Novice Drafters' Spatial Visualization Development: Influence of Instructional Methods and Individual Learning Styles

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Spatial visualization ability has been recognized as a predictor of success in many technology related fields (Strong & Smith, 2002). Engineers must be able to graphically depict structures; surgeons must be able to recognize organs by their shape; and astronomers must be able to envision the configurations of galaxies. Chemists, geologists, metallurgists, and medical researchers must be able to identify the crystalline makeup of a myriad of diverse materials (Baartmans & Sorby, 1996).

The pictorial representation of an object, person, place, or thing is one of the oldest forms of communication. These graphical images communicate an idea, outline a process, or provide a form of record keeping for future reference. The transfer of three-dimensional objects to images on two-dimensional surfaces by means of geometric drawings has evolved from the crude pictorial drawings of prehistoric man to the well-developed drawings of today (Dobrovolny & O'Bryant, 1984).

Using lines and symbols to represent the thoughts and ideas of engineers, designers, and technologists often provides a more effective means of communicating these concepts than verbal descriptions. Drawings of a house, a bridge, a tool, or a roadway can describe these objects far better than words. According to Bertoline, Wiebe, Miller, and Mohler (2002), 92% of the design process is graphically based, with the other 8% divided

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between mathematics and written and/or verbal communication. Mackenzie and Jansen (1998) state, “As the vernacular of industry, technical design, drafting, and drawings are essential to the curricula of all technology, engineering, and design programs” (p. 61).

The primary goal of educators in the design/drafting field is to teach beginning drafting students the fundamental concepts of orthographic projection (Nwoke, 1993). Traditional instructional methods teach pictorial visualization concepts through the use of transparencies, three-dimensional models, and demonstrations using drawing instruments on either whiteboards or chalkboards. The advancement of the computer has allowed the addition of computer-aided design drafting (CADD) software packages such as AutoCAD, CADKey, SDRC, Pro E, and other software for depicting three-dimensional objects. By adding the capabilities of the computer and CADD software, the technical educator can create and manipulate three-dimensional models to help enhance the learning process (Mackenzie & Jansen, 1998; Bertoline, 1991).

Many students have difficulty understanding or comprehending the graphic representation of three-dimensional objects. “One major limitation of traditional instruction is the problem of presenting 3 Dimensional spatial information in a 2 Dimensional format” (Mackenzie & Jansen, 1998, p. 62). According to Nwoke (1993), the problem isn’t necessarily the students’ inability to “visualize” spatial relationships but rather the instructional methods used to present the information. Silverman (1989) stated that imagination is a key element in the mental processing of visual-spatial learners. She believed that visual-spatial learners should be placed in an environment where there is a good match between their learning styles and the way they are taught.

James and Blank (1993) categorized learning styles into three realms: perceptual, cognitive, and affective. The perceptual realm includes up to seven ways learners take in and absorb information from their environment. According to Cherry (as cited by Harvey, 2002), these seven perceptual learning-style factors are aural (listening), haptic (touching or holding), interactive (verbalizing and discussing with others), kinesthetic (body movement), olfactory (employing the sense of smell), print (reading and writing), and visual (viewing pictures, images, objects, and activities). Galbraith and Sanders (1987) recommended that teachers employ a combination of instructional methods to incorporate these various student learning styles in their classrooms.

Teachers have at their disposal a wide assortment of instructional methods. These include techniques such as lecture, discussion, role-play, simulation, demonstration, and many others. However, new studies conducted by Stitt-Gohdes (2001) and Garton, Spain, Lamberson, and Spiers (1999) concluded that the instructor's learning styles affects the instructional method a teacher selects to present information..

According to Farrell and Kotrlik (2003), educators can become more effective teachers by assessing their students' preferred learning styles. This assessment can help in planning curriculum and in selecting appropriate instructional methods. Thus, research is needed to determine if there is a link between students' learning styles and their cognitive abilities such as spatial visualization.

