhance the student's spatial abilities. While also seeking to uncover how the use of a virtual prototyping software can influence a student's performance in a design course.

Spatial Ability and ASVT

Apparel design and product development studies requires the ability to visualize two-dimensional and three-dimensional shapes and figures. Spatial thought, products, and storage of information is involved throughout apparel design and development (Workman et al., 1999). Previous researchers examined the relationship between the Differential Aptitude Test—Space Relations (DATSR) and the Apparel Spatial Visualization Test (ASVT). From this examination, Workman et al. (1999) found that the ASVT as a function of training can improve general spatial

abilities. Results also indicated that spatial abilities are evident in the training of clothing construction and patternmaking (Workman et al., 1999). Spatial ability is a necessary cognitive ability for apparel design and product development, playing an important role when learning 3D technologies.

Effects of Individual Difference

Individuals' perceptions and behaviors influence individual differences in learning style, internalization, processing, and remembrance of information or skills (Workman & Khoza, 2009). Additionally, individual differences are present in the use of their cognitive abilities, use of different strategies, and processing of spatial information (Gitimu et al, 2005). These individual differences are important in trainability, including indirect training, performance of spatial tasks, and visualization. Furthermore, research has shown that individual differences in spatial ability exists specifically between individuals (Toomey & Heo, 2019). Men and women differ in the processing, problem solving spatial tasks, and strategy (Linn & Petersen, 1985). When examining individual differences among apparel design and product development student's spatial visualization ability, results indicated that males generally perform higher than females on spatial tasks (Workman & Lee, 2005). Thus, indicating training and biological factors influence performance on spatial tasks. Results from this study, also indicated that individuals have different learning preferences based on the influence of environmental factors. These factors include cultural influences, training, and strategies individuals use to solve problems (Workman & Lee, 2005). Previous research has shown that training can lead to improvement in spatial visualization ability, indicating that students in beginning levels of their major (i.e., Freshman level courses) will score low on spatial ability tests compared to students who are nearing the end of their education (i.e., Senior level courses).

Hypotheses

This study aims to develop the 3D ASVT test and identify relationship between the 3D ASVT test scores and spatial ability scores measured through paper folding and mental rotation tests (H1). Also, the study explores effects of PD course on 3D ASVT scores (H2) and performance in PD courses (H3). Finally, the effect of 3D ASVT scores on students' performance in PD courses is examined (H4). Therefore, following four hypotheses were suggested. Figure 1 presents the conceptual model.

H1: The paper folding, mental imagery, and 3D ASVT will have a positive relationship.

H2: The number of PD courses taken will positively influence 3D ASVT scores.

H3: The number of PD courses taken will positively influence on performance in PD courses.

H4: 3D ASVT scores will positively influence on performance in PD courses.

Conceptual Model

Figure 1. Conceptual Model

CHAPTER III: RESEARCH METHODOLOGY

Chapter III provides the following sections: (a) development of ASVT; (b) spatial ability tests; (c) research design; (d) dependent variables; (e) data collections; (f) data analysis techniques.

Development of ASVT in Virtual Environment

Using CLO3D, a 3D fashion design software for creating virtual garment visualizations, a 3D Apparel Spatial Visualization Test was developed (Figure 2). The proposed test consists of 20 questions, each question consisting of 5 possible answers. The original Apparel Spatial Visualization Test developed by Workman et al., (1999) measures spatial abilities specific to apparel product development and design. The ASVT consists of 20 sets of flat pattern pieces that may be constructed into a garment (Workman et al., 1999). Each question consists of 1 flat pattern piece and 5 garments sketches. Participants must determine the correct garment outcome made from the flat pattern piece (Workman et al., 1999). Similar to the original ASVT, the developed 3D ASVT consists of 5 garment outcomes and 1 possible flat pattern piece including front and back patterns. Further, the developed 3D ASVT differs from the original ASVT based on the format the test is provided in. The original ASVT is presented in a two-dimensional format, where the 3D ASVT is offered in a 3D environment. Additionally, the garment outcome is shown on a 3D avatar, giving the participants a visualization of how the garment pattern piece might appear on a body form. Participants can manipulate the video, by pausing, going forward,

or backwards in order to see how the garment appears in all areas of the body (i.e., front and back).

