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The Effects of 3-Dimensional CADD Modeling on the Development of the Spatial Ability of Technology Education Students

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Research Framework

Spatial abilities are fundamental to human functioning in the physical world. Spatial reasoning allows people to use concepts of shape, features, and relationships in both concrete and abstract ways, to make and use things in the world, to navigate, and to communicate (Cohen, Hegarty, Keehner & Montello, 2003; Newcombe & Huttenlocher, 2000; Turos & Ervin, 2000). Visualizing intangible boundaries such as state and national borders helps organize, orient, and compartmentalize knowledge of the world. In a similar way, this ability is used to envision new things, and establish relationships of concepts in the mind (Jones & Bills, 1998). One source estimates that 80% of jobs primarily depend on spatial ability, not on verbal ability (Bannatyne, 2003). Surgeons, pilots, architects, engineers, mechanics, builders, farmers, trades people, and computer programmers all rely on spatial intelligence (Bannatyne, 2003).

Newcomer, Raudebauch, McKell and Kelly (1999) reported that people who lack spatial ability are not good at interpreting graphic representations, have difficulty with directions and location of things, or are poor at estimating size or visualizing things and their relationships to one another. Yet, these people successfully function because they have more spatial ability than they realize. Spatial ability can be improved in children and adults (Potter & van der Merwe, 2001; Strong & Smith, 2001). A potential benefit of improving spatial abilities is the improvement of academic achievement in mathematics and science (Keller, Washburn-Moses & Hart, 2002; Mohler, 2001; Olkun, 2003; Robichaux, 2003; Shea, Lubinski & Benbow, 1992).

Educators debate whether increased spatial aptitude improves performance in science and other subjects (LeClair, 2003). Minimal academic training in science focuses on spatial thinking and most assume the existence of necessary

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spatial skills (Schultz, Huebner, Main & Porhownik, 2003). It is suspected that spatial ability contributes additional validity to mathematical and verbal reasoning abilities. Gardner (1993) suggested skill in spatial ability determines how far one will progress in the sciences. There is no consensus as to the number of distinct spatial abilities that exist. The two most commonly agreed upon categories are *mental rotation* and *visualization*. A third category is usually *perception*, although some sources name *orientation* as the third category (Hegarty & Waller, 2004; Kaufmann, Steinbugl, Dunser & Glueck, 2003). Bodner and Guay (1997) portray *orientation* and *visualization* as the two major categories as the result of factor analysis of various tests used to measure spatial ability.

Spatial Ability Development

Several studies indicate that spatial ability can be improved if training with appropriate materials is provided (Cohen et al., 2003; Kinsey, 2003; Newcomer et al., 1999; Potter & van der Merwe, 2001). Kinsey (2003) found that when university freshmen identified as at risk participated in a session on strategies to improve spatial ability skills, gender differences on the pretest were eliminated as a consequence of the instruction on spatial strategy (Kinsey, 2003). Cohen et al. (2003) found that it is possible to train participants to use mental rotation and perspective by modeling these spatial strategies with animation (Steinke, Huk & Floto, 2003). In another study, students with low spatial ability spent significantly more time viewing high quality videos and 3-D animations than did students who had high spatial ability (Steinke et al., 2003).

Not all studies indicate that the use of computer software is a significant factor in improving spatial abilities. In a study using 2-D and section models, no difference was found between active and passive controls. Shavalier (2004) investigated whether CADD-like software called *Virtus Walk Through Pro* could be used to enhance spatial abilities of middle school students. No significant difference was found between the control and treatment groups, and no treatment effects were found in measures related to gender or spatial ability levels.

Relationship of Spatial Ability to Mathematical Ability

Mathematical concepts and relationships are often intangible and are therefore difficult to teach. A relationship has been shown between spatial and mathematical ability, and some indicators suggest spatial ability is important for achievement in science and problem solving (Grandin, Peterson & Shaw, 1998; Keller et al., 2002). Yet, there is little emphasis in the educational system on the development of spatial abilities, perhaps because such abilities are taken for granted or believed to be innate.