Purpose of the Study

The purpose of this study was to determine whether novice drafters' ability to visualize three-dimensional objects and identify two-dimensional representations of three-dimensional objects was influenced by (a) basic drafting instructional methods or (b) the students' learning styles. The objectives of the study were to

1. Compare novice drafters' spatial visualization ability with the methods of drafting instruction they received
2. Compare novice drafters' spatial visualization ability with their preferred learning styles
3. Compare novice drafters' spatial visualization ability with their prior instruction or experiences in drafting and/or art
4. Verify whether novice drafters' perceptual modality learning styles changed from pretest to posttest.

Spatial Visualization Development

Spatial cognition, broadly defined, is "knowledge involving the interrelationships among people, objects, and space" (Devlin, 2001, p. xv). Gardner (1983) stated that researchers working with adult subjects have long recognized the centrality of spatial intelligence, but relatively little has been definitively established about such development at earlier ages. However, Jean Piaget studied the development of spatial understanding in children and saw spatial intelligence as "part and parcel of the general portrait of logical growth which he was assembling across his diverse studies" (Gardner, 1983, p. 178).

According to Devlin (2001), research on spatial cognition has resulted in several theoretical frameworks. Siegel and White (as cited in Devlin) took the constructivist view that knowledge is a compilation of meaning over time: "Arising from a history of philosophical and neurological analysis, we have the development of an argument that knowledge of extended space is a mental construction. This construction is a kind of temporal integration which man is neurologically predisposed to create" (Siegel & White as cited in Devlin, 2001, p. 10).

Technical drawing, or drafting, is a means of communicating technical ideas using graphical images (Giesecke, et al., 2002). For engineers or drafters to project graphical images on paper, they must be able to visualize those images in their minds. Sorby and Baartmans (2000) explained that well-developed spatial skills have been proven to be critical to a technical person's ability to develop creative design solutions to engineering problems.

The skills needed to develop a person's spatial ability are acquired through programs or activities that teach engineering or drafting (Olkun, 2003). Students are introduced to orthographic and multi-view projections using various multifaceted shapes. Educators seek to develop or enhance students' visualization skills through a series of drawing exercises. The first basic concepts of projection are explained and practiced using simple, solid objects such as rectangles, triangles, cylinders, and cones (Croft, Meyers, Boyer, Miller, & Demel, 1989).

Numerous studies have been conducted to identify techniques that will enhance the development of spatial visualization. Several studies have compared the effectiveness of instruction using the computer and three-dimensional CADD software with the traditional method of board drafting. Sexton (1991), Braukmann (1991), Johnson (1991), Braukmann and Pedras (1993), and Godfrey (1999) conducted such research pitting three- dimensional models and animated wireframes against orthographic projections and the use of two-dimensional pictorial representations. None of these studies revealed that the use of computer and three-dimensional CADD software enhanced the students' ability to visualize spatially. Research by Thomas (1996) tested the benefits of three-dimensional CADD instruction over instruction using two-dimensional CADD. Results showed the three-dimensional CADD method of instruction was more effective than the two-dimensional CADD method. Rogers (2004) compared the effectiveness of teaching using modular drafting methods with traditional, instructor-led methods and found no statistically significant difference between instructor-led and modular instruction for college students.

Sorby and Baartmans (2000) documented a six-year longitudinal study of an introductory course intended to enhance the three-dimensional spatial visualization skills of first-year engineering students. Isometric and orthographic sketching, pattern development, two- and three-coordinate drawing, rotation of objects, and cross sections of solids were taught using paper and pencil sketching techniques whereas concepts involving surfaces and solids of revolution and the intersection of solids were developed through the use of CADD. The authors concluded that year after year the students who had completed this introductory course showed statistically significant gains in scores and reported that these students maintained higher retention rates for the material than a control group who did not take the course.