Figure 2. Example of Developed ASVT in Virtual Environment

Spatial Ability Tests

To test general spatial ability, this study used the paper folding test and the measure of the ability to form spatial mental imagery (MASMI) test (Figure 4). Created by Ekstrom et al., (1976) the paper folding test consists of mentally visualizing the outcome of folding and unfolding a configuration after a hole has been punched. The purpose of this test is to measure participants varying aptitudes of spatial visualization skills. To test mental imagery, the MASMI test was used (Figure 5). The MASMI test, developed by Campos (2009), is based on the visualization fact of mental imagery. This test requires participants to mentally visualize a cube being folded together while by looking at an unfolded cube with different signs on each side (Campos, 2009).

Figure 3. Paper folding test

Figure 4. Mental Imagery test

Research Design

For this study, a quantitative approach was used. The quantitative survey included the following information: demographics, experience level, spatial orientation test, mental imagery test, and the developed 3D apparel spatial visualization test, satisfaction with major, perceived performance on courses in Textile and Apparel Management, and demographics (i.e., gender and years in college). Using a survey method allows the researchers within this study to develop and distribute an online experiment to the specific participants (Molnar, 2019). Participants in this study included apparel product development and apparel marketing and merchandising majors in the Textile and Apparel Management Department (TAM) from the University of Missouri – Columbia. Students from both Textile and Apparel Management tracks were surveyed.

Dependent Variables

This study consists of two dependent variables: satisfaction with major and perceived performance on courses in TAM. First, satisfaction with major refers to the level of satisfaction a textile and apparel management student is with their major in the department. The second variable, perceived performance on courses in TAM refers to the students anticipated performance within their major courses.

Data collection

This research utilized a survey method consisting of various spatial tasks to measure participants general and apparel specific spatial aptitude using the Qualtrics Survey Software. After approval from the Institutional Review Board, participants were recruited. Participants were recruited from the University of Missouri – Columbia, Textile and Apparel Management Department. The department has two tracks: Apparel Product development and Apparel Marketing and Merchandising. Students from both apparel tracks were personally recruited through their University email. The email contained instructions for the survey, a human subject consent form and a link to the questionnaire.

A total of 70 participants volunteered for this study. Before beginning the study, participants were given a brief description and purpose of the study in a consent form as well as contact information for both investigators. Participants were made aware that this was a voluntary study, and they could withdraw at any point. The participants then were asked check a box to confirm that they consented to participate before preceding to the next page ensuring they accepted the consent form information. Demographic information, perceived performance, and satisfaction with major were included at the end of the survey.

Data Analysis

Once the data was collected, it was analyzed using the Statistical Package for the Social Sciences (SPSS) software. Participants' age, gender, perceived performance, and satisfaction level were analyzed using frequencies and percentages. The first hypothesis was tested in SPSS to determine correlations. It showed no correlation between To test the remaining hypotheses, one-way analysis of variance (ANOVA) was used. One-way ANOVA is used to determine a significant difference between the means of three or more independent groups (Laerd Statistics, 2018).

CHAPTER IV: RESULTS

Chapter IV includes (a) description of the sample including demographic characteristics; (b) ANOVA results; (c) summary of results.

Description of the Sample

Demographics and Academic Background After following the recruitment protocol, a total of 80 student participants were gathered, 10 of which were deleted as they were incomplete (Table 2). Forty-three participants (61.4%) were female, while twenty-seven (38.6%) identified as male. The age of students ranged from 19-29 with the majority (31) reporting they are at least nine-teen years of age and twelve indicating they are twenty. Approximately 44.3% of the participants were university Freshman, 15.7% were Sophomores, 5.7% were Juniors, and 32.9% were Seniors. A majority of the participants were Textile and Apparel Management marketing and merchandising majors (65.7%, $n = 46$), while 24% ($n = 17$) were product development majors, and the minority being dual track majors (10%, $n = 7$). Of the students who participated, all were current TAM students. Looking closely at the academic background of participants, approximately 54% of students' GPA ranged between 3.4 to 3.8 on a 4.0 scale. When asked how many Product Development courses the participants have taken, 60% of participants have taken at least one to four courses, with 38.5% of students have taken at least six or more courses.