Relationship of Spatial Ability to Gender and Ethnicity

Previous studies indicate a possible relationship between gender and spatial visualization ability (Alias, Black & Gray, 2002). Some studies indicate that males perform better on spatial rotation tests, but not necessarily on other aspects of

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spatial ability (Grandin et al., 1998; Santacreu, 2004). Bodner and Guay (1997) stated that gender differences often account for only negligible fractions of the variance in spatial ability (Bodner & Guay, 1997). Although the largest difference was in mental rotation, tests of visualization factors show differences between genders are small or null (Burin, Delgado & Prieto, 2000). Indeed, meta-analyses reveal that biological factors account for no more than five percent of the variability in spatial performance (Schultz et al., 2003). Several studies found that gender was not related to various aspects of spatial ability (Postma, Izendoorn & De Haan, 1998; Voyer, 1998) while Hubona and Shirah (2004) found relationships between gender and various aspects of spatial ability.

Ritz (2004) found that disparities exist from ethnicity and socioeconomic factors. The largest disparity between African Americans and white students in grade eight is measurement. The gap increased from 40 points in 1990 to 58 points in 2000. A similar gap exists when comparing whites and Latinos (Ritz, 2004).

Background and Significance

Most ninth grade students in Mississippi take a modular Technology Discovery course that includes a computer-aided design and drafting (CADD) module. A characteristic of 3-D CADD modeling is the manipulation of geometric shapes using spatial ability. In order to implement 3-dimensional software in curricula statewide, *Pro/Desktop*® (2003) was made available through the *Design and Technology in Schools Program* sponsored by the Parametric Technology Corporation. Evidence did not exist about the effectiveness of using 3-dimensional CADD programs to develop spatial ability. This study investigated whether selected instructional methods using 3-dimensional CADD software had an effect on the development of spatial abilities of ninth grade Technology Discovery students.

Purpose and Research Questions

The purpose of this study was to determine if there was a difference in the development of the spatial abilities of Mississippi ninth grade Technology Discovery students by instructional treatment as measured by the Purdue Visualization of Rotations Test (PVRT) (Bodner & Guay, 1997). The research questions were:

1. What are selected characteristics of Technology Discovery students? The characteristics included were gender, ethnicity, co-registration in art, and co-registration in geometry.
2. Do differences exist in the spatial ability development of Technology Discovery students when they are taught using various methods (treatments), when the spatial ability pretest scores are controlled?
3. Do differences exist in the spatial ability development of Technology Discovery students when they are taught using various methods (treatments), when the spatial ability pretest scores, gender, ethnicity, co-registration in art, and co-registration in geometry are controlled?

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Method

A quasi-experimental design was used for this study. Intact ninth grade Technology Discovery classes were used, with teachers using *Pro/Desktop*® 3-D CADD software in a modular setting. The dependent variable was spatial ability as measured by the PVRT. The experimental treatments were as follows:

> *Teacher and Module (Experimental).* This group was taught by the teacher using researcher-developed lesson plans and 3-D CADD modeling software during the design unit, followed by module rotations in which pairs of students used researcher developed, student-directed material to learn more about the 3-D CADD modeling software. Both teacher-directed and student-directed lessons used 3-D physical models as an aid to instruction.
>
> *Module Only (Experimental).* This group was taught spatial ability using 3-D CADD modeling software without teacher-directed lessons. Instruction occurred only during module rotations in which pairs of students used researcher developed, student-directed curriculum material in conjunction with 3-D CADD modeling software to develop spatial ability. The lessons utilized 3-D physical models as an aid to instruction.
>
> *Existing Material (Experimental).* This group was taught spatial ability using 3-dimensional CADD modeling software during module rotations in which pairs of students used the methods and materials that had previously been used by that teacher, with no interventions or changes. It should be noted that a wide variety of materials existed.
>
> *No CADD Instruction (Control).* This group was not enrolled in Technology Discovery classes and the schools did not offer CADD.