Learning Styles

Instruction designed to appeal to a variety of student learning styles enhances the ability of students to achieve, increases their interest in subject matter, provides them enjoyment in learning the subject, and increases their desire to study other subjects (Ast, 1988). Ast stated that to design instruction that incorporates students' learning styles, the teacher must employ three steps: (1) examine students' learning styles; (2) classify the students' learning styles according to several large categories; and, finally, (3) incorporate students' learning styles into the instructional process. A variety of inventories to assess learning styles exist, and theorists disagree as to which instruments are the most valid and reliable. James and Blank (1993) critiqued a variety of learning style instruments based on perceptual, cognitive, and affective domains.

The learning styles of the students make up only one of several factors of the learning process that interweave in the classroom. The instructor's learning style itself plays a significant role in teaching since an instructor tends to teach in the style in which he or she learns best. Khoza (2003) echoed that the instructor is believed to be a key player affecting the learning process in the classroom. Galbraith and Sanders (1987) examined the relationship between the perceived perceptual learning style and teaching style of 138 community college professors from ten community colleges in several southwestern states. Participants represented subject areas in agriculture, health, human service, engineering, and other industrial related areas. The perceptual learning style inventory created by James and Galbraith (1985) was used to assess the learning styles of each professor based on the instrument's seven perceptual learning styles. The authors reported a very high positive correlation between the community college educators' learning styles and the instructional methods they used and proved that professors chose instructional methods which matched their own learning styles. Galbraith and Sanders (1987) concluded that other instructional methods should be used to accommodate the various learning styles of students in their classrooms.

Research conducted by Fazarro and Stevens (2003) sought to determine the learning style preferences of African-Americans and European-American enrolled in industrial technology and engineering programs. The study consisted of 540 students enrolled at two U.S. universities. The Productivity Environmental Preference Survey (PEPS) inventory created by Price, Dunn, and Dunn consisted of 100 questions and was considered ideal to examine adult learning styles. The authors reported statistically significant findings and recommended that industrial educators be aware of the cultural and learning-styles diversity in the classroom.

Research Method

To conduct this study, the researcher selected two intact groups of subjects—one to serve as the control group and the other to serve as an experimental group—from two intact classes of graphic engineering and basic drafting students. Because of program requirements and time constraints, these students could not be assigned randomly to treatments. Therefore, the nonequivalent control group design was chosen from the quasi-experimental design choices proposed by Tuckman (1999). This design was used since the researcher was not allowed to divide or disrupt the classes for random or equivalent sampling. Thus, to reduce the possibility of creating a selection bias problem, the researcher administered a pretest to both the control and the experimental groups. According to Tuckman (1999), by administering a pretest to both groups the researcher would be able to determine whether the two intact groups were equivalent as to the dependent variable at the beginning of the instructional program.

Study Subjects

This study took place during the fall of 2003 and the spring of 2004 and consisted of 49 full- and part-time community college students who volunteered to participate. All subjects were enrolled in either basic drafting or engineering graphics courses, which were offered once a semester at an Illinois community college. Both courses fulfilled requirements for graduation in one of two different programs. The engineering graphics course is part of the engineering program that leads to an associate in science degree and allows students to transfer to a university to complete a four-year degree in any engineering field. The basic drafting course is an entry-level drafting course leading to an associate of applied science degree. Students completing this degree may enter the workforce or transfer to a university to complete a four-year degree in a technical area, architectural, or workforce education program.

The basic drafting course is a prerequisite for other drafting classes. Students enrolled in drafting technology were majoring in manufacturing, architectural, or civil drafting. This course met twice a week for 2 hours and 45 minutes each class period. Students enrolled in the engineering graphics course were majoring in manufacturing engineering, construction technology, computer engineering technology, technology education, mechanical engineering education, graphic engineering, architectural engineering, or civil engineering. Because of the need to communicate pictorially in these various engineering fields, these students were required to enroll in the engineering graphics course as part of their program of study. The engineering graphics course met three times a week for 1 hour and 40 minutes each class period.

The researcher selected the 19 students who were enrolled in the engineering graphics course during the fall semester of 2003 and the 11 students enrolled in the basic drafting course in the spring of 2004 as the control group for this study. The 26 subjects who completed the two semesters comprised the total control group participants.

