Training in spatial visualization: The effects of training method and gender

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ABSTRACT
This paper reports the findings from an experimental study involving thirty three secondary school students (mean age = 15.5 years) in spatial visualization (SV) training through an interactive desktop virtual environment spatial trainer (DVEST). Stratified random sampling was used to assign students into two experimental groups and one control group. The first experimental group trained in interaction-enabled DVEST (i-DVEST), the second experimental group trained in animation-enhanced DVEST (a-DVEST), and the control group received conventional training. A multi-factorial pretest posttest design procedure was used and data were analyzed using 2-way ANCOVA. Participants trained in i-DVEST made the highest improvement gain in SV, followed by those trained in a-DVEST, and the control group achieved the lowest improvement gain. In general, male participants achieved higher SV improvement gain compared to female participants. Interaction effect between method of training and gender was observed indicating that male students tended to benefit more when trained in i-DVEST, moderately in a-DVEST, and poorly in conventional method. On the other hand, female students seemed to benefit from training irrespective of the method used.

Keywords
Animation, navigation, visualization, virtual environment, VRML

Introduction
Spatial ability is a cognitive ability that is very important to humans for everyday chores and specialized activities. Simple activities such as arranging furniture in home entail having some knowledge about spatial layout and orientation. The ability to drive on the highway safely requires a driver to be able to make accurate and quick judgment of distances and turns when maneuvering and stopping. In highly technical domains, engineers, architects, and computer-aided designers for example require sophisticated spatial skills and knowledge to understand blueprints and make inferences to the constructions of buildings, components, and artifacts. Without a well-developed spatial ability, a person may encounter serious problems affecting one’s academic pursuit or career.

Spatial ability is conceptualized as a psychological cognitive construct built upon several independent sub-abilities or skills. Linn and Petersen (1985) categorized spatial ability into three components namely spatial visualization, mental rotation and spatial perception. Prior to Maccoby’s and Jacklin’s (1974) study, spatial ability was regarded as an innate ability and thus immune from training effect. Findings from experimental studies thereof have established evidence that this ability is trainable when trainings are designed with specific focus on this ability. One of the important discoveries emerging from studies involving psychometric testing of spatial ability was the revelation of gender differences favoring boys. In general, boys were consistently found to perform better than girls on these tests suggesting that boys generally possess greater spatial skills than girls. Male advantages in spatial ability have been established in reviews by Maccoby and Jacklin (1974), Linn and Petersen (1985), and Voyer, Voyer, and Bryden (1995) where the trends of gender differences were found to be stable and consistent. Their meta-analyses show that the gender differences were highly, moderately and marginally robust in mental rotation, spatial perception and spatial visualization respectively. Interestingly, Maccoby and Jacklin (1974) found that some gender differences in spatial ability initially favored girls at young age, but began to favor boys as individuals approached adolescence. This suggests that environmental or experiential factors may influence the development of spatial ability adding credence to the claim that this ability can be nurtured. Apparently, the explanations of gender differences were premised on biological and environmental factors. Sex hormone (Halpern, 2000; Hier & Crowley, 1982), cerebral lateralization (Gur et. al., 2000; Voyer, Voyer, & Bryden, 1995), and x-linked genetic theory (Harris, 1978; Skuse, 2005) are a few treatises based on biological framework.
On the other hand, several propositions such as differential experience and socialisation (Baenninger & Newcombe, 1989; Quaiser-Pohl & Lehmann, 2002; Voyer, Nolan, & Voyer, 2000) and gender-role identification (Signorella & Jamison, 1986; Massa, Mayer, & Bohon, 2005) were fixated on environmental perspective attributing to social-cultural aspects. A new approach of interpretation has been advocated converging on these two perspectives where spatial performance differences were conceived to originate from an interaction of biological and experiential factors. Theories by Sherman (1978) and Casey (1996a, 1996b) supported this interaction by reporting on innate predisposition for spatial abilities that leads to self-selection of activities that ultimately influences the development of a person’s spatial ability or skills. Irrespective of the plethora of theories having substantial claims, many have agreed that experiential factors are detrimental in producing gender differences. Greater participation in spatial activities resulted in higher performance in spatial task, and both genders improved after spatial training (Baenninger & Newcombe, 1989; Olkun, 2003; Rafi, Khairulanuar, & Ismail, 2006). Of late, training in spatial ability has adopted new and novel technologies in particular virtual reality creating an interactive 3D computer-generated environment. Training became more efficient and effective through visualization, animations and greater interaction with virtual training objects (Mantovani, 2001; Moyer, Bolyard, & Spikell, 2001; Rafi, Khairulanuar, Haniff, Maizatul, & Mazlan, 2005). The focus of this study was on spatial visualization that is critical in technical education using the desktop virtual reality.

