A Comparison of Instructional Methods for Improving the Spatial-Visualization Ability of Freshman Technology Seminar Students

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Abstract

The purpose of the current pilot study was to investigate teaching methods for improving spatial visualization (SV) ability. Specifically, this pilot study sought to determine the effects of mechanical dissection manipulatives on improving the SV ability of freshmen enrolled in a Technology Systems course at Western Carolina University (WCU). For industry to remain competitive in the global marketplace, students graduating from engineering and technology programs must have strong SV abilities in order to communicate effectively and grow professionally in an engineering career. Researchers have previously investigated instructional methods for improving SV ability, however, only a small number of studies have been conducted, with no clear consensus showing the superiority of a certain approach.

Two, five-week (15 hours total) instructional methods developed to influence the SV ability of the 31 students were randomly assigned to the two course sections of Technology Systems. *Treatment E* group received lectures and exercises on engineering drawing principles and practices while *Treatment EM* group received hand-held mechanical dissection manipulatives for use in lectures and exercises on engineering drawing principles and practices. The researcher administered a demographic and experience survey at the beginning of the study. The Purdue Spatial Visualization Test: Rotations was used as the pre-post measure of SV ability.

The pilot study yielded several major findings. There was a statistically significant difference in the pre-post scores for Group EM, but no significant difference for Group E. There was no significant difference in the effectiveness of the two group treatments E and EM.
Within Group E, STEM majors had greater PSVT:ROT gains than non-STEM majors. Conversely, within groups EM, non-STEM majors had greater gains than STEM majors. Group E High Previous Experience participants had greater PSVT:ROT gains than Low Previous Experience Participants and Group EM Low Previous Experience participants had greater PSVT:ROT gains as compared to High Previous Experience participants.

Introduction

Improving the spatial-visualization ability of students is currently a major topic of interest for educators in engineering and technology disciplines and related industries. To remain competitive, industry has made clear the demands on graduates from engineering and technology disciplines when entering the global economic workplace. Engineering education researchers, the U.S. Department of Labor, and major industry representatives have revealed the necessity of improving the spatial-visualization ability of engineering and technology students. There is consensus for the necessity of further research along with educational measures to improve the spatial literacy of engineering and technology students [1] – [3]. Additionally, researchers have found positive correlations between spatial visualization ability and successful completion of engineering and technology degree requirements [1], [4].

With freshmen entering into colleges at historical rates, the importance of attracting those students into engineering and technology disciplines and insuring their success is critical for continued growth in the disciplines and subsequent support of industry needs. Since some students may enter the engineering and technology discipline with weak spatial visualization skills, interventions are needed to improve their spatial literacy in order to maximize their success in school and career. Therefore, the purpose of this pilot study was to compare the effect of mechanical dissection manipulatives for improving the spatial-visualization ability of freshman enrolled in a technology course at Western Carolina University (WCU).

Spatial-Visualization Ability in Engineering and Technology Education

Improving the spatial-visualization ability of engineering and technology students is a challenge for educational researchers. The importance of strong spatial visualization skills has been linked to retention and degree completion in the engineering and technology disciplines [1], [4]. Research on methods of testing and developing spatial visualization ability has been successful [5] – [7] and there is agreement that spatial visualization ability can be improved through instructional methods [8] – [10]. However, there has been no clear consensus on what combination or duration of instructional methods is most beneficial for improving spatial visualization ability.

The Accreditation Board for Engineering and Technology (ABET) governs the effectiveness and application of engineering and technology programs in the United States. Each year, ABET produces the criteria for accrediting engineering and technology programs along with evaluation and self-assessment guidelines [11]. Aside from criteria governing specific engineering disciplines, ABET requires all engineering and technology programs to meet the general criteria (labeled by ABET as “a through k criteria”). While the 2007-2008 “a through k” criteria are broad in scope, it can be argued that spatial visualization ability and related computer technologies may contribute to substantiating at least five of the eleven program outcomes and assessment measures.

