Are Spatial Visualization Abilities Relevant to Virtual Reality?

Chwen Jen Chen (Dr)
Faculty of Cognitive Sciences and Human Development
Universiti Malaysia Sarawak
E-mail: cjchen@fcs.unimas.my

Abstract

This study aims to investigate the effects of virtual reality (VR)-based learning environment on learners of different spatial visualization abilities. The findings of the aptitude-by-treatment interaction study have shown that learners benefit most from the Guided VR mode, irrespective of their spatial visualization abilities. This indicates that the VR-based learning environment is able to serve as a promising medium to accommodate individual differences in terms of this aptitude.

Keywords:
virtual reality, spatial visualization ability, aptitude-by-treatment interaction, learning environment

Are Spatial Visualization Abilities Relevant to Virtual Reality?

Aptitude-by-treatment interaction (ATI) research investigates the effects of learner aptitudes and traits on learning outcomes from different forms of instruction (Cronbach & Snow, 1969; Berliner & Cahen, 1973). The major assumption of this kind of research is that it is possible and desirable to adapt the nature of instruction to accommodate individual differences in terms of ability, style or preference to improve learning outcomes. Indeed, research concerning individual differences in the context of VR is still at its infancy. Chen, Czerwinski, and Macredie (2000) reports an overview of some approaches and major findings of various research studies concerning the effects of individual differences on the use of this new technology. However, most of these studies focus particularly on the human-computer interaction aspect. Salzman, Dede, Loftin, and Chen (1999) also points out the need for more study on the interaction of individual characteristics with the characteristics of VR.

Out of more than sixty educational projects that use VR technology as reported in Youngblut (1998), evaluation to identify the impact of learner characteristics on learning are conducted in only two of those projects. In the project on the Pacific Science Center Summer Camp, Byrne (1993) investigates the impact of gender, race, and scholarship factors on learners' interaction with and enjoyment of the VR, and the Virtual Reality Roving Vehicle Entrée program by Winn (1995) looks into the issue of gender and spatial ability. A recent study by Ogle (2002) investigates the effects of VR on recall in participants of differing levels of field dependencies. Looking at the scarcity of the ATI research done, it is thus, reasonable to investigate the effects of the VR-based learning environment of this project on learners with different aptitudes, focusing specifically on spatial visualization ability. The following section elaborates how this aptitude is related to VR and explains why it was chosen specifically for the case of novice car driver instruction, which was the learning problem employed in this study.

Spatial Ability and Vr

Spatial ability is a psychometric construct with two major factors: spatial orientation and spatial visualization (Michael, Guilford, & Fruchter, 1957). Ekstrom, French, Harman, and Dermen (1976) defines spatial orientation as a measure of the ability to remain unconfused by changes in the orientation of visual stimuli, and therefore it involves only a mental rotation of configuration, and McGee (1979) defines spatial visualization as a measure of the ability to mentally restructure or manipulate the components of the visual stimulus and involves recognizing, retaining, and recalling configurations when the figure or parts of the figure are moved.

There is currently much research activity involving VR and spatial behavior (Durlach et al., 2000). Durlach et al. (2000) highlights four types of major research involving spatial behavior and VR, which are listed as follows:

VR is being used as a research tool to help advance fundamental understanding of spatial behavior;

VR is being used to help assess spatial abilities and skills;

As VR users often find virtual environments confusing and difficult to navigate (people often get lost in virtual environments), efforts are being directed towards the development and evaluation of methods for improving spatial behavior in virtual environments;

Research is being conducted on the use of VR to improve spatial behavior in the real world.

The identification of these four major types of research once again supports the earlier claim that the research concerning individual differences, particularly on spatial ability in the context of VR, is still at its infancy. VR offers a promising medium for teaching people about the spatial characteristics of places and situations due to its inherent spatial nature. Indeed, there are still many interesting issues to be investigated regarding the interaction of individuals' spatial abilities with the characteristics of VR in the effort to adapt the nature of VR-based instruction to accommodate individuals of different spatial abilities.

Aim of the Study

This study aims to obtain empirical data in the effort to gain insight into how three different learning modes (Guided VR, Non-Guided VR, and Non VR) are related to the learners' spatial visualization abilities.

VR-based Learning Environment for Novice Car Drivers

Chen, Toh, and Wan (2003) conducts an initial study that look into the limitations of the current novice car driver instruction program in Malaysia, focusing solely on the cognitive aspect, and the potential of the VR technology to overcome those limitations. They found out that the methods of instruction in the current instruction program for traffic rules and traffic signs of various road scenarios employ two-dimensional representation of road scenarios. This representation is unrealistic because in a real context, the learner will perceive the road in a three-dimensional view from various physically possible viewpoints. The use of plan view in the two-dimensional representation has indeed presented a physically impossible viewpoint. Thus, transferring the learning gained from this representation to a real driving scenario involves another level of abstraction that requires the learner to mentally construct the respective three-dimensional road scenario from the plan view.