The experimental group consisted of the 11 students enrolled in the basic drafting course in the fall 2003 semester and the 17 students enrolled in the engineering graphics during the spring semester of 2004. In the experimental group, the total number of subjects that completed the two semesters was 23.

Each semester this study was conducted, the students in the classes comprising the control group were instructed using traditional methods of lecture and demonstration on paper or white board. Besides the traditional instruction, the experimental group received additional instruction that included methods appealing to the seven learning styles addressed in the Perceptual Modality Preference Survey (PMPS) developed by C. Edward Cherry (Harvey, 2002). Instruction for both groups used Auto Desk Auto CAD 2002 computer-aided drafting software. The experimental group's instruction incorporated combinations of lecture enhanced with PowerPoint presentations, class discussion, computer-based instruction, and group projects to aid the aural and interactive learners. To accomodate learners with visual and print learning styles, the instructor incorporated orthographic sketches; multiview, oblique, and isometric projections; as well as textbook readings, chapter outlines, class handouts, and workbook modules for spatial visualization. The instructor made use of three-dimensional physical objects to aid haptic or kinesthetic learners. A teaching method that addressed the olfactory learning style was not used in this study due to the unavailability of three-dimensional objects that could be used.

Instrumentation

Spatial Visualization. A single testing instrument for testing the spatial visualization ability was used for pretesting and posttesting both groups. Guay (1980) developed the Purdue Spatial Visualization Tests (PSVT) in 1976 to determine students' ability to visualize or recognize orthographic drawings. The PSVT is a multiple choice paper and pencil test.

The PSVT includes three sections: Developments, Rotations, and Views. Each section contains 12 questions for a combined total of 36 questions. The Development section requires the student to study a pattern of three-dimensional objects and determine the correct answer from five possible shapes listed below it. The Rotations section shows an object in two different positions. Shape one is rotated on the X-, Y-, or Z-axis to shape two, which is provided to show the rotation pattern. The student is required to select the object whose position represents the next rotation in the pattern. The Views section tests a student's ability to visualize a three-dimensional object from various perspectives. Bertoline and Miller (1990) recommended that this test be used for pretesting and posttesting to measure the spatial visualization processing of examinees.

The Rotations section of the PSVT was used numerous times during a three-year study conducted by Sorby and Baartmans (2000) to determine spatial ability of freshmen engineering students since the fall of 1993. The study was conducted to determine the prerequisite spatial skills needed by students enrolled at Michigan Technological University to succeed in engineering graphics courses. The Kuder Richardson-20 (KR-20) showed that the PSVT was a reliable instrument with a score of .80 or greater, except during the 1997 fall semester when the posttest score was 0.71 (Sorby & Baartmans, 2000). The authors stated that the posttest reliability of the PSVT for the 1997 fall semester was not a concern to them because the KR-20 used in studies during the past five years was generally greater then 0.8. They concluded that the instrument is a valid and reliable indicator in assessing a student's ability to visualize spatially.

The PSVT was also shown to be a valid and reliable instrument in another study conducted at North Carolina State University during the 1997 fall semester. The internal consistency coefficients of .82 and .80 were calculated for both parts of the computer-based PSVT (Branoff, 1998). Battista, Wheatley, and Talsma (1982) administered the PSVT to 82 preservice elementary teachers enrolled in an undergraduate geometry course and reported a KR-20 of .80. Guay (1980) used the PSVT on 217 university students, 51 skilled machinists, and 101 university students on three different occasions and reported an internal consistency coefficient (KR-20) of .87, .89, and .92.

Learning Styles. A second instrument administered in both the pretest and posttest sessions was used to identify the students' learning styles. C. Edward Cherry developed the Perceptual Modality Preference Survey v1.1 (PMPS) in 1981 (Harvey, 2002). The current version was obtained from Dr. Cherry with the author's permission for use in this study. The instrument is divided into seven learning styles: aural, interactive, haptic, kinesthetic, olfactory, print, and visual. Forty-two questions comprise the instrument with response choices being "always," "usually," "seldom," or "never." Each subject was instructed to circle the response they perceived as the best choice. Research conducted by Harvey (2002) established that the PMPS is a valid and reliable instrument in determining a person's perceptual modality preference.