**Theoretical considerations in developing the training application**

The topics of spatial training have been deliberated extensively in the literature covering interventional programs or applications developed to train users in spatial tasks. However, some of these training programs were generic and lacked sound theoretical framework for efficacious use. In this study, the authors adopted a theoretical approach informed through a review on the literature of current theories of learning and psychometric testing. The former will guide the development of instructional setting or training environment that helps learners maximize their learning or training potentials whilst the latter will ensure that relevant spatial tasks are developed using appropriate learning objects or training tools than tap on spatial ability. Pairing these two factors together will facilitate the development of an effective spatial training application.

The training application was designed based on the framework espoused by the constructivist view of learning. Dalgarno (2001) outlined three broad principles of this view based on studies by Kant (1946) and Dewey (1938) for the first principle, Piaget (1969) for the second principle, and Vygotsky (1978) for the third principle. The first principle informs that individuals formed their own representation of knowledge and there was no particular ‘correct’ representation of knowledge. The second principle prescribes that learning occurred when learners uncovered a deficiency in their knowledge representation or an inconsistency between their current knowledge representation and their experience during active exploration. Learning that takes place within a social context is the third principle of this constructivist view. These three broad principles have been adopted in formulating approaches to the teaching and learning process. To explicate the intricacies of the interpretation, Dalgarno (2001) cited Moshman’s (1982) categorization of constructivism into three distinct classes namely endogenous, exogenous, and dialectical constructivism. Endogenous constructivism emphasizes the individual nature of each learner’s knowledge construction process relegating the role of teachers to facilitators. Exogenous constructivism highlights the formation and refinement of knowledge representations through learning by instructions with support from exercises entailing active cognition. Dialectical constructivism supports learning through realistic experience coupled with social interactions among teachers, experts and peers providing the essential scaffoldings.

The appropriate use of training or learning objects was informed by reviewing the items in the psychometric test battery that are utilized as part of intelligence and employment assessments. These test batteries have been evaluated showing strong validity and reliability measures for the cognitive-psychological constructs such as spatial visualization, mental rotation and spatial perception. The development of the training objects was based on test items under the category of ‘count touching blocks’ that measures the ability to visualize forms in space and to manipulate them mentally (Wiesen, 2004). This ability is also considered a strong component of mechanical aptitude deemed vital in learning technical and industrial fields.
The development of an interactive Desktop Virtual Environment Spatial Trainer (iDVEST)

The training program comprises training objects as part of the instructional learning activities in a platform designed and adapted from the principles or views of constructivist learning theory. A desktop virtual environment was chosen capitalizing on two important criteria; three-dimensionality and practicality. The former is essential in engendering 3D-space learning environment that facilitates better understanding on spatial properties and relationships of objects and space. The latter is more concerned with the ease of development, implementation and maintenance in typical Malaysian schools. The terms virtual reality (VR) and virtual environment (VE) are interchangeably used to describe a computer-generated three-dimensional (3D) environment allowing real-time interactions by means of one or more control devices and involving one or more sensorial perceptions (Ausburn & Ausburn, 2004; Schneiderman, 1993). Though lacking the immersion factor associated with high-end immersive virtual reality systems, desktop virtual environment has made significant impact in learning and training given the continually increasing processing capability of desktop computers providing faster and better graphics delivery. Desktop VR technology emerged in formats such as a mouse-controlled navigation in a 3D-environment that is affordable especially for general classroom usage (Ausburn & Ausburn, 2004). Realism, flexibility, interactivity, and easy learner control of the screen-based environments offer great learning potentials for users in the desktop VR (Shneiderman, 1993). The development of open-standard, non-proprietary Virtual Reality Modeling Language (VRML) (Beier, 2004) has added wider adoption of desktop VR that is web-deliverable over the Internet for greater distribution.

The development of an interactive desktop virtual environment spatial visualization trainer (iDVEST) was carried out as a web-based application that constitutes a series of exercises pertaining to spatial visualization tasks involving the configuration of stack of blocks. Each exercise is presented with a question requiring a learner to count the virtual blocks that are in contact with a virtual target block. Interactions with the virtual objects are performed through a viewer application viz. Parallel graphic’s Cortona VRML client. Animations of the virtual objects were also programmed along specified paths in iDVEST as a cognitive tool for assisting learners in visualization and provision of correct spatial solutions. The interaction mode of the former and animation mode of the latter were operationally categorized as the two experimental treatments namely i-DVEST and a-DVEST training conditions respectively. Feedback mechanism was also added to acknowledge learners the incorrect or correct responses facilitating the correction of mistakes and development of new plans.