Population and Sample

Schools that operated on a 4x4 block schedule and offered Technology Discovery were included in the 3 treatment groups. Students in these schools completed the Technology Discovery course during one semester, with class periods of at least 94 minutes per day. Participating schools with intact classes provided cluster samples. Block schedule schools typically operated three classes per day. Technology Discovery was designed for a maximum class size of 24 students. Each teacher assigned student pairs to instructional module rotations at the beginning of the school year. Each class had the potential of having 12 rotations with two students per rotation.

To avoid researcher bias, schools (with their teachers and students) were randomly assigned to one of three experimental treatments (instructional methods). Teachers located in the same schools were assigned to the same instructional method. The design used a control group from schools not offering CADD. To facilitate consistency, teachers participating in the study received oral and written instructions about study procedures. They were contacted at least two times by telephone and email prior to beginning the study. Instructional

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materials, tests, information forms, instructions for test administration, and return envelopes were mailed. Standard consent forms were used to obtain consent from parents or guardians for the students to participate in the study. Table 1 summarizes the instructions provided to each teacher. Usable data were obtained from 464 students by instructional method, as follows: Teacher Instruction with Module – 101 (21.8%), Module Alone - 164 (35.3%), Existing Materials – 116 (25.0%), and No CADD Instruction (Control Group) – 83 (17.9%).

Table 1
Instructions provided to technology discovery teachers participating in the study.

	Instructions Provided to Teachers		
Treatment	**Test administration, submission of data**	**3-D student module material, use of physical models**	**Teacher centered instruction**
1 - Teacher with module	Yes	Yes	Yes
2 - Module alone	Yes	Yes	No
3 - Existing materials	Yes	No	No
4 - No CADD	Yes	No	No

Note. Verbal and written instructions were provided to each teacher.

Treatment Development

Lesson plans and instructional material were developed by the researcher. The researcher is a certified *Pro/Desktop*® trainer and highly qualified to develop material for the software. Instructional sessions were developed using PowerPoint. An existing instructional tutorial for *Pro/Desktop*® CADD software was utilized in the final lesson.

The instructional materials incorporated the recommendations by Kinsey (2003) regarding the need to provide a combination of methods, including 3-D physical models, observation, and hands-on computer use while learning to use CADD software. The design also incorporated the recommendations by Roschelle, Pea, Hoadley, Gordin, and Means (2001) who stated computer technologies should enhance student learning when the four factors of active engagement, participation in groups, frequent interaction and feedback, and connections to real-world contexts are kept in mind while designing instruction. Lesson plans for 160 minutes of teacher-directed instruction supported by physical models were designed. The physical models were then located at the CADD workstation for student use with the instructional module. Module materials for learning the CADD software and physical models were prepared to support instruction for both the *Teacher and Module* and *Module Alone* instructional methods (1 and 2). Student material included rotation of the objects being modeled on the computer. The connection between geometry and engineering drawing (Keller et al., 2002; Lowrie, 1994; Smith, 2001) led to the inclusion of a review of basic geometric shapes and terms in the modular

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instructional materials. The student-directed modular instructional material was developed for approximately 450 minutes of modular instructional time. Both instructional methods 1 and 2 used this material.

Five teachers who were certified as *Pro/Desktop*® trainers reviewed the material for face validity. These teachers suggested improvements to the physical models and revisions to the PowerPoint presentation, including wording and the order of the module sessions. These revisions were made prior to dissemination of the materials. The *Existing Materials* treatment group (3) was instructed to continue to use materials that were in use during the 2004-2005 school year. These consisted of tutorials utilized in the training of teachers. The *No CADD Instruction* treatment group (4) used no software and did not study CADD.

Data Collection and Analysis

Teachers administered the PVRT as a pretest to all Technology Discovery students in their classes near the beginning of the semester, along with a student information sheet that gathered data on gender, ethnicity, and whether they were currently enrolled in art or geometry. The posttest was given 5-7 school days after each student completed the CADD module rotation. The time between module and posttest was chosen to measure student achievement at a consistent amount of time after instruction.