Table 2. Demographic and Academic Background

Variables	Frequency	Percent %
Gender		
Male	27	38.6
Female	43	61.4
Birth Year		
1992	1	1.4
1998	11	15.7
1999	13	18.6
2000	2	2.9
2001	12	17.1
2002	31	44.3
Major		
TAM Marketing and Merchandising	46	65.7
TAM Product Development	17	24.3
Dual Track	7	10.0
Grade Level		
Freshman	31	44.3
Sophomore	11	15.7
Junior	4	5.7
Senior	23	32.9
Number of Courses Taken		
1*	13	18.6
1,2*	5	7.1
1,2,3*	6	8.6
1,2,3,4*	18	25.7
1,2,3,4,5*,6*	1	1.4
1,2,3,4,5,6,7*	13	18.6
1,2,3,4,5,6,7,8*	1	1.4
1,2,3,4,5,6,7,8,9*	12	17.1
Experience		
Apparel Industry Experience	26	37.1
Other	42	60.0

*Note: *1 = TAM 1200 Apparel Design and Production; 2 = TAM 2280 Apparel Production; 3 = TAM 2380 Integrated Apparel Design and Production I; 4 = TAM 2480 Apparel and Textile Presentation; 5 = TAM 2580 Digital Textile and Apparel Applications; 6 = TAM 3380 Integrated Apparel Design and Production II; 7 = TAM 3480 Technical Design; 8 = TAM 4480 Creativity and Problem Solving; 9 = TAM 4980 Apparel Production Management*

Perception toward spatial ability Participants were also asked about their perception toward spatial ability (Table 3). When asked “do you know what spatial ability is” 43% of participants indicated they do not know what spatial ability is, 24.3% of participants were unsure, and 31.4% indicated they know what spatial ability is. Along with analyzing spatial knowledge, we asked participants if they believed product development courses could improve spatial ability. A majority of participants (57.1%) indicated that they were unsure, while 41.5% believed product development courses could improve spatial ability. Participants were also asked if they believed it would be beneficial to introduce spatial training into the classroom. Results showed 41.4% of participants were unsure, while 55.7% indicated it would be beneficial to introduce spatial training into the classroom. When asked whether participants believed spatial ability is important in the apparel industry, 38.6% indicated they were unsure while 58.6% of participants believed it is important in the industry.

Table 3. Perception toward Spatial Ability

Variables	Frequency	Percent %
Do you know what spatial ability is?		
<i>Definitely not</i>	27	38.6
<i>Probably not</i>	3	4.3
<i>Might or might not</i>	17	24.3
<i>Probably yes</i>	21	30.0
<i>Definitely yes</i>	1	1.4
Do you believe product development courses could improve spatial ability?		
<i>Definitely not</i>		
<i>Probably not</i>		
<i>Might or might not</i>	40	57.1
<i>Probably yes</i>	16	22.9
<i>Definitely yes</i>	13	18.8
Do you believe it would be beneficial to introduce spatial training into the classroom?		
<i>Definitely not</i>		
<i>Probably not</i>	1	1.4
<i>Might or might not</i>	29	41.4
<i>Probably yes</i>	17	24.3
<i>Definitely yes</i>	22	31.4
Do you think spatial ability is important in the apparel product development industry?		
<i>Definitely not</i>		
<i>Probably not</i>	1	1.4
<i>Might or might not</i>	27	38.6
<i>Probably yes</i>	21	30.0
<i>Definitely yes</i>	20	28.6

Correlation Results: H1

In order to examine whether there was a significant relationship among each spatial ability test, we used Pearson's r to test for a correlation among the variables. Alpha at .01 was used to determine significance for all statistical analyses. The results for the correlation analysis are shown in table 4. when examining the relationship between the paper folding test and mental imagery test, results show that the Sig. (2-tailed) value is 0.000. This indicates a positive correlation between the scores of the paper folding test and the mental rotation test scores $r = .413$, $n = 70$, $p = .000$. However, when comparing scores of the mental imagery and 3D ASVT results indicated there is no significant correlation between the two tests $r = .044$, $n = 70$, $p = .717$. Similarly, when comparing 3D ASVT and the paper folding test, results indicated there is no significant correlation between the two tests $r = .127$, $n = 70$, $p = .127$. Finally, H1 was rejected.