Spatial visualization ability coupled with 3D computer modeling and analysis technologies could play an important role in meeting ABET general criteria. The application of knowledge in mathematics, science, and engineering (criterion a) to design a system, component or process within realistic constraints (criterion c) through identifying, formulating, and solving engineering problems (criterion e), using modern engineering tools and techniques (criterion k) may be enhanced by using spatial visualization abilities coupled with 3D parametric solid modeling and analysis computer technologies. Additionally, design application and analysis could be effectively communicated (criterion g) through the many output formats and visualization tools offered by most 3D parametric solid modeling and analysis packages. Aside from departments earning accreditation, exposure to curricula designed to use and strengthen spatial visualization ability seems to benefit students overall academically [4].

Spatial-Visualization Ability in Business and Industry

Calls for improved spatial-visualization ability in engineering and technology education are paralleled by similar requests from industry. Spatial reasoning accounts for 90% of the engineering research and design process [12]. On a larger scale, industry consultants Marks and Riley [13] reported that, "eighty percent of the manufacturing gross national product passes through CAD, CAM, and CAE systems at some point. Every vehicle, aircraft, sophisticated electronics system, most industrial and manufacturing equipment, and most consumer products depend upon these tools." Outsourcing of manufacturing and high-tech jobs coupled with plant closings have resulted in the diminishment of many local economies. The Society of Manufacturing Engineers reported three million fewer manufacturing jobs in 2004 as compared to 1998 [14]. These reported problems have forced traditional industries to become more competitive through efficient use of technology in the creation of highly innovative design projects and products. Constraint-based 3D CAD software is currently accepted among researchers and practitioners as the primary medium for communicating and implementing innovative research and design ideas in industry, as well as a means of increasing competitiveness in the global market place [15]. Spatial visualization is a core fundamental ability used in creating robust and flexible 3D CAD models. Therefore, improving the spatial-visualization ability of the workforce is essential for industries that have a desire to be competitive.

The United States Department of Labor Bureau of Labor Statistics, in the *Occupational Handbook for Engineers, Life and Physical Scientists*, reported employment opportunities in engineering and related fields would experience average growth through 2014, where employees would be needed to design, build, test and improve products [16]. The report discussed the relevance of competitive pressures and technological advances compelling industries to become more innovative, efficient, and productive through new technologies that will enable innovative rapid product development. The report additionally noted technological advances were not expected to limit employment opportunities, unlike in other fields, because of the development of new products and processes.

In a 2006 publication entitled, *Framework of Competencies by the Advanced Manufacturing Industry*, the Department of Labor detailed the competencies necessary for advanced manufacturing organizations in the United States to remain competitive in the global marketplace [17]. Tiers 1 through 4, a categorical system outlining basic employee characteristic, encompassed the competencies expected from all employees in the advanced manufacturing industry. Tier 2, the foundational academic competencies, listed applied geometric principles that ranged from familiarity with geometric terminology and basic analysis of 2D and 3D geometric shapes to using spatial visualization as an aid in problem solving coupled with CAD/CAM/CAE applications. Entry-level technical and academic competencies expected by advanced manufacturing organizations make clear the necessity of developing strong spatial-visualization ability in engineering and technology students so that they will be successful in industry.

The importance of spatial visualization ability has surfaced over the last decade due to efforts by engineering and other STEM researchers to fully address the learning needs of students. Industry competitiveness relies heavily on the skills and knowledge graduating engineering and technology students transfer to the workplace and use as a foundation for professional growth throughout their career. Improving the spatial-visualization ability of engineering and technology students and professionals in industry is a challenge that calls for more investigation into testing and early intervention practices.

Factors Related to Spatial Visualization Ability

The current study was based on the definition of spatial visualization developed by McGee: "The ability to mentally rotate, twist, or invert pictorially presented visual stimuli" [18]. Consistent with supporting citations, spatial visualization ability is treated as a malleable characteristic that is amenable to intervention [1], [8] - [10]. Many factors have been related to spatial visualization ability.

Overall, there is agreement that sex differences are not biologically based, but are influenced by experience and environment. The development of spatial strategies, a holistic strategy for problem solving, was a commonly espoused key remediation practice within the gender-related literature [9], [19] - [21]. Additionally, self-efficacy and self-confidence seemed to play an important role in performance on spatial problems, especially for female students [1], [21]. Age had no influence on spatial abilities after adolescence [21] - [23]. Some environmental factors have been identified, with experiences with construction and building toys and other eye-to-hand coordination activities as well as previous design courses showing high correlations to spatial visualization ability [21], [24].