![Figure 1: The iDVEST comprising VRML client interface, virtual objects and questions](image)
Dalgarno (2001) advised judicious use of elements from each view to produce an efficacious training environment. Exercises are in the form of a series of questions requiring learners to read carefully the instructions hinged on exogenous constructivist view emphasizing the role of direct instruction. Interacting with the virtual objects to observe spatial configuration from multiple views helps learners construct and refine their mental models reflected the endogenous constructivist view. The combination of the feedbacks to inform learners the correct or incorrect status of the responses and animations constitutes a scaffolding mechanism in line with the dialectical view of constructivism helping them to arrive at the correct solutions. Figure 1 shows the layout of the iDVEST containing the questions and virtual training objects.

**Purpose of study**

Spatial ability or skills such as spatial visualization are essential cognitive abilities in secondary education especially for students enrolled in technology education. Investigation on spatial visualization improvement based on method of training and gender was carried out in this study with emphasis on active exploration and interaction in the interactive desktop virtual environment. The study sought to compare the effectiveness of spatial training using three methods of training conditions namely interaction-enabled desktop virtual environment (i-DVEST), animation-enhanced desktop virtual environment (a-DVEST), and conventional method. Three research questions to address the issues in the study are as follows:

a) Is there a significant improvement in participants’ spatial visualization after training?
b) Are there significant differences in improvement gain of spatial visualization based on the method of spatial training?
c) Is gender a significant factor in influencing the training outcome after the participants trained in spatial training?

Three hypotheses were formulated to answer the three research questions pertaining to spatial visualization improvement, effectiveness of training method, and influence of gender. The three hypotheses are as follows:

a) Participants’ spatial visualization will improve significantly after spatial training.
b) Improvement gain in spatial visualization will be higher in i-DVEST training, moderate a-DVEST training, and least in conventional training.
c) Spatial Visualization improvement gain will be greater for male students compared to their female counterparts.

**Methods**

**Participants**

A class of technical education program comprising thirty-three secondary school pupils (13 girls and 20 boys, mean age = 15.5 years) of SMK, Kuala Kubu, Selangor, Malaysia volunteered to participate in this experimental study. Stratified sampling rather than simple random sampling was used as the sample did not have equal number of genders where the student class comprised approximately 40% girls and 60% boys. Proportionate allocation technique ensured that randomized assignment of students into groups would reflect the same male and female strata. Three groups were formed namely two experimental groups and one control group. The first experimental group (4 girls and 7 boys) trained in the interaction-enabled desktop virtual environment (i-DVEST), the second experimental group (4 girls and 7 boys) received training in animation-enhanced desktop virtual environment (a-DVEST), and the control group (5 girls and 6 boys) was exposed to conventional training.

**Instrument and Instructional Materials**

The spatial trainer developed by the authors contains spatial tasks specifically focusing on mental exercises tapping on spatial visualization. It is an integrated web-based application developed on desktop virtual environment containing virtual objects that serve as training objects for the spatial exercises. Instructional information were organized with questions and presented on the lower half of the screen and objects for training were presented on the top half of the same web page. The spatial trainer contains features that support training namely interaction via mouse-controlled VRML client, animations and response feedbacks. The first training condition was set to allow only navigation and exploration (operationalized as interaction) with the virtual objects and response feedbacks. The
second experimental condition involved training with animation and response feedback features. The control condition employed similar questions of the spatial exercise in the conventional way (i.e. printed material) supplemented with static graphics.

A computerized spatial visualization test based on the Spatial Visualization Test (Middle Grade Mathematical Project, 1983) was also developed by the authors to measure participants’ spatial visualization prior to and after training providing the pretest and posttest measures of this ability. The use of this instrument was qualified by the Cronbach’s reliability coefficients ranging from .72 to .88. The test comprises 32 multiple-choice items, which is to be completed in 15 minutes. Each item involves an object made up of small unit cubes seen from a certain perspective. Participants are required to determine which one of the five other objects is the same as the one depicted, but from another view. Scoring is based on the number of correct answers out of 32 possible and converted this to a percentage. In addition, a 12-item questionnaire with one open-ended question was administered to every student after the completion of the training. This instrument measured students’ perceptions on essential training factors namely training effectiveness, motivation and system usability (applicable to i-DVEST only). Each item response was rated along a Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly disagree) yielding a maximum 20 points for each factor. The open-ended question helped reveal greater insight about the training experienced by the students. A professor who has expertise in educational research reviewed the questionnaire and the researchers used reflective analysis to evaluate a phenomenon relying on intuition and judgment as recommended by Gall, Borg and Gall (2003). All the comments were translated from Malaysian language to English by the researchers.

Procedure

A multi-factorial pre-test post-test experimental (3 x 2) design procedure comprising two independent variables namely training method (3 levels: i-DVEST, a-DVEST, and control) and, gender (2 levels: girls and boys). The dependent variables in the study were the spatial visualization mean scores providing both the pretest and posttest measures. The training program was conducted for four weeks with the first used for computerized pretest on spatial visualization, administration of consent forms, briefing and familiarization of the training application. Actual training began on the second week involving two labs for the experimental groups and a classroom for the control group. Table 1 shows the training activities spanning the 4-week duration.

