ENHANCING A LOW-COST VIRTUAL REALITY APPLICATION THROUGH CONSTRUCTIVIST APPROACH: THE CASE OF SPATIAL TRAINING OF MIDDLE GRADERS

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ABSTRACT
The aim of this study is to develop and to test a low-cost virtual reality spatial trainer in terms of its effectiveness in spatial training. The researchers adopted three features deriving from the constructivist perspective to guide the design of the trainer, namely interaction, instruction, and support. The no control pre test post test experimental procedure was used as the research design involving a sample, which comprised a class of 35 middle graders (15 girls and 20 boys) with mean age of 15.5 years. The researchers hypothesized that there would be a significant improvement in spatial visualization after training and the three training attributes would receive different ratings from the participants. The research instruments used were Spatial Visualization Test (for pre-testing and post-testing) and usability survey questionnaire. The participants used the trainer for four consecutive weeks, with each session lasting for three hours. Data collected were analyzed using Statistical Package for Social Science (SPSS). Result of a paired samples t-test indicated that the participants had made significant improvement after training, thus supporting the first research hypothesis. However, the results of independent samples t-test did not support the second hypothesis, where all the three training features were rated equally. Interestingly, subtle but significant orientations were detected, where the instructive and interactive features were rated differently by girls and boys, respectively. The researchers also discuss the practical implications of the low-cost virtual reality application for spatial training by proposing a set of design guidelines.

Keywords: constructivist principles, instruction, interaction, low-cost virtual reality, support, spatial visualization.

INTRODUCTION
Virtual Reality (VR), a term coined by Jaron Lanier, has become a niche in selected fields, notably in military (Wilson, 2008), architecture and engineering (Mobach, 2008), avionics and entertainment industry (Craig, Sherman, & Will, 2009) Typically, this technology enables a user to interact with computer-generated, synthetic three-dimensional (3-D) environment through interactive devices, engendering a sense of presence (Coelho, Tichon, Hine, & Wallis, 2006). Users' movements are continuously tracked in real time by motion sensors, thus updating all the related sensorial feedback, notably visual input, that immerse them in the artificial world such as touring a virtual museum. What used to be a prohibitively expensive technology – mostly enjoyed by a few elite sectors – is now making inroads in other fields, notably educational domain. The wider VR adoption is made possible through advances in computing technology in terms of processing speed and multimedia capability, in particular desktop platform, which effectively lower the cost of ownership, making it possible even for a decent elementary school to own such a novelty. The appeal to use desktop VR in schools owes to its cost-effective implementation that can help teachers and instructors to improve pupils' learning achievements by capitalizing on cognitive and affective domains of learners (Lee, 2011). Evidence supporting the effective use of low-cost VR applications in challenging scenarios is also appearing gradually in the literature, where for instance, a case

involving several physically challenged patients who had received rehabilitative training managed to recover their motor ability successfully (Sung, Chiu, Chen, Tsai, & Henrich, 2011).

Lately, in the educational realm, desktop VR has been used to train students for a variety of reasons; however, one particular theme seems to dominate the studies, namely spatial visualization. One reason for this focus on spatial ability training may be due to its importance in engineering (Russell & Churches, 2010), science (Clement, Zietsman, & Monaghan, 2005; Wai, Lubinski, & Benbow, 2009) and mathematics (Presmeg, 2008). Once an obscured cognitive concept, spatial ability is now recognized to be one of the important intellectual constructs in humans. The imperative to study this ability is best captured through the world renowned educational psychologist Howard Gardner's book titled *Frames of mind: the theory of multiple intelligences*. Spatial intelligence is one the multiple intelligences that concerns one's ability "… to recognize and use the patterns of wide space and more confined areas" (Gardner, 1983 cited in Smith, 2008). Gardner's treatise asserts that educators should not only focus teaching on the development of linguistic and logical-mathematical abilities, but efforts should be invested to develop other abilities as well, including spatial intelligence (Smith, 2008). In addition to the term spatial intelligence, the literature is replete with many definitions (e.g., spatial thinking, spatial cognition, and etc.) that complicate discussions; however, all researchers agree that this ability is an amalgam of several interrelated sub-abilities or dimensions such as mental rotation, spatial visualization, and spatial perception (Linn & Petersen, 1985). Another focus of debates revolves around the nurture versus nature in the development of spatial ability, and the evidence gleaned over the years suggests that persons with poor spatial ability can be trained to improve their spatial skills through training (Alkan, 2011; Mohler, 2008; Rafi & Khairulanuar, 2009). These encouraging findings have a crucial implication in that low spatial skill pupils can be treated. In today's training realm that is dominated by electronic learning approach, gender factor is likely to favor boys than girls because the former have more experience and expertise in technology (Islam, M. A., Abdul Rahim, N.A., Liang,T.C. & Momtaz, H., 2011). In the context of training in virtual environments, boys may have greater advantage than girls because the former have greater familiarity with virtual stimuli, leading them to a greater acceptance of the virtual world (Felnhofer, Kothgassner, Beutl, Hlavacs, Kryspin-Exner, 2012). In view of these potential threats, training has to be based on appropriate design principles to cater the needs of users from a diverse background (Rafi & Khairulanuar, 2010). In this regard, any application to be used for spatial training should be guided by a theoretical framework to make it sound and worthy. Failing to adhere to any sound theoretical underpinnings to guide the development of training application may result in spurious learning rather than effective learning (Nworie & Haughton, 2008). In light of the issues discussed, the researchers undertook this study primarily to answer the following research questions as follows:

a. Will the participants' spatial visualization improve after training in the DVR trainer?
b. What are the participants' perceptions of the features of the DVR trainer?

To address the research questions, two research hypotheses were formulated as follows:

a. There will be a significant difference of the participants' spatial visualization before and after training.
b. Participants' perceptions of the constructivist features of the DVR trainer will differ significantly.

THE APPLICATION OF CONSTRUCTIVIST ELEMENTS IN THE DEVELOPMENT OF THE SPATIAL TRAINER

Emerging affordable technologies, such as desktop virtual reality (DVR), have been gaining wide acceptance by the training communities across the globe. Lately, DVR is getting more and more prominent due to the pervasive use of the universally accepted 3D scene format *Virtual Reality Modeling Language* (VRML) by the Internet communities worldwide that can create virtual environments that are deliverable over the World Wide Web (Beier, 2000). The wide adoption of this relatively low cost technology that runs on desktop computing platform has its reasons: improved processing power, enhanced graphics, and lower total cost of ownership. However, the use of this technology has to be carefully planned to optimize its capability. The use of the technology for training must be carefully considered in relation to two vital issues: one relating to the needs for appropriate level and style of contents; and the other relating to the needs to use the right software and delivery mechanisms (Beier, 2000; Fernie & Richard, 2003). More importantly, the development of any training application must be informed through current theories of learning to ensure that its implementation will be able to achieve its stated goals through optimizing the training or learning process (Hudak, 2007). In this study, spatial training to improve spatial visualization must be planned accordingly using appropriate or authentic tasks that tap on the required cognitive functions. Training must be designed such that it evokes spatial strategy – rather than analytical strategy – when solving spatial tasks. For this reason, the researchers developed the spatial trainer in the form of a 3D virtual environment, consisting of three features to foster effective training, namely spatial exercises, interactive 3D virtual objects, and feedback; the three elements were designed along the constructivist perspective that emphasizes on instruction, interaction, and support, respectively (see Table 1).

The appropriate use of training objects to be utilized was informed by reviewing the items of the psychometric test battery. Spatial ability tests have been developed by many cognitive psychology institutions to be utilized as part of intelligence and employment assessments. These tests possess strong validity and reliability measures for the cognitive-psychological constructs such as spatial visualization. Appropriate items of the tests were first reviewed, and then they were developed into training objects as part of the instructional materials that participants used for spatial training. A constructivist framework was used in the design of the training application based on the constructivist interpretations by Moshman (1982) in which he categorizes constructivism into three distinct classes: endogenous, exogenous, and dialectical principles. Firstly, endogenous principle stresses on individual nature of each learner's knowledge construction process relegating the role of teachers to facilitators. Secondly, exogenous principle underscores the formation and refinement of knowledge representations through learning by instructions with support from exercises entailing active cognition. Thirdly, dialectical principle espouses learning through realistic experience coupled with essential scaffoldings. In designing the trainer, the researchers conceptualized these three principles as being the interactive, instructive, and supportive features, respectively. These features serve as the theoretical underpinnings of the trainer that were realized in the DVR platform. Table 1 shows both the theoretical underpinnings (to guide the design of the trainer) and practical considerations (to help develop the trainer).