Spatial Ability Research in the STEM Disciplines

Spatial ability research in the engineering and technology disciplines have revealed the benefits of improving the spatial-visualization ability among this population of students. Male and female engineering students with stronger spatial visualization ability are retained within the discipline at a higher rate as compared students with lower spatial visualization ability [4]. The relationship between learning and using 3D CAD and the improvement of spatial visualization ability is minimal [25], [3], [7]. Sorby and colleagues argued the most effective means of developing 3D spatial-visualization ability in students was through multi-view sketching of hand-held objects and suggested using mechanical dissection as a method of instruction [4], [26]. Czapka et al. argued rapid prototype physical models should be included in the instruction of all 3D CAD courses [6]. Studies in other STEM disciplines have revealed similar findings.

Sorby and colleagues showed that Computer Science and Biology students were able to significantly improve their spatial visualization ability by taking a remedial spatial visualization course [10]. Cohen supported student use of hand-held manipulatives in problem solving tasks [27]. Piburn, Reynolds, McAuliffe, Leedy, & Birk argued that the manipulation of 3D computer objects in a virtual terrain could significantly improve students' spatial ability [28]. Pribyl and Bodner found a significant relationship between spatial ability and the students' ability to solve organic chemistry problems [29].

Based on these studies, spatial ability appears to be a malleable trait that is crucial for student success in the STEM disciplines. However, no clear picture has emerged as to the most effective instructional method for improving spatial visualization ability. The current pilot study was designed to further this research by establishing a base-line for determining the effect of hand-held mechanical dissection manipulatives on improving the spatial-visualization ability of students enrolled in a freshman technology course.

Method

The main construct under investigation was spatial visualization ability. The instrument selected for measuring spatial visualization ability was the PSVT:ROT of the Purdue Spatial Visualization Test Battery (PSVTB). The PSVT:ROT has been shown to provide valid and reliable measure of an individual's spatial visualization ability [30]. The researcher randomly assigned one of two instructional methods (experimental treatment) to two sections (groups) of a Technology Systems course at WCU. The dependent variable under investigation was the difference in pretest and posttest scores on the PSVT:ROT. The independent variables under investigation were the experimental condition (two methods of instruction), major, and previous spatial visualization experience.

Along with the PSVT:ROT, a background and experience survey was administered to each participant at the beginning of the study, which occurred during the fifth week of the semester. The survey was used to determine the gender and college major for each of the study participants. The survey was also used to collect background information on past experiences such as childhood play with construction/building related toys, previous experience in design drawing courses, play with 3D video games, and choice of major field of study.

The sample for this study was 31 students enrolled in two course sections of freshman seminar, ET190 Technology Systems, at WCU. Technology Systems courses have traditionally been populated with more male than female students and with more students majoring in the STEM disciplines; however, students from other majors frequently sign up for the course. While the choice of a freshman seminar was made in an effort to broaden the sample characteristics and promote the generalizability of the findings, enrollment in the Technology Systems course in the Fall 2007 semester was somewhat lower than expected, with a total of 31 students attending after the 5th week of classes. Two, five-week (15 hours total) instructional methods developed to influence the SV ability of the 31 students were randomly assigned to the two course sections of Technology Systems. The two treatments were termed *Treatment E* and *Treatment EM*.

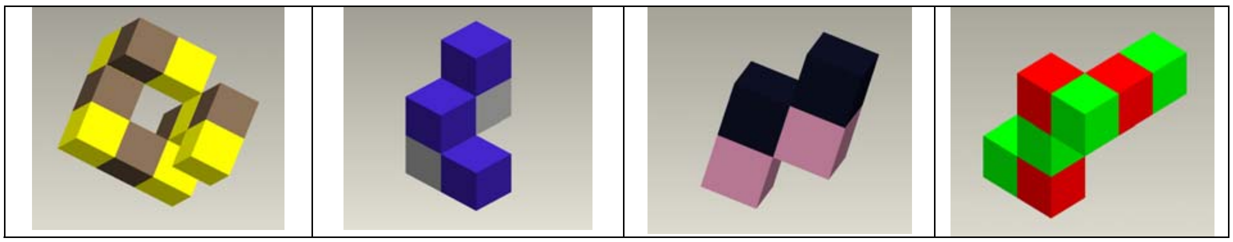
Treatment E group received lectures and exercises on engineering drawing principles and practices. Engineering drawing is a standard method used to communicate technical ideas effectively through graphical representations [12]. Group E received treatment E for five weeks. Treatment E consisted of traditional orthographic projection instruction and laboratory exercises involving sketching, using multi-view projection, of simple isometric drawings representing 3D solid objects. The lecture focused on common introductory level materials consisting of an overview of engineering graphics, technical rules for standardization, orthographic projection, and multi-view sketching practices and techniques using the whiteboard [12].