The PVRT was used for both the pretest and posttest. It is appropriate for use with adolescents and may be administered either in groups or individually. This test is among the spatial tests least likely to be confounded by analytic processing strategies (Bodner & Guay, 1997). The test measured the ability to visualize the rotation of 3-dimensional objects. The instrument was chosen because of its high correlation with similar instruments measuring visualization that were not cost effective to use. The PVRT instrument included 30 questions in which an object was pictured in one position, and then it was shown in a second image, rotated to a different position. Participants were shown a second object and given five choices, one of which matched the rotation of the example object. They were asked to select the object that showed the same rotation as the example for that question. Students had 15 minutes to complete the timed test. Reliability for the PVRT reported by Bodner and Guay (1997) using KR-20 and split half reliability coefficients ranged from .78 to .85 in nine studies that involved samples sizes ranging from 127 to 1,648.

Teachers assigned students to rotation schedules at the beginning of the semester, using methods prescribed during teacher training for Technology Discovery. They were asked to adjust the rotations to ensure that no other CADD or Spatial Information Technology module was completed prior to the module under investigation, nor in the week prior to the posttest. Other than the adjustment stated above, their usual assignment procedures for rotations were applied.

Students in the control group (No CADD group) took the PVRT test with a five-week interval between pretest and posttest. Schools in the control group administered the test in ninth grade English I classes in order to provide the

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module under investigation, nor in the week prior to the posttest. Other than the adjustment stated above, their usual assignment procedures for rotations were applied.

Students in the control group (No CADD group) took the PVRT test with a five-week interval between pretest and posttest. Schools in the control group administered the test in ninth grade English I classes in order to provide the appropriate equivalent sample population. English I classes were used because the course was required of all ninth grade students.

The *alpha* level was set *a priori* at .05. Descriptive statistics including values and percentages were used to analyze the data for Research Question 1. Analysis of covariance was used for Research Questions 2 and 3. The number of schools in the sample was 14, including 10 schools that offered Technology Discovery and 4 that did not.

Results

Characteristics of Population

Most of the students in the study were female and white. A higher number of female students were in each of the treatment groups. There were more black male and female students in the No CADD instruction treatment (control) group, and more white male and female students in the other three treatment groups (see Table 2).

Table 2
Ethnic background and gender reported by treatment group

		Ethnicity									
		Black		**White**		**Hispanic**		**Asian**		**Other**	
		n	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Teacher Instruction	**F**	16	29.2	35	63.6	1	1.8	2	3.6	1	1.8
& Module *n* = 101	**M**	4	7.9	41	89.1	0	0.0	0	0.0	1	2.2
Module Alone	**F**	25	27.8	62	68.9	1	1.1	0	0.0	2	2.2
***n* = 164**	**M**	19	25.7	52	70.3	2	2.7	0	0.0	1	1.3
Existing Materials	**F**	20	31.7	43	68.3	18	0.0	0	0.0	0	0.0
***n* = 116**	**M**	21	39.6	30	56.6	14	1.9	0	0.0	1	1.9
No CADD Instruction	**F**	26	56.5	18	39.1	0	0.0	1	2.2	1	2.2
(Control) *n* = 83	**M**	18	48.7	14	37.8	1	2.7	2	5.4	2	5.4
Total		149	32.1	295	63.6	6	1.3	5	1.1	9	1.9

There were 61 (13.1%) students enrolled in art, 48 (10.3%) enrolled in geometry, and 17 (3.4%) students enrolled in both art and geometry. The

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Table 3
Participants co-enrolled in art and/or geometry by treatment group

	Treatment Group				
Courses	**Teacher Instruction and Module % (*n*)**	**Module Alone % (*n*)**	**Existing Materials % (*n*)**	**No CADD Instruction % (*n*)**	**Totals % (*N*)**
No Art or Geometry	52.5 (53)	81.2 (133)	81.0 (94)	71.1 (59)	73.0 (339)
Art	16.8 (17)	14.6 (24)	12.1 (14)	7.2 (6)	13.2 (61)
Geometry	23.8 (24)	2.4 (4)	6.0 (7)	15.7 (13)	10.3 (48)
Both Art Geom.	6.9 (7)	1.8 (3)	0.9 (1)	6.0 (5)	3.5 (16)
Total	100.0 (101)	100.0 (164)	100.0 (116)	100.0 (83)	100.0 (464)