Table 1. The conceptual framework of the spatial trainer

Theoretical underpinnings:		**Practical implementation aspects:**		
Constructivist elements:	Attributes of training:	Essential features:	Enabler:	Enabling technology:
Endogenous	Individual nature of learner's knowledge construction process	*Interactive*	Training Scene: 3D objects and navigational tools	Desktop VR
Exogenous	Formation and refinement of knowledge representations	*Instructive*	Spatial exercises: Spatial Visualization	XML
Dialectical	Training through realistic experience coupled with essential scaffoldings	*Supportive*	Cognitive tool: Animations and Feedback	Desktop VR + XML

The spatial trainer provides a series of exercises to improve spatial visualization by solving spatial tasks consisting of 3D regular blocks (see Figure 1). Each exercise consists of a question with several options that are presented in textual format, and the 3D blocks are presented as virtual objects. Interactions with the 3D blocks are performed using a mouse-controlled DVR interface. Animations of the virtual objects are made available as a cognitive tool to assist users by providing them with correct spatial solutions. Feedback mechanism is also available to inform users the status of their responses. This feedback is vital because users can learn their current state of knowledge in order to lead them to develop new strategy for the next step of learning. Figure 1 shows a snapshot of the spatial trainer with the learning features as discussed.

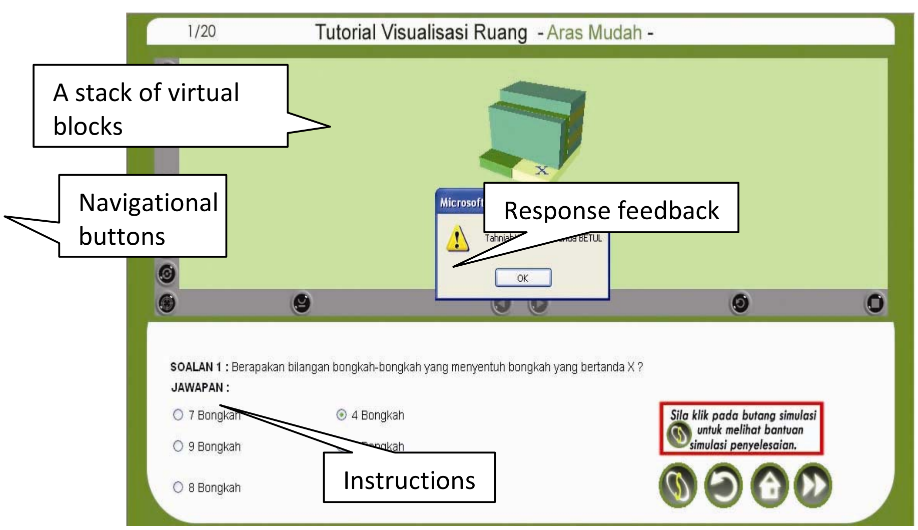

Figure 1. The spatial visualization exercise of the spatial trainer

RESEARCH METHOD

The research used a no control group pre post test research design and a survey research method to answer the first and second research questions, respectively. Details of the implementation of both research methods are as follows:

Participants

The sample of the study was derived by a convenience sampling involving a class of 35 middle graders whose mean age was 15.5 years. The sample comprised 15 girls and 20 boys who were average academic achievers. Their participation was secured through personal contact of the first researcher with their class teacher. The pupils were assured that they could drop out from the study at any time, if they wished to do so.

Training Application and Research Instruments

The training application used by the participants was the spatial trainer developed by the researchers as discussed. The spatial trainer contains a series of spatial exercises that are divided into three classes: low, moderate, and high levels of difficulty. The levels of difficulty are based on the density and configuration of the stacks of virtual block. The research instruments were the Spatial Visualization Test developed by the Mathematics Department of Michigan State University for the Middle Grade Mathematics Project (MGMP-SV) (1981) and the usability survey questionnaire developed by the researchers. The MGMP-SV comprises 32 multiple-choice items, each with five options. The test contains 10 different types of items. The types of representations used are as follows: (a) 2D- flat views, (b) 3D-corner views, and (c) a "map plan," which depicts the base of a building using numbers within squares to indicate the number of cubes to be placed on each spot. The reliability of this instrument is reasonably high, having Cronbach's alpha coefficients ranging from .72 to .88. The second research instrument contains 15 items, with 5 items to measure each of the constructivist features of the spatial trainer. Each question asked the participants to provide their level of agreement along 5-point Likert scales, ranging from '1' (*strongly disagree*) to '5' (*strongly agree*). Internal consistency computed for this instrument showed reasonable reliability, having attained a Cronbach's alpha coefficient of .77.