Table 4. Relationship among scores of paperfolding, mental imagery, and 3D ASVT

	1.	2.	3.
1.Paper Folding	--		
2. Mental Imagery	.413**	--	
3. 3D ASVT	.127	.044	--
<i>M</i>	7.69	3.86	10.54
<i>(SD)</i>	1.097	2.299	4.356

Effects of number of PD courses taken on 3D ASVT scores: H2

Using a median split, the number of courses taken was split into three separate groups (Table 5). Participants in the first group ($n = 18$, 25.7%) have taken one or two TAM courses;

TAM 1200 and TAM 2280. The second group (n = 25, 35.7%) have taken three to six courses; TAM 1200 TAM 2280, TAM 2380, TAM 2480, TAM 2580, TAM 3380. Participants in the third group (n = 27, 38.6%) have taken seven to nine courses; TAM 1200 TAM 2280, TAM 2380, TAM 2480, TAM 2580, TAM 3380, TAM 3480, TAM 4480, TAM 4980. A median split is used to turn a continuous variable into a categorical one by splitting the variables into equal groups (DeCoster et al., 2011).

Table 5. Number of product development courses taken

Variable	Frequency	Percent	Std. Deviation	Std. Error
1-2 classes	18	25.7	4.26	1.00
3-6 classes	25	35.7	2.45	.490
7-9 classes	27	38.6	5.02	.967

To test H2, an ANOVA analysis was conducted to compare the effect of number of product development courses taken on scores of 3D ASVT. Results showed the effect of number of PD course taken on 3D ASVT scores was significant: $F(2, 69) 6.091, p = .004$ (Table 6). Further, to test differences in mean scores of 3D ASVT scores across three groups, multiple comparison was conducted (Table 6.1). From the results, there is a significant difference in scores for students who took 1 to 2 courses and 7 to 9 courses. There is even a significant difference among scores of students who took 1 to 2 courses and 3 to 6 courses. Thus, meaning the more product development courses a participant has taken the higher 3D ASVT results the student received. The fewer amount of product development courses, the lower the 3D ASVT results. Therefore, H2 was accepted.

Table 6. 3D ASVT ANOVA Results

Variable	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	201.43	2	100.72	6.091	.004
Within Groups	1107.94	67	16.54		
Total	1309.38	69			

Table 6.1. Mean difference of 3D ASVT scores across three groups

(I) Three groups	(J) Three groups	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
					Lower	Upper
1 – 2 classes	3-6 classes	-.551	1.257	.900	-3.56	2.46
	7-9 classes	-3.778*	1.237	.009	-6.74	-.81
3 – 6 classes	1-2 classes	.551	1.257	.900	-2.46	3.56
	7-9 classes	-3.227*	1.129	.015	-5.93	-.52
7 – 9 classes	1-2 classes	3.778*	1.237	.009	.81	6.74
	3-6 classes	3.227*	1.129	.015	.52	5.93

*. The mean difference is significant at the 0.05 level

Effects of number of PD courses taken on performance in PD courses: H3

Similar to H2, to test H3, an ANOVA analysis was conducted to compare the effect of number of product development courses taken on performance in PD courses. The product development courses were chosen from a list of required PD courses for apparel product development majors with the addition of one course, TAM 1200, that is not a core requirement for PD students but is product development centered. To examine performance in PD courses, students were asked to report their grade, average for all PD courses, out of 100%, (i.e., 94%, 95%, etc.). Results showed there were no significant differences among performance in product development courses and number of product development courses taken $F(2, 36) = 2.222, p = .123$, where students reported their overall perceived grade for product development courses out of 100% (table 7). Further, to test differences in mean difference of number of courses taken

across three groups, multiple comparison was conducted (Table 7.1). From the results, there is not a significant difference among the mean difference of numbers of course taken and performance. Thus, H3 was rejected.

Table 7. ANOVA Results

Variable	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28.30	2	14.15	2.22	.123
Within Groups	229.29	36	6.37		
Total	257.69	38			

Table 7.1. Mean difference of number of courses taken and performance

(I) Three groups	(J) Three groups	Mean Difference (I-J)	Std. Error	Sig.	95% CI Lower Upper	
1 – 2 classes	3-6 classes	-2.029	1.887	.535	-6.64	2.58
	7-9 classes	1.679	.887	.123	-3.71	.36
3 – 6 classes	1-2 classes	2.029	1.887	.535	-2.58	6.64
	7-9 classes	.350	1.872	.981	-4.22	4.92
7 – 9 classes	1-2 classes	1.679	.833	.123	-.36	3.71
	3-6 classes	-.350	1.872	.981	-4.92	4.22

Effects of 3D ASVT scores on performance in PD courses: H4

Using a median split, the scores of the 3D ASVT were split into three separate groups. The first group (n = 24, 34.3%) scored low on ASVT. Participants in the second group (n = 19, 27.1%) had scores in the mid-range. The third group (n = 27, 38.6%) had high scores on the ASVT (Table 8.).