Typically, standard multi-view drawing layout includes the top, front and right side views of an object, sometimes including an isometric view of the object. Related exercises focused on sketching orthographic views (top, front, and right side views) and projections (isometric views) of simple 3D solids, derived from commonly-used engineering graphics texts [12], using paper or the whiteboard. Group E was not exposed to any form of hand-held manipulatives during the treatment period. Participants in Group E were allowed to work in small groups on all assignments.

Treatment EM group received hand-held mechanical dissection manipulatives for use in lectures and exercises on engineering drawing principles and practices. The lectures and exercises on engineering drawing principles and practices followed the same procedures as described in Treatment E with the addition of instructional methods incorporating hand-held mechanical dissection manipulatives. Mechanical dissection manipulatives were used in every session of Treatment EM. Mechanical dissection manipulatives have been hypothesized to improve spatial visualization ability [3]. Additionally, the use of hand-held manipulatives [6], [27] and the multi-view sketching of those manipulatives [4] have been shown useful in improving spatial-visualization ability of college students.

Students were asked to use the hand-held manipulatives during Treatment EM lectures and exercises. Additionally, students performed mechanical dissection exercises using the hand-held manipulatives. During the mechanical dissection exercises, a group of three students was presented an engineering drawing of an object for use in assembling the hand-held manipulative. Once completed, the hand-held manipulative was disassembled and drawings to describe the processes of re-assembly were created. The reassembly directions along with the disassembled hand-held manipulative were passed to another group of three students who attempted to reassemble the manipulative based on the graphical directions. The second group of students, the reassembly group, made suggestions to the first group, the disassembly group, on possible improvements in communicating the graphical instructions for reassembly of the hand-held manipulative. Hand-held manipulatives were built with Snap Cubes™ and rapid prototyped components designed by the researcher. Participants in Group EM were allowed to work in small groups on all assignments. An example hand-held mechanical dissection manipulatives may be found in Figure 1.

Instructional Object 1: Isometric print and mechanical dissection model



Instructional Object 1 is comprised of objects 1A, 1B, 1C, and 1D

Figure 1: Example hand-held mechanical dissection manipulative

Results

The demographic and experience survey was analyzed to gain insight into the basic characteristics and past spatial visualization experiences of the students. Of the 31 students reporting, 10 different major fields of study (78.8%) were represented, with 21.2% of the students undecided about their major. Group EM was comprised of a larger percentage of Undecided majors (27.8%) as compared to Group E (13.3%). Of particular interest was the representation of STEM disciplines (33.4%). Group E was comprised of the largest percentage (40.0%) of STEM majors followed by Group EM (27.8%). Engineering Technology, Electrical Engineering Technology, Computer Science, and Biochemistry majors were classified as STEM majors, while all other majors were classified as non-STEM. The two groups used in the current study were entirely composed of male participants. Table 1 presents the demographic characteristics of the sample.

The PSVT:ROT pretest and posttest scores were compiled and descriptive statistics were used to determine the effects of each of the two methods of instruction. Analyses of the data for both the sample as a whole and the individual treatment groups were conducted. The PSVT:ROT pretest and posttest means and standard deviations for the sample of 31 students and treatment groups are presented in Table 2.