Procedure

The participants trained for 12 hours throughout the study, spread equally for four consecutive weeks. Spatial training was done with simple exercises in the first week, then followed by moderate exercises on the second week, and ended with complex exercises on the third week. Pre-testing and post-testing were carried out using the MGMP-SV, which was administered to the participants immediately before and after training to measure their spatial skills. The usability survey questionnaire was also administered to the participants after the training was completed in the final week.

FINDINGS

Data collected were analyzed by using the Statistical Package for Social Science, SPSS version 19.0 to provide both the descriptive and inferential statistics. For the measurement of spatial visualization before training, the participants attained a mean score of 16.26 (SD = 3.11), where the mean scores of the 15 female and 20 male participants were 16.13 (SD = 3.07) and 16.35 (SD = 3.22), respectively. For the measurement of spatial visualization after training, the participants attained a mean score of 21.60 (SD = 2.78), where the mean scores of the 15 female and 20 male participants were 21.13 (SD = 3.11) and 21.95 (SD = 2.52), respectively. Analysis based on *paired-samples t-test* showed that the difference between the pre- and post-measurements of spatial visualization was significant, $t(34) = 24.65$, $p = 0.001$ (see Table 2).

Table 2. Means and std.deviations of the pre-test and post-test scores

Gender	Spatial visualization test scores			
	Pre-test		*Post-test*	
	Means	SD	Means	SD
Females (n=15)	16.13	3.07	21.13	3.11
Males (n=20)	16.35	3.22	21.95	2.52
All (N=35)	16.26	3.11	21.60	2.78

Statistical analysis performed on data collected from the survey showed that for interactive feature of the trainer was reasonably high, the 15 female and 20 male participants ascribed mean scores of 3.27 (SD = .30) and 4.60 (SD = .68), respectively. In total, this interactive feature attained a mean score of 4.03 (SD=.98) from all the participants. For the supportive feature of the spatial trainer, the mean scores received from the 15 female and 20 male participants were 3.60 (SD = .74) and 3.55 (SD = .66), thus attaining an overall mean score of 3.57 (SD=.70) from all the participants. Likewise, for the instructive feature of the spatial trainer, the mean scores received from the 15 female and 20 male participants were 4.27 (SD = .80) and 3.45 (SD = .69). Thus, this feature received an overall mean score of 3.80 (*SD*=.83) from all the participants. Table 3 below summarizes the findings of the rating received from all the participants pertaining to the three feature of the training environment.

Table 3. Means and std.deviations of participants' perceptions of spatial trainer's features

Gender	Training features					
	Interactive		*Supportive*		*Instructive*	
	Means	SD	Means	SD	Means	SD
Females (*n*=15)	3.27	.80	3.60	.74	4.27	.80
Males (*n*=20)	4.60	.68	3.55	.69	3.45	.69
All (*N*=35)	4.03	.98	3.57	.70	3.80	.83

A series of independent samples t-tests were also performed to determine whether there were significant differences among the ratings of the three features of the spatial trainer. The difference between the ratings of the interactive and supportive features was found to be non-significant, $t(68) = 1.24$, $p > 0.1$. Similarly, the difference between the ratings of the interactive and instructive features was found not significant, $t(68) = .29$, $p > 0.1$. Likewise, the rating of the supportive feature did not differ significantly from the instructive feature, , $t(68) = .22$, $p > 0.1$. In essence, the three features of the trainer were equally rated by all the participants in this study. The researchers also performed similar tests to detect significant differences among the three features across gender. There was a significant difference in the ratings of the interactive feature between female participants (Mean=3.27, *SD*=.80) and male participants (Mean=4.60, *SD*=0.68); t (27)=5.20, $p = 0.001$. Likewise, there was a significant difference in the ratings of the instructive feature between female participants (Mean=4.27, *SD*=.80) and male participants (Mean=3.45, *SD*=0.69); t (28)=3.17, $p = 0.01$. However, was no significant difference in the ratings of the suppotive feature between female participants (Mean=3.60, *SD*=.74) and male participants (Mean=3.55, *SD*=0.69); t (29)=.20, $p > 0.1$.