> The seven perceptual modalities overall demonstrated a strong indication of construct validity of the PMPS by estimating the chi-square (x^2), Goodness of Fit (GFI), Comparative Fit Index (CFI), and the Root Mean Square Error of Approximation (RMSEA). The chi-square (x^2) reported □>.05 to be no less than 81.20 with the highest estimate being 142.48. There were no GFI estimates for any of the seven perceptual modalities lower than .95

> except the visual (.93) and interactive (.91). The RMSEA estimates for all modalities were acceptable fits with estimates less then .08.
>
> The seven perceptual modalities demonstrated an overall consistency to score acceptable values for determining reliability. The Cronbach Coefficient alpha (α) was used because it measures internal consistency of the instrument. Visual (.68), interactive (.68), haptic (.69), and aural (.71) all demonstrated sufficient reliability . . . . The remaining three modalities: olfactory (.84), print (.85), and kinesthetic (.86) scored very high (α≥.80) demonstrating internal consistency of the PMPS. (Harvey, 2002, p. 28)

Table 1
Subjects' Demographic Data By Experimental and Control Groups

Demographic Characteristic	Experimental *n*	Experimental %	Control *n*	Control %
Age				
18 - 25	21	91.3	21	80.8
26 - 35	0	0.0	2	7.7
36 - 45	2	8.7	2	7.7
46 - 55	0	0.0	1	3.8
56 +	0	0.0	0	0.0
Total	23	100.0	26	100.0
Gender				
Male	19	82.6	22	84.6
Female	4	17.4	4	15.4
Total	23	100.0	26	100.0

Research Results

Study Subjects

Based on the demographic survey, 8 (16.3%) of the subjects who participated in this study were female; the remaining 42 (83.7%) were male, and 42 (85.7%) were between the ages of 18 and 25 (see Table 1).

Less than half of the subjects reported they had taken an art, manual drafting, or computer-aided drafting course or a combination of at least one to three of those courses (see Table 2).

Table 2

Prior Related Instruction Completed By Experimental and Control Groups

Related Course Work Since 8th Grade	Experimental *n*	Control *n*
Related Courses Completed		
17	0	1
12	0	1
6	0	1
5	1	2
4	3	2
3	2	4
2	5	5
1	4	7
0	8	4
Types of Related Courses Completed		
Art	9	13
Manual Drafting	9	12
CAD Drafting	9	9

Note: More than one course may have been taken.

Approximately 9 (56.3%) of the 33 (67.3%) subjects who reported exposure to blueprints/drawings stated they had two to three years of work-related experience (see Table 3).

Table 3
Prior Related Work Experience By Experimental and Control Groups

Blueprints/Drawings	Experimental		Control	
Experience	*n*	%	*n*	%
Experience				
Yes	4	17.4	12	46.2
No	19	82.6	14	53.8
Total	23	100.0	26	100.0
No. of Years' Experience				
0 - 1	1	4.4	4	15.4
2 - 3	3	13.0	6	23.1
3 – 4	0	0.0	0	0.0
4 - 5	0	0.0	1	3.8
6+	0	0.0	1	3.8
Total	4	17.4	12	46.2

Note: Total for control group under No. of Years' Experience does not equal 46.2% due to rounding.

Research Findings

These results were obtained during the fall 2003 and spring 2004 semesters from 49 subjects, 26 from the control group and 23 from the experimental group.

Regarding the first research objective, to compare novice drafters' spatial visualization ability with the methods of drafting instruction they received, no statistically significant difference existed between novice drafters' spatial visualization ability scores as measured on the PSVT and the instructional methods used by their instructors (see Table 4).