<table>
<thead>
<tr>
<th>Week</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pretesting, administration of consent form and task familiarization.</td>
</tr>
<tr>
<td>2</td>
<td>Spatial visualization training of low tasks.</td>
</tr>
<tr>
<td>3</td>
<td>Spatial visualization training of moderate task.</td>
</tr>
<tr>
<td>4</td>
<td>Spatial visualization training of complex task, posttesting, and administration of questionnaire</td>
</tr>
</tbody>
</table>

Each training session lasted for two hours with first session dealing with easy spatial exercises, moderately difficult exercises on the second session, and complex spatial tasks on the third session. Each exercise requires the participants to determine the correct solution among six choices for a given task (i.e., the correct number of blocks touching a target block contained in a stack of blocks). The authors and their subject teacher assisted in the supervision throughout the training sessions.

Participants in the i-DVEST condition initially worked through the spatial exercises by following the instruction posted in the questions and then interacting with the virtual objects via mouse control on the VRML client interface. The interactions involved panning, twisting, rotating, and rolling of the virtual stack of blocks providing multi-point viewing that enhances visual perception. Participants in the a-DVEST group performed the same spatial exercises as the first group except that the interaction mode was disabled. However, they could use the animation button to launch the animations to help them solve the spatial exercises. Each animation highlights individual blocks in contact with a target block and then shows the movement of the blocks one by one away from the target block (see Figure 2).
This effectively suspends the blocks in space effectively exposing the target block in its canonical position facilitating visualization of the tasks. The control group followed through the training by performing similar spatial exercises presented in printed materials containing similar instructional activities. Solutions to the spatial exercises comprise static graphics that show exploded views of the stack of blocks helping them in the visualization of the spatial configuration. The posttest was administered immediately after the completion of the final training session using the same computerized spatial visualization test. A short survey questionnaire was then administered to elicit information regarding participants’ perception on the effectiveness of the training they received.

Findings

The participants’ levels of spatial visualization (SV) were measured using the appropriate spatial measurement instruments prior to spatial training. The scoring procedure for SV was based on the percentages of correct responses. The mean score of the pretest for girls \((n = 13)\) and boys \((n = 20)\) were 42.38 and 47.55 summarized in Table 2.

| Measures               | Females | | | Males | | | |
|------------------------|---------|---|---|-------|---|---|
|                        | \(n\)   | Mean | SD | \(n\)   | Mean | SD |
| Spatial Visualization  | 13      | 42.38| 15.26| 20      | 47.55| 15.63|

Differences attributed to gender factor in spatial visualization were investigated prior to the treatments of spatial training. An independent samples t-tests were performed to detect if there were any gender differences among the participants in the study. For the spatial visualization pretest, the difference in mean scores of male and female participants was not statistically significant, \(t(31) = -0.94, p = 0.36\), establishing that the participants’ spatial visualization were equivalent prior to training. Descriptive statistics and univariate analysis of variance (ANOVA) were conducted to detect if there were significant differences among the three groups. The ANOVA procedure performed used the means scores of SV as the dependent variables and condition of training as the independent variables. Table 3 summarizes the descriptive statistics of the three groups.

| Measures               | Training condition | | | | |
|------------------------|--------------------|---|---|---|
|                        | i-DVEST | | | a-DVEST | | | Control | | |
|                        | \(n\)   | Mean | SD | \(n\)   | Mean | SD | \(n\)   | Mean | SD |
| Spatial visualization  | 11      | 53.36| 17.19| 11      | 40.00| 12.69| 11      | 45.52| 15.46|
For the pretest measure of SV, the 11 participants in the i-DVEST group had a mean of 53.36 (SD = 17.19); the 11 participants in the a-DVEST group had a mean of 40.00 (SD = 12.69), and the 11 participants in the control group had a mean of 45.52 (SD = 15.46). Table 4 summarizes the result of the analysis of variance for SV measure in the three groups.

Table 4: Summary of ANOVA for Spatial Visualization Pretest

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1072.061</td>
<td>2</td>
<td>536.030</td>
<td>2.445</td>
<td>.104</td>
</tr>
<tr>
<td>Within Groups</td>
<td>6576.182</td>
<td>30</td>
<td>219.206</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7648.242</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There were no significant differences between these groups prior to spatial training, \( F(2,30) = 2.45, p = .10 \). In other words, all the groups on the onset of this study were statistically equivalent in spatial visualization. After spatial training, the 33 participants had an average difference from pretest to posttest spatial visualization scores of 6.56 (SD = 6.54), indicating that the spatial training had improved their spatial visualization levels, \( t(32) = 5.76, p = .001 \) thus supporting the first hypothesis of the study.