Table 1: Participants' Major Field of Study

	Total		Group E		Group EM	
Major	*N*	%	*N*	%	*n*	%
Undecided	7	21.2	2	13.3	5	27.8
Construction Mngt.	6	18.1	5	33.3	1	5.6
Engineering Tech	4	12.1	2	13.3	2	11.1
Computer Science	3	9.1	3	20.0		
Computer Inf. Sys.	4	12.1			4	22.2
Elec. Eng. Tech.	3	9.1	1	6.7	2	11.1
Graphic Design	1	3.0			1	5.6
Business Admin.	1	3.0			1	5.6
History	2	6.1	2	13.3		
Biochemistry	1	3.0			1	5.6
Hospitality & Trsm.	1	3.0			1	5.6
Totals	31	100	15	100	18	100

Table 2: PSVT:ROT Pretest and Posttest Results for the Sample

	Pretest			Posttest			Difference		
Group	*M*	*SD*	*P*	*M*	*SD*	*P*	Δ*M*	*SD*	*P*
Total	22.00	5.59	73.3	23.58	4.57	78.6	1.58	2.55	5.27
E	23.62	4.50	78.3	24.69	3.88	82.3	1.08	2.69	3.6
EM	20.94	6.40	69.8	22.77	5.11	76.7	1.94	2.46	6.47

An ANOVA was used to determine that there was no significant difference between the two groups on the pretest, $F(1, 29) = 1.93$, $p = .175$. The average PSVT:ROT pretest (M = 22.00, SD = 5.59), posttest (M = 23.58, SD = 4.57), and gain ($\Delta M = 1.58$, $SD = 2.55$) scores for the sample as a whole was determined. Analysis of the two group PSVT:ROT pretest scores revealed that Groups E (M =23.62, SD = 4.50) scored higher on average as compared to Group EM (M = 20.83, SD = 6.11). Using the reduced sample data, analysis of the three group PSVT:ROT posttest scores revealed that Group E (M = 24.68, SD = 3.88) scored higher on average compared to Group EM (M = 22.77, SD = 4.95). On average, Group E scored higher on the PSVT: ROT pretest and posttest as compared to Group EM.

The mean difference of the PSVT:ROT pretest and posttest scores for the reduced sample as a whole and Groups E and EM were determined. The mean difference in PSVT:ROT pretest and posttest scores for the reduced sample was determined to be 1.24 (SD = 2.89). Additionally, the mean difference between PSVT: ROT pre-posttest scores for Groups E (ΔM = 1.08, SD = 2.69) and EM (ΔM = 1.94, SD = 2.46) were determined. Student receiving Treatment EM for the five-week study experienced a larger positive PSVT:ROT pre-posttest gain (ΔM = 1.94, SD = 2.46) on average as compared to students receiving Treatment E (ΔM = 1.08, SD = 2.64).

The Wilcoxon Signed Ranks Test was employed to further investigate the effects of each treatment. Based on negative ranks, these tests revealed there was a statistically significant difference (T = -2.83, p = .005) in the PSVT:ROT pre-posttest scores for Group EM, but no significant difference in PSVT:ROT pre-posttest scores for Group E (T = - 1.85, p = .064). Table 3 presents a summary of the Wilcoxon Signed Ranks Test.

Table 3: Summary of Wilcoxon Signed Ranks Test Results for Each Group

	Mean Rank		
Group	Negative	Positive	p
E	9.50	5.06	.064
EM	7.00	8.71	.005

To further examine whether the within-group PSVT:ROT pre-post differences varied across groups, a Mixed Model ANOVA was employed to test the null hypothesis, which stated the following:

$$H_0 = \mu_{\text{E posttest}} - \mu_{\text{E pretest}} = \mu_{\text{EM posttest}} - \mu_{\text{EM pretest}} = \mu_{\text{EMC posttest}} - \mu_{\text{EMC pretest}}$$

The results revealed there was no significant difference in the effectiveness of the two group treatments, $F(1,29) = 1.003$, $p = .375$, $\eta^2 = 0.045$. Therefore the null hypothesis was retained.

A comparison of means was conducted to explore potential differences in treatment effectiveness by major field of study, prior spatial visualization experience, and gender. Due to the small group sizes, descriptive statistics were used to explore the data. No inferential tests were conducted. A new variable was created in SPSS termed STEM, which determined whether the student's major field of study was classified as a STEM discipline. A comparison of mean PSVT:ROT scores and major field of study was conducted using the STEM variable. Table 4 presents the descriptive data used in determining the relationship between major field of study and the effectiveness of treatments E, EM, and EMC.