Differences in Spatial Ability Posttest Achievement with Pretest Covariate

Research Question 2 asked if differences existed in spatial ability test scores of Technology Discovery students as measured by the PVRT, when the pretest scores were controlled, and students were instructed using differing treatments (instructional methods). An analysis of covariance (ANCOVA) was conducted to determine if there was a difference in student achievement among the instructional methods. The independent variable of instructional treatment included the four levels described in the research question. The dependent variable was the posttest, the covariate was the pretest, and the fixed factor for the analysis was the instructional method.

The preliminary analysis using Levene's Test revealed that the variances in the posttest scores did not differ among the treatments ($F_{(3, 460)}=.71; p=.548$). Therefore, equal variance across treatment groups was assumed. In addition, a model lack-of-fit test was conducted to determine if there was evidence that the effects of the treatments were nonlinear. The non-significant results of the lack-of-fit test ($F_{(88, 368)} =1.25; p=.086$) indicated that the effects were likely linear. In addition, the interaction between the method factor and the pretest covariate was not significant, ($F_{(3, 456)}$ =1.83, p>.05), indicating that the differences on the posttest among groups did not vary as a function of the covariate. Therefore, the pretest was an appropriate covariate in the analysis of covariance.

Significant differences existed among the means by instructional method ($F_{(3,459)}$ =6.6, p<.001, partial eta^2=.04) (see Table 4). According to Green and Salkind (2003) the partial eta^2 level of .09 indicates a moderate relationship between posttest scores and teaching methods, with pretest scores as the covariate. Table 5 presents the unadjusted and adjusted means of posttest scores for each instructional method and the control group with the covariate

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included. The adjusted mean for the Teacher Instruction and the Module groups is larger than the adjusted means for the other instructional treatment groups and the control group. The pairwise comparison conducted using the Bonferroni procedure revealed that the test scores for the Teacher Instruction and Module group were significantly higher than the other three groups.

Table 4.
ANCOVA test for differences among treatment means with pretest covariate

Source	*SS*	*df*	*MS*	*F*	*p*	Partial *eta*^{2}
Corrected Model	9317.53	4	2329.38	141.59	<.001	.55
Intercept	76170.31	1	76170.31	4630.04	<.001	.91
Instructional Method	741.58	3	247.19	15.03	<.001	.09
Pretest	8575.95	1	8575.95	521.29	<.001	.53
Error	7551.16	459	16.45			
Total	93039.00	464				
Corrected Total	16868.69	463				

Note. R^2 = .55 (Adjusted R^2 = .55).

Differences in Spatial Ability Posttest Achievement with Multiple Covariates

Research Question 3 asked if differences existed by treatment (instructional method) in the spatial ability of Technology Discovery students as measured using the PVRT when spatial ability pretest scores are controlled, and explanatory factors of gender, ethnicity, co-registration in either art and/or geometry are added to the model. Analysis of covariance with simple contrasts for the explanatory factors was conducted to analyze the data for this research question. The dependent variable was the posttest score; the covariate was the pretest score, and additional explanatory factors were gender, ethnicity, co-enrollment in art, and co-enrollment in geometry. The fixed factor was the instructional treatment method. Gender was not significantly correlated to the dependent variable posttest scores; therefore, gender was not included in the analysis.

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Table 5
Posttest unadjusted and adjusted mean student scores by instructional method with pretest covariate

Instructional Method	*n*	Unadjusted *M*	Unadjusted *SD*	Adjusted *M*	Adjusted *SD*
Teacher Instruction and Module	101	15.01	5.97	14.38[a]	.41
Module Alone	164	12.56	5.41	12.59[a]	.32
Existing Materials	116	11.37	5.87	12.30[a]	.39
No CADD Instruction	83	12.66	6.83	11.97[a]	.45
Totals	464				

[a]Covariate in the model is evaluated with pretest value of 11.49.