Two-way analysis of covariance (2-way ANCOVA) was utilized to test the main effects of training condition and gender on spatial visualization, controlling the effects of prior spatial visualization. This statistical procedure also tested the interaction between training condition (i-DVEST, a-DVEST, control) and gender (girl, boy). The dependent variables, covariates, and independent variables were SV posttest measurements, SV pretest measurements, and gender and training condition respectively. The appropriateness of using this analysis was tested by first conducting the analysis using statistical model containing interaction terms between the covariates (i.e., the pretest mean scores of spatial visualization) and the independent variables to assess the assumption of homogeneity of slopes. The analysis of the ANCOVA to test this assumption is summarized in Table 5.

Table 5: ANCOVA results for differences in Spatial Visualization scores by training condition, gender, covariate and their interactions

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training condition</td>
<td>84.176</td>
<td>2</td>
<td>42.088</td>
<td>1.461</td>
<td>.251</td>
</tr>
<tr>
<td>Gender</td>
<td>7.917</td>
<td>1</td>
<td>7.917</td>
<td>.275</td>
<td>.605</td>
</tr>
<tr>
<td>Pre_Spatial Vis.</td>
<td>4047.715</td>
<td>1</td>
<td>4047.715</td>
<td>140.503</td>
<td>.000</td>
</tr>
<tr>
<td>Pre_Spatial Vis*Condition.</td>
<td>8.883</td>
<td>2</td>
<td>4.441</td>
<td>.154</td>
<td>.858</td>
</tr>
<tr>
<td>Pre_Spatial Vis*Gender.</td>
<td>29.735</td>
<td>1</td>
<td>29.735</td>
<td>1.032</td>
<td>.319</td>
</tr>
<tr>
<td>Error</td>
<td>720.218</td>
<td>25</td>
<td>28.809</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8241.061</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The interaction of the covariates (i.e., prior spatial visualization) with training condition that was used to test for homogeneity of regression for the spatial visualization test was not statistically significant, \( F(2,25) = .15, p = .86 \). The homogeneity of regression test for the interaction between the covariate and gender was also not statistically significant, \( F(1,25) = 1.03, p = .32 \). This indicated that the assumption of parallelism of slopes was met supporting the use of ANCOVA.

For the posttest measure of SV, the 11 participants in the i-DVEST group had an adjusted mean of 55.74 (SD = 16.83); the 11 participants in the a-DVEST group had an adjusted mean of 51.59 (SD = 11.44), and the 11 participants in the control group had an adjusted mean of 47.26 (SD = 12.83) as summarized in Table 6.

Results of the ANCOVA revealed a statistically significant main effect for training condition, \( F(2,26) = 15.53, p = .001 \) as shown in Table 7. Participants trained in i-DVEST outperformed others and participants in the a-DVEST were better than control group. To determine where the differences among the training methods were, Bonferroni’s Post Hoc Test was employed to test for significance. All tests were conducted using the adjusted means, controlling for any differences in prior spatial visualization ability.
Table 6: Observed Means, Adjusted Means, and Standard Deviations for Spatial Visualization after training by gender and training condition

<table>
<thead>
<tr>
<th>Gender</th>
<th>i-DVEST</th>
<th>a-DVEST</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Females</td>
<td>4</td>
<td>52.75</td>
<td>15.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(48.96)</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>7</td>
<td>70.79</td>
<td>14.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(62.53)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>64.23</td>
<td>16.83</td>
</tr>
<tr>
<td>obs. means</td>
<td>(55.74)</td>
<td></td>
<td>adj. means</td>
</tr>
</tbody>
</table>

Note: Adjusted means are presented in parentheses

Table 7: Analysis of Covariance of Spatial Visualization after training

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre_Spatial Vis.</td>
<td>4530.639</td>
<td>1</td>
<td>4530.639</td>
<td>394.957</td>
<td>.000</td>
</tr>
<tr>
<td>Condition.</td>
<td>356.262</td>
<td>2</td>
<td>178.131</td>
<td>15.528</td>
<td>.000**</td>
</tr>
<tr>
<td>Gender.</td>
<td>70.836</td>
<td>1</td>
<td>70.836</td>
<td>6.175</td>
<td>.020*</td>
</tr>
<tr>
<td>Condition * Gender.</td>
<td>453.209</td>
<td>2</td>
<td>226.605</td>
<td>19.754</td>
<td>.000**</td>
</tr>
<tr>
<td>Error.</td>
<td>298.252</td>
<td>26</td>
<td>11.471</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total.</td>
<td>8241.061</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05, **p<.01

The post hoc test for the training condition variable was tested at the pre-established alpha level of .05. The i-DVEST condition was compared to the a-DVEST condition revealing a mean difference of 4.156 and a significance of .048 that indicated that there was significant difference between the two training methods as depicted in Table 8.