DISCUSSION

Before training, participants' spatial visualization was slightly above the average level; however, after training their spatial visualization improved significantly. Comparison of the difference between their spatial visualization before and after training showed that they had improved by almost twice the standard deviation of this spatial ability. Thus, this finding supports the first research hypothesis of the study, which demonstrates that this spatial ability is malleable to training. This finding strongly supports the use of DVR technology as an alternative technology, which is affordable and equally effective, that is comparable to other expensive cutting-edge technologies. More importantly, the finding reinforces the imperative of instructional design in the development of training applications. Laid on a strong theoretical foundation, training can become efficacious as learners will be cognitively primed in the appropriate 'frame of mind' to discover and utilize concepts related to a particular task being performed.

For the second part of the analysis, the finding of the inferential analysis indicates that all the three training features (i.e., interactive, instructive, and supportive attributes) were equally important on a moderate level as reported by the participants in the study. Hence, there is no evidence to support the second research hypothesis – all the three training features were deemed relevant without any element superseding the others. However, the comparison of these training features based on gender showed interesting results. In general, male participants tended to rate the interactive feature higher than their opposite counterparts. In this study, spatial training normally involved a series of steps to be performed by the participants: reading the instructions and questions (instructive feature), interacting with virtual 3D objects (interactive feature), and, when necessary, using animations (supportive feature) to show the correct spatial solutions. In addition, anecdotal evidence based on the authors' observation during training sessions indicates that male participants were engrossed in navigating the virtual environment. In contrast, female participants used the interface very cautiously, probably because of their inherent nature to be meticulous and vigilant before committing effort to carry out a task. In addition, this cautionary approach may also reflect poor navigational skill of female participants compared to male participants. This problem will be more pronounced as the spatial tasks in DVR environment become more complex, which will disadvantage female students (Ausburn, Martens, Washington, Steele, & Washburn, 2009), whereas males will be able to capitalize on such a setting given ample evidence that suggests the boys have greater familiarity and experience in computer-based media such as video games (Adamo-Villani, Wilbur, & Wasburn, 2008). For the instructive feature of the trainer, female participants rated this feature significantly higher than their counterparts. This finding suggests that information (in written form) is critical to female learners in performing tasks that require clear, precise instructions. Similar argument asserted previously (females being heedful to details) may also apply to partly explain the tendency of female learners to rate the instructive feature higher than male learners. This finding is hardly surprising given that female students, in general, pay more attention to details and are more cautious than male students (Meit, Borges, Cubic, & Seibel, 2007). Finally, the supportive feature of the trainer (in the form of animations) was moderately and equally rated by both gender; thus, this feature provides cognitive scaffolding to learners irrespective of their biological background. This finding is congruent with Sanchez and Wiley's (2010) finding that showed animations had helped eliminate performance differences between girls and boys in learning scientific concepts. From the cognitive perspective, a solution being shown as an animation helps the learner to better construct their understanding through improved visual input. Based on the findings of this research, the researchers propose a set of design guidelines that may help instructional designers, multimedia developers, and trainers in the development of spatial training applications based on the DVR platform as explained below.

The guidelines for developing a desktop virtual reality trainer

i) Determining the specific training in appropriate spatial ability dimension

The first step involves identifying the specific components of spatial ability that are required for training. This is important given the multi-facet nature of spatial ability consisting of several distinct but overlapping components. Failure to address this step may risk successful outcomes of spatial training as the training activities will be too generic rather than specific. This first stage is essential as it paves the way for instructional designers to search appropriate learning or training objects to be used by learners as required in the ensuing steps. As demonstrated in this study, training spatial visualization will entail specific objects that are not only unique but efficacious in enhancing the intended skills or ability.

ii) Selecting the appropriate training objects for spatial training

There are a range of test batteries for spatial ability, namely mental rotation, spatial visualization, and spatial perception. Many items of spatial ability have been developed and tested that show high reliability and validity. Thus, using the test items as objects for spatial training will ensure spatial activities or tasks carried out by learners will tap on the precise mental reasoning for the construct to be trained or learned. This strategy of selecting training objects is not only reliable, but it can save time as developing new training objects is time-consuming and risky. The selected test items can be developed into training objects that can be interacted, animated, and interrogated during training to enrich the training experience. Hence, learners can become proficient and skillful in performing the intended tasks. In this research, the training objects were stacks of 3D regular blocks in virtual environment. Using the DVR interface, learners could navigate the 3D environment in many ways that will be perceived as rotations and translations, giving a sense of control and presence.