Table 4: Relationship Between Major Field of Study and the Effectiveness of Treatments

		Pretest		Posttest		Difference	
Group	*n*	*M*	*SD*	*M*	*SD*	Δ*M*	*SD*
E							
STEM	6	22.67	5.34	24.33	4.32	1.67	2.25
Non-STEM	7	24.43	3.87	25.00	3.79	0.57	3.10
EM							
STEM	5	24.20	5.81	25.80	3.42	1.60	2.70
Non-STEM	13	19.54	5.93	21.62	5.06	2.08	2.47

On average, STEM majors who received Treatment E scored lower on the PSVT:ROT posttest (M = 24.33, SD = 4.32) on average, as compared to non-STEM majors (M = 25.00, SD = 3.70) who received Treatment E, STEM majors experienced a larger PSVT:ROT pre-posttest gain (ΔM = 1.67, SD = 2.25) on average as compared to non-STEM majors (ΔM = 0.57, SD = 3.10). Therefore, on average, Treatment E was more effective for STEM majors as compared to non-STEM majors.

On average, STEM majors who received Treatment EM scored higher on the PSVT:ROT posttest (M = 25.80, SD = 3.42) on average, as compared to non-STEM majors (M = 21.62, SD = 5.06) who received Treatment EM, non-STEM majors experienced a larger PSVT:ROT pre-post gain (ΔM = 2.08, SD = 2.47) on average as compared to STEM majors (ΔM = 1.06, SD = 2.70). Therefore, on average, Treatment EM was more effective for non-STEM majors than STEM majors.

The relationship between previous experience and effectiveness of treatments was determined by creating a new variable termed Previous Experience. The Previous Experience variable was used to sort students into one of two groups termed High Previous Experience and Low Previous Experience. The researcher investigated the relationship between Previous Experience and the effectiveness of the three treatments. Table 5 presents the descriptive data used in analyzing the relationship between Previous Experience and the effectiveness of the treatments.

Table 5: Relationship Between Previous Experience and Effectiveness of Treatments

		Pretest		Posttest		Difference	
Group	*n*	*M*	*SD*	*M*	*SD*	Δ*M*	*SD*
E							
Low	3	23.00	5.57	23.67	2.08	0.67	6.11
High	2	25.00	2.83	27.00	4.24	2.00	1.14
EM							
Low	4	16.25	4.86	19.25	1.71	3.00	4.24
High	5	21.20	6.91	23.20	5.22	2.00	2.34

On average, the students classified as high in Previous Experience who received Treatment E scored higher on the PSVT:ROT posttest (*M* = 27.00, *SD* = 4.24) as compared to the students who received Treatment E and were classified as low in Previous Experience (*M* = 23.67, *SD* = 2.08). Students classified as high in Previous Experience who received Treatment E experienced a larger PSVT:ROT pre-post gain (Δ*M* = 2.00, *SD* = 1.14) on average as compared to students who received Treatment E and were classified as low in Previous Experience (Δ*M* = 0.67, *SD* = 6.11). Therefore, Treatment E was more effective on average for students classified as high in Previous Experience as compare to students who received Treatment E and were classified as low in Previous Experience.

On average, the students classified as high in Previous Experience who received Treatment EM scored higher on the PSVT:ROT posttest (*M* = 23.20, *SD* = 5.22) as compared to the students who received Treatment EM and were classified as low in Previous Experience (*M* = 19.25, *SD* = 1.71). However, students classified as low in Previous Experience who received Treatment EM experienced a larger PSVT:ROT pre-post gain (Δ*M* = 3.00, *SD* = 4.24) on average as compared to students who received Treatment EM and were classified as low in Previous Experience (Δ*M* = 2.00, *SD* = 2.34). Therefore, Treatment EM was more effective on average for students with low Previous Experience than those with high Previous Experience.

Conclusions

Group E and EM experienced an average positive gain in PSVT:ROT scores over the five-week treatment period. Further investigation revealed there was a statistically significant difference in the PSVT:ROT pre-posttest scores for Group EM, but no significant difference in PSVT:ROT pre-posttest scores for Group E. Only Treatment EM produced a significant effect on the dependent variable for students in Group EM. However, well over half of the students in Group E demonstrated some level of improvement in PSVT:ROT scores from pre to post. Therefore, the average effects of the two treatments on the spatial-visualization ability of students in each group were positive with only Treatment EM producing significant gains.