Table 8: Bonferroni Post Hoc Test results by training condition

<table>
<thead>
<tr>
<th>(I) Training condition</th>
<th>(J) Training condition</th>
<th>Mean Difference (I-J)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental 1</td>
<td>Experimental 2</td>
<td>4.156*</td>
<td>.048</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>8.484**</td>
<td>.000</td>
</tr>
<tr>
<td>Experimental 2</td>
<td>Control</td>
<td>-4.156*</td>
<td>.048</td>
</tr>
<tr>
<td>experimental 1</td>
<td></td>
<td>4.328*</td>
<td>.022</td>
</tr>
<tr>
<td>Control</td>
<td>Experimental 1</td>
<td>-8.484**</td>
<td>.000</td>
</tr>
<tr>
<td>Experimental 2</td>
<td></td>
<td>-4.328*</td>
<td>.022</td>
</tr>
</tbody>
</table>

*p<.05, **p<.001.

The comparison of the i-DVEST condition with the control condition revealed a mean difference of 8.484 indicating a significant difference (.001) between the two types of training. A mean difference of .4.328 with significance level of .022 was found when comparing the a-DVEST and control training methods indicating a significant difference between participants’ spatial visualization in the two groups. Clearly, the post hoc test showed there were spatial visualization differences on all the three training conditions.

Similarly, there was significant main effect of gender, $F (1,26) = 6.18$, $p = .02$, favoring boys as shown in Table 8. The interaction between training condition and gender was found to be statistically significant, $F (2,26) = 19.75$, $p = .001$, indicating that the effectiveness of training method varied depending on participants’ gender. Figure 3 illustrates the trend analysis of adjusted mean spatial visualization performance scores by training condition and gender.
The intersection of the slopes shows that boys were better at spatial visualization tasks than girls for the i-DVEST condition. Both genders were equivalent in their spatial visualization after training in the a-DVEST condition. The same high performance of boys was not replicated in the control condition. In fact, female participants were better than their male counterparts were when trained using the traditional method as shown in Figure 3. In addition, data elicited from the questionnaire provides additional quantitative data (from the 12-item questions) and qualitative data (from the open-ended question). The followings are the mean scores for perceived training effectiveness indicating improved visualization: 13.50, 16.43, and 15.36 (for i-DVEST); 14.50, 16.71, and 15.91 (for a-DVEST); 14.40, 14.67, and 14.55 (for conventional). The followings are the mean scores for perceived motivation after training as reported by girls, boys, and all students: 12.25, 16.57, and 15.00 (for i-DVEST); 15.50, 16.29, and 16.00 (for a-DVEST); 13.60, 12.00, and 12.73 (for conventional). The mean scores for system usability of i-DVEST as perceived by the girls, boys and all respondents are 12.75, 15.57, and 14.55 respectively.

Ten of the thirty-three participants answered the open-ended question involving 5 participants (3 girls, 2 boys) in i-DVEST, 3 participants (2 girls, 1 boy) in a-DVEST, and two girls in the control group. Most of them indicated that their visualization has improved after going through the spatial visualization exercises.

**Discussion**

**Potential gender and group differences prior to spatial training**

Prior to training, all groups were equivalent in spatial visualization ability ensuring that resultant differential outcomes of the spatial training were attributed to the effects of the training methods. Gender parity was also observed where both boys and girls were equivalent in spatial visualization. This was not unexpected given that gender differences are minimally small in spatial visualization compared to robust differences in other spatial abilities especially in mental rotation (Halpern, 2000; Linn & Petersen, 1995; Maccoby & Jacklin, 1974). Another plausible reason is that boys and girls were from similar academic backgrounds that correlate well with their spatial abilities. Students involved in this study were drawn from a class of technology education program having good mathematics grades as one of the prerequisites for technical studies prescribed by the Malaysia’s Ministry of Education policy (KPM, 1998). Significant relations between mathematics achievements and spatial ability measures have been established suggesting that high spatial individuals were better in mathematics compared to low spatial individuals (Baenninger & Newcombe, 1995; Kulp, Earley, Mitchell, Timmerman, Frasco, & Geige, 2004; Tartrre,
1990). It is highly probable that there were no superiority of spatial abilities of one gender over the other since both genders were of similar level in mathematics. Seeing from a wider perspective, this finding may not be unique as gender differences on cognitive and psychosocial tasks are getting smaller and declining (Hyde, 2005; Linn & Hyde, 1989).