iii) Developing the appropriate instructional approach for spatial training

The third step is a very critical stage in determining the appropriate instructional and/or pedagogical approach to be employed in training. Identifying the proper instructional training setting at this stage will require an understanding of current theory of learning. There are several learning theories and their numerous variants, but essentially they can be categorized along a continuum of two opposite poles, namely instructivist and constructivist perspectives. Experience gained from the research suggests using a mix of the two paradigms where the former can help develop focused training activities through clear training goals and instructions, while the latter can help learners in knowledge construction through active participation in the training process. At this stage, the researchers propose the following steps, which involve the development of the appropriate instructions, organization of training units, and sequence of training tasks as listed below.

a. Developing clear, precise instructions to be followed by the learners prior to engaging spatial exercises will entail communicating and explaining the training objectives that learners should focus on in order to achieve those goals after the completion of spatial training. Having a clear understanding of what learners are expected to achieve after training will help them concentrate on the spatial tasks to be solved.
b. Organizing the training objects into training units with appropriate instructions that are structured and ordered will need careful analysis of the spatial tasks in terms of the level of difficulty. Then, questions should be crafted carefully that ask learners to derive the solutions by making use of the training objects. Ideally, training units or modules should be categorized into simple, moderate and complex spatial tasks.
c. Sequencing the tasks of spatial training will entail solving the simple tasks first, then progressing to the moderate tasks, and finally completing the complex tasks. The duration of the spatial training for the tasks will not necessarily be the same because the degrees of difficulty of the tasks are different. Some spatial training may need more time to practice, particularly for tasks where performance measures are not only based on accuracy but also speed or reaction time in solving the spatial problems.

i) Developing the appropriate environment for spatial training

The fourth step of the design process entails the creation of an environment for spatial training that can transform the spatial tasks containing training objects into a convenient form. There are important technological and financial considerations at this stage as developing a particular training environment needs to intricately balance these two main factors. The level of sophistication of training application will affect the cost of procurement and ownership, whhich can be prohibitive for schools. The experimental research of this study demonstrates that even a low cost training application can be effective for spatial training that is applicable in school context. In this research, a desktop virtual environment was created containing 3D objects, navigation interface, text-based instructions, and animations. The effectiveness of any training application is not solely dependent on the degree of technology wizardry, but instructional strategy plays a crucial role in training.

ii) Establishing the level of sophistication for the training environment.

Three factors that can help application developers to select an appropriate training platform are the adoption of the development tools, time to develop the intended application, and training to use the application by the intended users. Experience from the experimental research suggests that the use of non-immersive DVR technology is affordable for schools. The development time of the training objects and environment of the DVR application will be manageable. Training or learning curve to use such an application is not steep as no specialized input and output devices will be used. For spatial training to be highly effective the correspondence of the virtual training objects and environment should be as close as possible to the real life situation – the higher the correspondence the greater the impact of spatial training. Several technological aspects that are important to address this requirement are the levels of immersion, interaction or navigation, and realism. Each of the three factors lies on a continuum of a dimension between low and high extremes. The combination of the three dimensions will engender a sense of presence for learners when they use such a training environment. Higher sense of presence will engage learners to train more effectively. The level of immersion is typically low in DVR and very high in immersive VR that are associated with special data gloves and head-mounted gear. Interaction in a virtual environment ranges from simple navigation using the desktop mouse to highly complex navigation using gestural- and voice-based inputs. The level of realism of the virtual artifacts and environment can be programmed to low level using shaded objects or to high level using rendered objects. Thus, these factors need to be considered when creating such an training environment not only from the technological aspect but also from the financial aspect as well. In summary, we acknowledge that the findings of this study have to be interpreted with caution given its small sample size. Nonetheless, the methodological approach of this research can be used again by using a larger sample size to improve the generalizability of future research. Despite this limitation, which precludes generalization to a larger population, we strongly believe that the findings do shed some light with regard to the use of DVR to improve spatial visualization. In this study, the reseachers have demonstrated that a subset of spatial ability, namely spatial visualization is malleable to training. In addition, the training of this ability is realizable through an affordable, less expensive system, notably the DVR technology, which provides greater opportunity to instructional developers and training personnel to carry out spatial training for their employees, staff or students. More importantly, the findings of this research highlight the major implications of adopting well-establised theoretical principles (i.e., interactive, instructive, and supportive elements) to guide the development of a spatial trainer so that training can be efficacious. Finally, the lessons learned from the study helped the researchers conceive a set of guidelines to guide the development of such a spatial trainer based on the DVR platform.

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