Table 4
2 X 2 Mixed Analysis of Variance (ANOVA) on Spatial Ability

Source	Sums of Squares	*df*	Mean Square	*F*	Significance Level
Developments	.012	1	.012	.001	.979
Rotations	21.637	1	21.637	1.110	.297
Views	2.248	1	2.248	.107	.745
Total	10.018	1	10.018	.066	.798

Note: Significance at 0.05 level (2-tailed)

When comparing novice drafters' spatial visualization ability with their learning styles, the second objective of the study, a statistically significant relationship did exist between novice drafters' spatial ability posttest scores on the Developments section of the PSVT and posttest "aural", pretest "interact", and posttest "print" learning styles as assessed on the PMPS. In addition, a negative relationship was found between posttest scores on the Developments section of the PSVT and pretest "olfactory" learning style on the PMPS (see Table 5).

In analyzing the third objective of the study, to compare subjects' spatial visualization ability with their prior instruction or experience in drafting and art, a negative correlation existed between novice drafters' spatial ability test scores on several components of the PSVT and the number of prior CADD courses completed. The PSVT scores that correlated negatively with the number of CADD courses completed were the scores on the Developments section pretest, both the pretest and posttest scores on the Rotations section, and the PSVT pretest total scores. There was a negative correlation, as well, between work experience and the scores on the Developments section of the PSVT (see Table 6).

The last research objective was to verify whether novice drafters' perceptual modality learning styles changed from pretest to posttest. A negative statistical significance was found between the pretest and posttest "haptic", "interact", and "olfactory" learning styles (see Table 7).

Table 5
Spearman Rho Analysis Between Spatial Ability and Learning Style

	PSVT							
	Developments		Rotations		Views		Total	
PMPS (*N*=49)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Aural								
Pre	-.119	.246	-.078	.080	-.249	.076	-.185	.153
Post	-.017	.318*	-.175	.057	-.256	.062	-.257	.105
Haptic								
Pre	.101	-.154	.028	-.039	.073	-.109	.162	-.058
Post	-.002	-.243	.098	-.014	.042	-.126	.113	-.189
Interactive								
Pre	.240	.265*	.168	.156	.013	.187	.130	.250
Post	-.097	-.033	-.121	-.054	-.078	-.079	-.212	-.133
Kinesthetic								
Pre	-.076	.076	.127	.050	.037	.057	.048	.032
Post	-.024	.011	.162	.059	.062	.059	.093	.039
Olfactory								
Pre	-.083	-.326*	-.132	-.144	.065	-.109	-.009	-.183
Post	-.059	-.220	-.001	-.070	.183	-.044	.072	-.075
Print								
Pre	.096	.188	-.129	-.083	.121	.112	-.050	.104
Post	.231	.301*	-.054	-.003	.206	.218	.056	.171
Visual								
Pre	-.211	-.224	-.031	-.153	-.015	.041	-.114	-.139
Post	-.061	-.068	.159	-.084	-.031	-.016	.027	-.088

Note: *Significant at 0.05 level (2-tailed)

Discussion

Several factors are worthy of being addressed in analyzing these findings. First, the number of subjects from the control group (26) was three more than in the experimental group (23). The statistical methods used to test for significance used aggregated means to compare the variables. However, when comparing the individual scores on the PSVT pretest to those on the PSVT posttest in the experimental and control groups, a notable difference between the two groups is observed: In the control group, 6 individuals out of 26 (23%) showed an increase of five points or more from pretest to posttest. By contrast, in the experimental group, 13 individuals out of 23 (56%) had an increase of five or more points from pre- to posttest.