The effects of training method and gender on spatial visualization training

Comparison of mean scores of spatial visualization before and after spatial training for all groups indicates that the participants have considerably improved their spatial ability. This suggests that spatial training in the three training have improved their spatial visualization thus lending support for the first hypothesis. This finding was further qualified from the data elicited from the self-reported questionnaire indicating all participants did agree that their visualization have improved after engaging in spatial exercises. Additionally, the qualitative data helped explain this result. The major responses of the participants particularly i-DVEST for the open-ended question revealed that interacting with the training objects enables better comprehension of the spatial configuration of stacked blocks in space. Phrases such as “I can see more clearly from this view”, “It helps when I picture it in my mind”, “Viewing from several angles is helping me”, and “rolling and twisting the objects exposes hidden faces” are indicative of better visual perception leading to improved visualization.

Further examination revealed that there was a significant main effect of treatment condition of spatial training thus supporting the second hypothesis. Post hoc test analysis revealed that the greatest performance difference was between i-DVEST group and control group. The difference in spatial visualization between i-DVEST group and a-DVEST group was also quite substantial. The a-DVEST group was better than the control group indicating that spatial training was less effective in the conventional training method. The statistical analysis also lends support for the third hypothesis favoring the boys. In addition, there was a substantial interaction between method of spatial training and gender was observed where a pattern emerged indicating the convergence and divergence of performance measurements of girls and boys respectively (see Figure 4). Boys tended to gain differential level of improvement gain in spatial visualization based on different training conditions whilst girls were more likely to improve irrespective of training method used.

Spatial training in i-DVEST condition

The effectiveness of i-DVEST compared to the other two methods of spatial training only manifested for male participants. Girls in the same group were comparable insofar to the other two groups. In fact, when comparing the means of spatial visualization posttest scores, girls in the experimental group attained the lowest performance across all groups. The high degree of interaction in the i-DVEST had benefited male participants since this feature was absent in other types of training. In solving the spatial visualization tasks, users were able to interact with the virtual objects by panning, twisting and rolling in the interactive desktop virtual environment giving multiple viewpoints thus facilitating the visual perception and processing of objects in 3D space. Learners could view these objects from close up or from a distance when examining specific and holistic features of the artifacts respectively concurring with Smith’s (2001) study that suggested alternating between interaction and observation was the best way to learn spatial visualization. Although there were no significant gender differences in spatial visualization, boys were more superior then girls in this cognitive ability influencing the effort put in when learning in i-DVEST. Heeter (1994) found that boys generally were more interested in VR learning experiences with interaction compared to girls. Similarly, Ziemek’s (2006) indicated that gender has an influence on how attracted an individual is to the electronic games. Three-dimensional (3D) and two-dimensional (2D) electronic games are most appealing to boys and girls respectively. Boys probably were more adept at moving around in virtual environment and interacting with the virtual objects due to their superior spatial ability compared to girls. Observations during the training paralleled her finding indicating that boys were far more active in exploring i-DVEST than girls were. This gender influence was qualified by the qualitative data from two female respondents’ comments (e.g., “need time to get used to using the interface” and “it’s not that straight forward to have a good scene”) pointing out that navigating the virtual training environment can be quite daunting for them. In contrast, a male respondent’s comment (e.g., “I found it engaging to do the exercises in this setting”) seemed to reinforce the gender gap in virtual environment. From the constructivist perspective, the training process seemed to have helped boys trained in i-DVEST to continually construct and refine the correct mental schema of the solutions of the spatial problems. Most revealing comment (e.g., “If I committed an error or got confused, I can get back to and navigate the scene till it becomes more meaningful”) was from one male
respondent indicating that when he committed an error, he could always return to view the training objects from other directions thus avoiding further errors. Clearly, this learner’s comment demonstrates evidence of accessing prior experience and comparing his flawed understanding to new experience in the training environment indicative of a constructivist training. This mode of training effectively allows him to revise and refine his imperfect mental model by making correct inferences resulting in enriched experience. Additionally, participant motivation elicited from the questionnaire indicated that boys rated the novel training higher than girls did. Studies have shown that motivation influenced the level of engagement in task thus affecting performance.

Spatial training in a-DVEST condition

The second most effective in spatial visualization training was the condition of training in a-DVEST with animation features. Participants utilizing these features gained better insights and understanding of tasks that demand visual perception and cognitive processing based on spatial visualization. Animations were used to fulfill a cognitive function where in this role they support students’ cognitive processes that ultimately make them understand the subject matter better (Love, 2004). Qualitative data from two girls’ responses (e.g., “animations help!” and “the steps are clear”) suggest that animations serves as a cognitive tool to facilitate them seeing the proper steps that they could replicate in their minds during problem solving. These two girls and a boy indicated that they found the animated feature to be helpful especially in solving difficult tasks. The set of spatial tasks designed in this study requires the participants to solve problems associated with stack configurations composed of regular rectangular block. In determining the number of blocks making contact with a target block, the participants have to visualize the blocks in terms of their positions and relations in the 3D space. Animations for the relevant virtual blocks are launched when each will be highlighted (i.e., changing into flashing color) in its position in relation to the target block and then moves away from the target block. This allows participants to observe the target block positioned in space and its relation to the moved blocks. Apparently, the effect of these animations might have facilitated the externalization of the internal visualization process that the participants would invoke in solving the spatial visualization tasks that consequently lessens the cognitive effort in problem solving. Spatial training enhanced with animations seems to benefit both male and female participants in this study where their performances in this group were equivalent.