Table 8. 3D ASVT Scores (3 groups)

Variable	Frequency	Percent	Valid Percent	Cumulative Percent
Low ASVT Score	24	34.3	34.3	34.3
Mid ASVT Score	19	27.1	27.1	61.4
High ASVT Score	27	38.6	28.6	100.0

To test H4, an ANOVA analysis was conducted to compare the effect of 3D ASVT scores on performance in PD courses. The results indicated a significant difference in terms of high ASVT scores $F(2, 36) = 10.411, p = .000$ and performance in product development courses (Table 9). Meaning, when a student received a high 3D ASVT score, they were likely to report a higher-grade percentage in their overall product development courses. Further, to test differences in mean scores of the three groups, multiple comparison was conducted (Table 9.1). The results indicate that there is a significant difference among the mean difference of 3D ASVT scores and performance. Groups with high ASVT scores had greater perform in PD courses than the group that had low and mid ASVT scores. Thus, H4 was accepted.

Table 9. ANOVA Results

Variable	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	94.40	2	47.20	10.41	.000
Within Groups	163.20	36	4.5		
Total	257.69	38			

Table 9.1. Mean difference of 3D ASVT scores and performance in product development courses

(I) Three group_3D ASVT Scores	(J) Three group_3D ASVT Scores	Mean Difference (I-J)	Std. Error	Sig.	95% CI Lower Upper	
Low 3D ASVT score	Mid 3D ASVT score	.894	1.083	.690	-1.75	3.54
	High 3D ASVT score	-2.882*	.730	.001	-4.67	-1.10
Mid 3D ASVT score	Low 3D ASVT score	-8.94	1.083	.690	-3.45	1.75
	High 3D ASVT score	-3.766*	1.083	.004	-6.42	-1.13
High 3D ASVT score	Low 3D ASVT score	2.882*	.730	.001	1.10	4.67
	Mid 3D ASVT score	3.776*	1.083	.004	1.13	6.42

Note: Mid = middle; *. The mean difference is significant at the .05 level

Summary of Results

A positive correlation among scores of paper folding, mental imagery, and 3D ASVT was not evident thus, H1 was rejected. The number of product development courses taken will positively influence performance on 3D ASVT scores was supported by the one-way ANOVA results thus, H2 was accepted. One-way ANOVA results showed, the number of product development courses taken will not influence performance in product development courses so, H3 was rejected. The one-way ANOVA results also showed that 3D ASVT will positively influence performance in product development course, H4 was accepted.

CHAPTER V: CONCLUSIONS

This chapter includes (a) summary of the study, (b) implications and contributions of findings, and (c) study limitations and future research suggestions.

Summary

The future of fashion continues to change as technology rapidly reshapes the fashion industry. As technology continues to infiltrate the design atmosphere, understanding how spatial ability plays a role in design visualization is important. The purpose of this study was to develop and apply a 3D Apparel Spatial Visualization test using the design software, CLO3D, in order to understand spatial ability of current TAM students. By examining the visualization skills and mental imagery in a virtual prototyping, this research sought to understand how 3D ASVT training could influence student's performance in a product development course. It also sought to examine how experience level (i.e., number of courses a student has taken) effects performance on 3D ASVT. Results from this study indicated there was no relationship among scores of paper folding test, mental imagery test, and 3D ASVT. Although there was a weak relationship between scores of the paper folding test and mental imagery, H1 was rejected. Results showed that the number of product development courses taken positively influence scores on 3D ASVT thus, H2 was accepted. When looking at the number of product development courses taken, the results showed there is not a significant difference among number of courses taken and performance H3 rejected. Lastly, results indicated that scores on 3D ASVT positively influence performance in product development courses, H4 accepted.