The average differential effect of the treatments E and EM on the participants was somewhat varied. Student receiving Treatment EM for the five-week study experienced a larger positive PSVT:ROT pre-posttest gain on average as compared to students receiving Treatment E. A larger percentage of students in Group EM (77.8%) experienced a positive gain as compared to Group E (69.2%).

Further analysis revealed there was no significant difference in the effectiveness of the two group treatments E and EM. It is important to note that this study only manipulated the dependent variable for a duration of 5 weeks (15 hours total). This study revealed that over a five-week period, only Treatment EM produced a significant effect in the dependent variable among participants. Therefore, the duration of the treatments may have been insufficient to produce differential effects across the two groups.

Students in this study who only received treatment EM showed significant improvement on the PSVT:ROT pre-post measure. Therefore, the superior performance of Group EM, as compared to Group E, may be largely attributed to the sketching of hand-held mechanical dissection manipulatives component of the treatment. While, the sketching of hand-held objects has been shown to significantly improve spatial visualization ability [4], the mechanical dissection component of Treatment EM may have additionally contributed to their superior performance. The researcher speculated that the mental processes necessary to assemble and dissect the hand-held mechanical dissection manipulative may require students to invoke brain functions highly associated with spatial visualization ability. Congruent to McGee's definition of spatial visualization ability, the assembly and dissection of hand-held mechanical dissection manipulatives would require the participant to physically and mentally twist, rotate, and invert stimuli. Additionally, the researcher speculated that repeated exercises invoking the use of these brain functions may have possibly increased spatial visualization ability. However, to be certain of the possible benefits of the instructional use of hand-held mechanical dissection manipulatives, further research is needed. Data collection using think-aloud procedures may be a possible way for the researcher to better understand the underlying processes contributing to the benefits of Treatment EM.

Treatment E was found to have no significant effect on spatial visualization ability. A possible reason for the less than expected effect of Treatment E on the dependent variable may be attributed to an insufficient duration of Treatment E. Furthermore, Treatment E may have been an ineffective instructional method for improving the spatial visualization ability of freshman technology seminar students. Group E's high average PSVT:ROT posttest scores may have minimized the possible effect of Treatment E, due to a ceiling effect with the measure. The PSVT:ROT questions range in complexity and corresponding difficulty. Therefore, Treatment E may not have provided the participants with enough advanced learning concepts, or the duration of advanced concepts were too condensed, to correctly complete the more complex questions on the PSVT:ROT, thus decreasing their potential overall PSVT:ROT gain.

Relationships reported between Major Field of Study and the effectiveness of the three treatments are speculative. Low sub-group size prevented any inferential analysis of the relationship between Major Field of Study and the effectiveness of treatments; therefore the researcher explored the data for potential relationships. The researcher found that within Group E, STEM majors had greater PSVT:ROT gains than non-STEM majors. Conversely, within groups EM and EMC, non-STEM majors had greater gains than STEM majors.

The researcher compared the within-group PSVT:ROT gains based on Low Previous Experience and High Previous Experience classifications of previous spatial visualization experience. Relationships reported between Previous Experience and the effectiveness of the three treatments are speculative. Low sub-group size prevented any thorough analysis of the relationship between Previous Experience and the effectiveness of treatments, therefore the researcher explore the data for relationships. The researcher found that on average, in Group E High Previous Experience participants had greater PSVT:ROT gains than Low Previous Experience Participants and in groups EM Low Previous Experience participants had greater PSVT:ROT gains as compare to High Previous Experience participants.

Activities such as playing with construction/building toys and other eye-to-hand coordination activities significantly contributed to the spatial visualization abilities of engineering students [21], [24]. The findings of this study support both refute and support those of other researchers [21], [24]. PSVT:ROT pretest scores were larger on average for High Previous Experience sub-groups; however, Low Previous Experience sub-groups on average reported greater gains. The current pilot study provided the base-line for further research on improving the spatial visualization ability of freshman technology students at Western Carolina University.

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