Spatial training in conventional condition

Another interesting trend in the interaction between training condition and gender was observed in the control group. Girls in this group exhibited higher spatial visualization compared to boys. In fact, male participants in this particular group showed the lowest improvement in spatial visualization among all groups that warrants some explanation to this unexpected finding. The conventional training required participants to work through a similar set of questions in printed exercise worksheets complemented with solutions of the tasks consisted of ‘exploded views’ of the blocks. This type of training was found to advantage boys since earlier study by Geiger and Litwiller (2005) noted that gender differences were found for question answering information from diagrams but not for textual information. The fact that male advantage was not replicated in this setting may be attributed to motivational rather than cognitive construct as indicated by low perceived motivation in the self-reported questionnaire. Girls’ motivational scores of the questionnaire were almost similar with other training conditions reflecting consistent interest and level of effort they invested in training. However, the boys reported lower perceived motivation as they reported learning based on printed materials were less appealing consequently undermining effort to practice. In addition, girls were observed to spend more time practicing on the task compared to boys.

Conclusions

Several important findings emerged from the discussion revealing insights in spatial visualization training are summarized as follows:

a) Spatial visualization training in interaction-enabled desktop virtual environment (i-DVEST) was the most effective where the participants had made substantial improvement. Interactions with the virtual objects provides better visual perception of spatial arrangements of the spatial tasks that leads to better visualization especially for boys. On the other hand, the lack of prior computer experience or familiarization and a slight disadvantage in spatial ability might have confounded girls’ performance in training requiring a high degree of interaction and
navigation. Consequently, girls might have not experienced better visual cues and visualization of the task that led to higher cognitive effort to imagine these spatial configurations leading to poor problem solving ability.

b) Animation-enhanced desktop virtual environment (a-DVEST) training was the second most effective in spatial visualization. Animations of the tasks provide the perceptual cues of the spatial arrangements of the spatial problems leading to improved visualization. Both genders benefited in this training setting indicating that animation helped minimize the cognitive effort to visualize the spatial tasks. Training with animations seemed less cognitively challenging that the above method of training.

c) Conventional training relying on printed materials was least effective among the three methods of training. Poor representation of training objects of 3D into 2D dimensional format minimizes cognitive correspondence between the two representational methods hindering visualization of the spatial tasks. Girls gained relatively higher SV improvement than boys that might be partly attributed to motivational factor as the latter were found to be less enthusiastic in training in this condition. Lack of motivation induced less commitment to engage in training leading to poor performance.

The outcomes of the research may contribute positive educational values in actual teaching of courses in technology education that rely on spatial intelligence or spatial skills. This is particularly importance in the learning of technical graphics (i.e., engineering drawing), computer aided design (CAD), engineering design, and mathematics. Significant positive correlation between technical graphics and spatial visualization has been consistently reported in the literature of spatial training indicating the strong emphasis of developed skills of the latter for successful learning of the former. Students with low spatial ability namely spatial visualization taking technical graphics are most likely at risk in learning the subject matter thus impeding their success. Interventional or remedial programs can be instituted employing technology-driven learning or training tools such as iDVEST to help improve students’ spatial visualization.

Technical graphics course conducted in selected Malaysian schools encompasses one-and-half hour teaching session followed by a 2-hour lab practice session per week. The application of such tools can be embedded into normal lab practice sessions for spatial training of 30-45 minute duration spaced evenly throughout a semester enabling low spatial students to engage in constant practice to help develop their spatial skills. Through this gradual development of spatial skills, these students will be able to learn the subject matter with greater efficacy as they may have attained the proper and efficient strategy in solving technical graphic tasks or problems that are spatial in nature.

The applicability of this study is quite limited given the size of the sample used. Inevitably, the study used the only available class of technology education study in the selected school that is typical in most Malaysian schools. In addition, the authors were only allowed four weeks to conduct the study where gender differences were observed. Future research should use substantial sample size and longer training duration to improve generalizability and address gender difference respectively. Overall, the study has shed some light regarding the effectiveness of an interactive desktop virtual environment as a training platform for spatial visualization. High degree of interaction coupled with programmed dynamic behaviors of virtual objects and feedback mechanism can enrich the training process. However, a cautionary approach to utilizing this training method is advised. An intricate interplay between gender and method of training has been observed entailing careful selection of appropriate objects and tasks, method of instructional delivery and training environment in spatial training.

References


Middle Grade Mathematical Project (1983). *Spatial visualization test*, Department of Mathematics, Michigan State University.