Contributions and Implications

This research is significant as it is the first study to create a 3D ASVT to examine spatial ability in apparel related research. While previous researchers examined spatial ability in apparel

research using developed a 2D ASVT (Workman et al., 1999), there was little research on spatial ability and CAD technologies in apparel research (Park et al., 2010). Results show that the more product development courses a student took the higher their 3D ASVT scores. This indicates that students with more knowledge in product development were able to identify the correct garment outcomes by looking at a basic pattern block. Students with little to no product development experience were not able to visual manipulate a set of pattern pieces to determine the outcome. If a student has more experience in product development, they have more spatial ability than those students who do not have previous experience in product development. Thus, further research can dive deeper into understanding level of spatial ability if product development students and the benefits of a 3D ASVT training tool in the classroom. We found that 3D ASVT scores were not significantly related to scores achieved from paper folding and mental rotation tests. Although previous studies indicated potential relationship among those scores (Miyake et al., 2001), we could not identify this. This might be mainly because our sample size is limited. Most importantly, this study found that the number of PD course taken did not explain student's performance on PD courses while 3D ASVT scores could enhanced the performance. Given the finding that 3D ASVT scores were positively influenced from PD courses taken (Workman & Ahn, 2011; Park et al., 2010), this shows that potential mediation role of 3D ASVT scores between the number of PD courses on student performance. This also provide implications on future directions on curriculum development of product development courses. If the PD course can enhance students' 3D special ability related to multi-dimensions of apparel products (i.e., 3D ASVT scores), students' performance would be enhanced.

Limitations and Scope of Future Research

One of the limitations with this study is its sample size. With only 70 participants, 17 being product development students, this study was limited to a small group of participants. This may likely be due to the fact that the survey was sent at the end of the semester. As the end of the semester is usually the busiest, students are not interested or do not have the time to participate in a voluntary study. Thus, researchers should continue to aim to reach a larger sample size in the future. A second limitation is a small representation of TAM product development students. As mentioned previously, only 17 out of the 70 participants indicated that they are product development majors. Future studies could expand its recruitment to multiple universities to capture a larger number of apparel product development students and broaden the findings of the current study. Third, this research compares the 3D ASVT to both the paper folding and mental imagery test, but does not compare itself to the original ASVT. Future research should seek to examine how the original ASVT and the 3D ASVT compare to one another and test the reliability of the 3D ASVT. Along with these recommendations, future studies could compare how the 3D ASVT compares to other spatial ability tests. In doing so, this would help to understand why the results indicate a slight but not significant relationship between the two other spatial ability tests presented in this study and the 3D ASVT. Despite these limitations, this study created a three-dimensional apparel spatial visualization test that can be used in future research to understand apparel related spatial ability.

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APPENDIX A

SURVEY INSTRUMENTS

Consent Form

Title of Study: Spatial ability of transitioning 2D to 3D apparel design: Applying Apparel Spatial Visualization Test (ASVT) into virtual environment

This is an academic research project. Please take your time in deciding, if you would like to participate. Your answers are very important to this research, focusing on developing a three-dimensional Apparel Spatial Visualization Test (ASVT). **The purpose of this study is to develop a 3D Apparel Spatial Visualization Test to examine visualization skills and mental imagery in a virtual prototyping environment of students who major in textile apparel management at the college level.** You are invited to participate in this research as an adult consumer a) ages 18 years or older who is currently b) a Textile and Apparel Management major in either focus. Participants are required to c) have experiences in some TAM courses. We appreciate your willingness to participate in this survey.

If you agree to participate in this study, you will be asked to complete an online survey that will take approximately **30 minutes**. When you start the survey, you will be asked to complete a series of questions related to apparel spatial visualization. After that, you will complete a series of questions related to spatial orientation. Then you will complete a series of questions related to spatial mental imagery. After that, you will complete a series of questions related to three-dimensional apparel spatial visualization. Following questions will ask your thoughts and opinions about the service. The last part of the survey will ask you to provide your general background information including age, gender, ethnicity, etc. All the questionnaires will use multiple choice. You will indicate your response by clicking the answer that best describes your opinions and experiences for each question. If you have already completed the survey, you cannot complete it again.

Your participation in this study is completely voluntary and you have the right to refuse to participate or leave the study at any time without any penalty. If you decide to not participate in the study or leave the study early, it is up to your decision. You can skip any question if you do not feel comfortable answering.

If you have questions or concerns about this study, you may contact Anna Moritz at armgc7@mail.missouri.edu or you may contact Dr. Song-yi Youn at syoun@missouri.edu. For questions or concerns about your rights as a research participant, please contact MU Human Subjects Research Protections Program/IRB, at irb@missouri.edu

Your answers to survey questions indicate that you voluntarily agree to participate in this study. Thank you for your participation.