Table 6

Spearman Rho Analysis of Spatial Ability Scores and Prior Instruction or Experience in Drafting/Art

		Number of Classes in Years			
PSVT		Art	Manual Drafting	CAD	Work Experience
Developments					
	Pre	.171	-.256	-.355**	-.301*
	Post	-.118	-.135	-.183	-.323*
Rotations					
	Pre	.093	-.099	-.386**	-.165
	Post	.081	.029	-.333*	-.141
Views					
	Pre	.230	-.072	-.018	-.053
	Post	.069	-.220	-.231	-.257
Total					
	Pre	.115	-.160	-.281*	-.182
	Post	-.052	-.134	-.297*	-.297*

Note: *Significant at 0.05 level (2-tailed)
**Significant at 0.01 level (2-tailed)

Based on these findings, it seems plausible that a considerable difference in novice drafters' spatial visualization ability scores results when modality learning styles are addressed as part of the instructional process. Research on the effectiveness of incorporating teaching methods that appeal to a variety of

Table 7

Wilcoxon Signed Rank Analysis of Pretest and Posttest Perceptual Modality Learning Styles

Variable	Ranks	*N*	Mean Rank	Sum of Ranks	Z	*P*
Aural						
Post	Negative	24	19.44	466.50	-.333	.739
Pre	Positive	20	26.18	52.50		
	Ties	5				
Haptic						
Post	Negative	33	25.73	849.00	-3.376	.001*
Pre	Positive	13	17.85	232.00		
	Ties	3				
Interactive						
Post	Negative	15	21.77	326.50	-2.340	.019*
Pre	Positive	31	24.34	754.50		
	Ties	3				
Kinesthetic						
Post	Negative	18	21.53	387.50	-1.673	.094
Pre	Positive	28	24.77	693.50		
	Ties	3				
Olfactory						
Post	Negative	31	23.11	716.50	-2.944	.003*
Pre	Positive	12	19.13	229.50		
	Ties	6				
Print						
Post	Negative	20	22.05	441.00	-.864	.388
Pre	Positive	25	23.76	594.00		
	Ties	4				
Visual						
Post	Negative	23	25.37	583.50	-.046	.963
Pre	Positive	25	23.70	592.50		
	Ties	1				

Note: *Significant at 0.05 level (2-tailed) learning styles in order to enhance the learning process supports the use of these methods in the classroom. Brown (2003) pointed out that instructors who desire the learning process to be more student-centered must become aware of the different kinds of learning experiences.

The study findings also suggest that enrollment in prior CAD courses was not effective in developing novice drafters' spatial visualization ability. Likewise, it could also be stated that prior work experience with exposure to blueprints or drawings was similarly not beneficial to the spatial visualization development. Researchers believe that the most critical component skill in graphic representation is the ability to visualize objects spatially (Wiley, 1990; Sorby, 1999; Miller & Bertoline, 1991). Numerous theorists have attempted to define how, at what age, and what tools or methods are most effective in teaching this skill. Miller and Bertoline believed that more research would provide information as to what methods—use of sketching, three-dimensional solid modeling, or other curricular tools such as three-dimensional handheld models or enrollment in specific courses—could be used to enhance the ability to spatially visualize.

It is also plausible that the instrument used for determining modality learning styles may not accurately measure students' true learning styles because the instrument was based on the subjects' self-reported perception of how they learned best. In their review and critique of available learning-style instruments for adults, James and Blank (1993) stated that one of the most important and troubling results of various studies is that they "fail to yield solid evidence that the construct of learning style truly exits" (p. 54). They also stated that many researchers who conduct these studies have also created instruments and are biased as to which instrument is valid and reliable. James and Blank concluded that "a solid research base for many of these claims does not exist" (p.55).

Recommendations

The literature review and the results of this research study support the following recommendations for teaching graphical representation. Educators in technical education programs should

1. Incorporate instructional methods that address modality learning styles when teaching spatial visualization
2. Use modality learning styles to help students with a single dominant learning style strengthen weaker learning styles
3. Incorporate tools such as sketching, three-dimensional handheld models, three-dimensional solid model software, and orthographic and isometric projections to aid in developing spatial visualization.

To further the understanding of factors that may affect spatial visualization ability, future research should

1. Investigate learning styles using different instrumentation
2. Incorporate other demographic variables, such as gender and age, into the research design
3. Attempt to isolate more precisely the impact of prior instruction and work experience
4. Analyze the impact of instructors' learning styles on instructional methods selected.

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