An analysis was conducted to determine if the variances in the posttest scores were equal among the treatment groups when the fixed factors were included. The non-significant Levene's Test ($F_{(3, 460)}$ =1.11; p=.344) suggests that the variance of the postest scores was approximately equal for the four treatment groups, and equal variance across treatment groups was assumed. A model lack of fit analysis was conducted and it was not significant ($F_{(212, 288)}$ 1.02; p=.433).

An initial ANCOVA tested for the interaction effects. The interaction between the dependent variable posttest and covariate pretest was not significant. Interaction between the dependent variable posttest and ethnicity was not significant, nor was interaction between posttest and co-enrollment in either art or geometry. Since no significant interactions existed, the interaction effects were removed from the ANCOVA prior to conducting the final analysis. Table 6 reports the final analysis of covariance. This analysis resulted in a significant outcome for instructional method ($F_{(3,455)}$ =15.02, $p < .001$). The strength of the differences between the fixed factor instructional method and the dependent variable posttest was moderate as indicated by a partial eta^2 of .09 (Green & Salkind, 2003). It is interesting to note that the partial eta^2 in this analysis was the same as the result presented for research question 2.

Table 7 presents the unadjusted and adjusted means of posttest scores for each instructional treatment and the control group. The adjusted mean for the Teacher Instruction and Module group is larger than the adjusted means for each of the other instructional treatment groups and also larger than the control group. In order to determine whether the difference in means was statistically significant, further analysis using the Bonferroni *post hoc* procedure was conducted which confirmed that the mean scores for students in the Teacher Instruction and Module group were significantly higher than the other three groups.

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Table 6.
Analysis of Covariance for Differences among Posttests by Instructional Method Groups with Pretest Covariate and Explanatory Factors

Source	SS	*df*	*MS*	*F*	*p*	*eta*^{2}
Pretest	8575.95	1	8575.95	521.10	<.001	.53
Method	741.58	3	247.19	15.02	<.001	.09
Ethnicity-white	27.07	1	27.07	1.65	.200	<.01
Ethnicity-black	8.83	1	8.83	.54	.464	<.01
Co-enrollment in Art	13.91	1	13.91	.85	.358	<.01
Co-enrollment in Geometry	3.25	1	13.25	.81	.370	<.01
Error	7488.11	455	16.46			
Total	93039.00	464				

R^2 = .56 (Adjusted R^2 =.55).

Conclusions and Discussion

In this sample, less than 30% of Technology Discovery students are black; fewer than 5% are Hispanic, Asian, or other ethnic backgrounds; and nearly 70%, are white. Since Mississippi public schools average slightly more than 50% black students enrolled statewide, the fact that less than 30% of the students in the classes were black is unusual. Over half of the Technology Discovery students are female. Both black and white females outnumber black and white males in the classes. Few Technology Discovery students enrolled in art or geometry.

Table 7
Posttest Unadjusted and Adjusted Mean Scores of Students by Instructional Method

		Unadjusted		Adjusted	
Instructional Method	***n***	***M***	***SD***	***M***	***SE***
Teacher Instruction & Module	101	15.01	5.97	14.19[a]	.42
Module Alone	164	12.55	5.41	12.61[a]	.32
Existing Materials	116	11.37	5.87	12.34[a]	.38
No CADD Instruction	83	12.66	6.83	12.20[a]	.46
Totals	464	12.81	6.04		

[a]Covariates appearing in the model are evaluated at the following values: pretest = 11.49, Ethnicity-White = .64, Ethnicity-Black = .32, Geometry Class = .14, Art Class = .17.