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Measure of the Ability to Form Spatial Mental Imagery (MASMI)

1		A		B		C		D	
2		A		B		C		D	
3		A		B		C		D	
4		A		B		C		D	
5		A		B		C		D	
6		A		B		C		D	
7		A		B		C		D	
8		A		B		C		D	
9		A		B		C		D	
10		A		B		C		D	

Paper Folding Test (PFT)

		A	B	C	D	E
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

3D Apparel Spatial Visualization Test (ASVT)

1

A:

B:

C:

D:

E:

2

A: B:

C:

D: E:

3

A: B:

C:

D:

E:

A: B:

C:

D: E:

5

A:

B:

C:

D:

E:

6

A: B:

C:

D:

E:

7

A:

B:

C:

D:

E:

8

A:

B:

C:

D: E:

A: B:

C:

D:

E:

A:

B:

C:

D:

E:

11

A:

B:

C:

D:

E:

12

A:

B:

C:

D:

E:

13

A: B:

C:

D:

E:

14

A: B:

C:

D:

E:

15

A:

B:

C:

D:

E:

16

A: B:

C:

D:

E:

17

A: B:

C:

D:

E:

18

A:

B:

C:

D:

E:

19

A:

B:

C:

D: E:

20

A:

B:

C:

D: E:

What is your year of birth?

▼ 1991 (1) ... 2003 (13)

What is your gender?

- ☐ Male (1)
- ☐ Female (2)
- ☐ Non-binary (3)
- ☐ Prefer not to say (4)
-

Are you a current student in Textile and Apparel Management at the University of Missouri?

- ☐ Yes (1)
- ☐ No (2)
-

Are you satisfied with your performance in the product development courses you have taken?

- ☐ Definitely not (1)
 - ☐ Probably not (2)
 - ☐ Might or might not (3)
 - ☐ Probably yes (4)
 - ☐ Definitely yes (5)
-

Are you satisfied with your grades in the product development courses you have taken?

- ☐ Definitely not (1)
 - ☐ Probably not (2)
 - ☐ Might or might not (3)
 - ☐ Probably yes (4)
 - ☐ Definitely yes (5)
-

What is your overall grade for **Apparel Product Development courses** out of 100%? (ex. 94%)

What is your overall grade for **All TAM courses** out of 100%? (ex. 94%)

What is your program track in Textile and Apparel Management?

- ☐ Textile and Apparel Management: Marketing and Merchandising (1)
 - ☐ Textile and Apparel Management: Product Development (2)
 - ☐ Textile and Apparel Management: Dual track - Marketing and Merchandising and Product Development (3)
 - ☐ Textile and Apparel Management Minor (4)
 - ☐ Other (5)
-

What is your current grade level?

- ☐ Freshman (1)
- ☐ Sophomore (2)
- ☐ Junior (3)
- ☐ Senior (4)

What Textile and Apparel Product Development courses have you taken? (Check all that apply)

- ☐ TAM 1200: Apparel Design and Production (1)
 - ☐ TAM 2280: Apparel Production (2)
 - ☐ TAM 2380: Integrated Apparel Design and Production I (3)
 - ☐ TAM 2480: Apparel and Textile Presentation (4)
 - ☐ TAM 2580: Digital Textile and Apparel Applications (5)
 - ☐ TAM 3380: Integrated Apparel Design and Production II (6)
 - ☐ TAM 3480: Technical Design (7)
 - ☐ TAM 4480: Creativity and Problem Solving (8)
 - ☐ TAM 4980: Apparel Production Management (9)
 - ☐ TAM 2100: Digital Presentation Techniques (10)
 - ☐ None of the above (11)
-

Do you think spatial ability is important in the apparel product development industry?

- ☐ Definitely not (1)
 - ☐ Probably not (2)
 - ☐ Might or might not (3)
 - ☐ Probably yes (4)
 - ☐ Definitely yes (5)
-

If yes, please state why?

Do you know what spatial ability is?

- ☐ Definitely not (1)
- ☐ Probably not (2)
- ☐ Might or might not (3)
- ☐ Probably yes (4)
- ☐ Definitely yes (5)

Do you have any experience in the apparel industry? (ex. internship, job)

☐ Yes (1)

☐ No (2)

If yes, what was that experience?