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A difference exists in spatial ability based on the method used to instruct students using 3-D CADD modeling software, with the instructional method of Teacher with Module being more effective than either the Module Alone or the Existing Materials method in improving spatial ability achievement scores. This occurred both in the analysis for Research Question 2, where the only covariate was the pretest, and in Research Question 3, where gender, ethnicity, co-enrollment in art and co-enrollment in geometry were included as covariates. It can be concluded that the use of 3-dimensional CADD modeling software affects student spatial ability development when a combination of teacher-lead and student-directed instruction is used with 3-dimensional physical models.

The teacher-led lesson was the likely factor explaining the Teacher with Module group's gain in spatial ability. Roschelle et al. (2001) stated that social contexts such as teacher-directed group lessons give students the opportunity to successfully perform more complex skills than they could manage alone. Working on a task with others not only provides opportunities to replicate what others are doing, but also to discuss the task and ideas involved.

No difference was found among the spatial ability of students who studied CADD using the Module Alone method, the Existing Materials method, and students who did not study CADD at all. This occurred both in the analysis for Research Question 2, where the only covariate was the pretest, and in Research Question 3, where gender, ethnicity, co-enrollment in art and co-enrollment in geometry were entered as covariates. The instructional methods Module Alone and Existing Materials were both based on self-directed student learning.

A cursory review of test scores indicated that some students appeared to gain in the ability to mentally rotate an object. Others showed little or no gain. There may be a connection between this and the study done by Battista (2002) which cited the theory of constructivism as a basis for instructional design for teaching mathematics. The theory proposes that to understand new ideas, students must personally construct meaning using their own knowledge and reasoning. Though student-directed modular learning is based on this theory, it was not supported by this study. Student use of modules was only effective in increasing the spatial ability to mentally rotate objects when the teacher established a common understanding of the views used in the software prior to modular instruction. Various factors may account for the lack of gain in the Module Alone and Existing Materials groups. Due to the typical teacher-centered learning environment with which students are familiar, they may not consider instruction that is student-directed to be as important as traditional instruction. Constructivist learning theory suggests that by reflecting on experiences, students construct their own understanding of the world. In order for students to learn in this manner, they must actively participate in the planned activities of a lesson. In a modular learning environment some students may not seriously concentrate on the lessons provided, considering themselves as passive learners responsible only for material that is presented by teachers for which they expect to be tested. Although multimedia has been relatively successful as a learning tool, it is not enough by itself to guarantee that students

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will actually learn. The exclusive use of multimedia is intriguing, but it does not necessarily require the learner to be in active control of the learning process or necessarily thinking about what is being presented (Mohler, 2001). In addition, if two students are working at a learning station and only one computer is available, one of the pair may dominate the interaction with the software. The passive student may not take responsibility for her or his learning, allowing a partner to interact more with the software. When students are placed in the relatively passive role of receiving information, they often fail to develop sufficient understanding to be able to apply what they have learned to other situations (Roschelle et al, 2001).

Moreover, hands-on manipulations may divert the short-term memory resources of some students, reducing the possibility of comprehending the simultaneous manipulation of a larger number of mental elements (Smith, 2001). In addition, Steinke et al. (2003) found that some students required observation with no activity in order to process new concepts.

Recommendations for Future Research

Based on the findings of this study and the review of literature, one can conclude that little is known about how the use of Computer Aided Design and Drafting technology affects student spatial ability development. Continued research in this area is both vital and needed. Replication of this study in other states would contribute to the research and knowledge base for both CADD instruction and spatial ability improvement. Further research is needed to determine whether the conclusions reached in this study would be consistent with other similar studies and, specifically, whether or not a particular instructional method using 3-D CADD modeling is consistent in the improvement of the spatial ability of students. This would contribute to the goal of the National Research Council (2006) to include an emphasis on learning to think spatially in education systems.

Numerous studies indicate a high correlation between mathematics achievement and spatial ability. Other studies have found that spatial ability affects student achievement in science as well as other subjects. Therefore, research that specifically examines development of spatial ability when using 3-D modeling software should be continued. It is possible that the development of spatial visualization ability could be the most important contribution that technology education could make to learners. Consequently, it could be the most defensible reason for the inclusion of technology education for all students.

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