The use of two-dimensional representation also increases the learner's cognitive load as the task of imagining the two-dimensional representation in three-dimension entails the knowledge of isometric, parallel and perspective projections, elevations, materials, dimensioning and so on. This knowledge depends very much on the learner's spatial visualization ability. The fact that different individuals have different spatial visualization abilities raises the ambiguity on the ability of the learning gained through the use of two-dimensional representations to be transferred to the real practice. Hence, this project further investigates the effects of the use of the VR-based learning environment, which was developed for this particular learning problem, on learners with different spatial visualization abilities. Chen, Toh, and Wan (2004) provides a detail description of the instructional design theoretical framework of this VR-based learning environment, and Chen and Toh (2005) provides an elaboration of the instructional development model that guides the design, development and evaluation process of the learning environment.

Operational Definitions

Guided VR: A learning mode that employs the developed VR-based learning environment. This learning environment makes available additional navigational aids; in the form of a tracer that provides a real-time indicator of the virtual vehicle position on a map, and directional arrows.

Non-Guided VR: A learning mode that employs the developed VR-based learning environment, except without the additional navigational aids.

Non VR: A conventional learning mode that relies on lectures and reading materials.

A high spatial visualisation ability learner: A learner who scores above the mean in the Bennett, Seashore and Wesman Space Relations Test.

A low spatial visualisation ability learner: A learner who scores equal or below the mean in the Bennett, Seashore and Wesman Space Relations Test.

Research Questions

1. Is there a difference in gain score for the VR-based test between the low spatial visualisation ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)?
2. Is there a difference in gain score for the VR-based test between the high spatial visualisation ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)?

3. Is there a difference in gain score for the VR-based test between the high spatial visualisation ability learners of the Guided VR mode and the low spatial visualisation ability learners of the same mode?
4. What is the interaction effect between the learners' spatial visualisation abilities and the learning modes, related to the gain score of the VR-based test?

Research Design

This study employed the multiple-group pretest-posttest quasi-experimental design (Spector, 1981). It involved two experimental groups (Guided VR and Non-Guided VR) and a control group (Non VR). Each group was given a pretest and a posttest. However, all these groups did not have pre-experimental sampling equivalence. The groups constituted intact classes, in which equivalency could not be presumed or assured.

The use of factorial design allowed the study of the interaction of the independent variable with one or more other variables, known as moderator variables (Fraenkel & Wallen, 1996). A 3 by 2 quasi-experimental factorial design was used in which the learning modes were crossed with the spatial visualization abilities of the learners.

Variables

The independent variable was the learning mode (Guided VR, Non-Guided VR, and Non VR). The dependent variable was the gain score, which was measured by the posttest score minus the pretest score. The moderator variable, spatial visualization ability (high/low) was included to investigate its effects on the three learning modes.

Population and Sample

The current law in this country allows any person who is 17 years old and above to undergo the novice car driver instruction program. Although the age of these candidates may vary greatly, according to Mohd Kifli, the former Head of the Driving License Unit at Penang RTD, a majority of them are from the younger group, those who are just above the eligible age (personal communication, February 25, 2003). Hence, only individuals from this group of population were chosen to evaluate the VR-based learning environment.

The accessible population for this study encompassed the Form Four students (limited to those who had not undergone a driver instruction program) of any secondary schools that were well-equipped with multimedia computer laboratories in the Penang Island. Form Four students were chosen because they were of non-examination class and more important, they were within the targeted population as their age was approximately the minimum eligible age to undergo the novice car driver instruction program. School students instead of general public were chosen in order to obtain better-controlled samples. The sample size was 184 and the average age of the participants was 16.45 years old.

Initially, a list of daily secondary schools in Penang Island that fulfilled criteria such as (a) similar socio-economic background, (b) co-education, (c) multi-racial to represent the population of this country, and (d) well-equipped with multimedia computer laboratories, was formed. Four different secondary schools were then randomly selected (based on the simple random sampling technique) from the list. For each school, two or three intact classes were chosen. All eligible students (those who had not undergone the driver instruction program) of the selected classes were included in the study. These selected classes were randomly assigned to either control or experimental groups.

Material and Instruments

The VR-based learning environment served as the treatment for the experimental groups. The instruments that were used include the VR-based test (pretest and posttest) and the Bennett, Seashore and Wesman Space Relations Test. These instruments are described below.

VR-Based Test (Pretest And Posttest)

The VR-based pretest and VR-based posttest that were employed in this study were computer-based. Each test consisted of 15 questions and aimed to assess the learners' understanding of traffic rules and traffic signs. Unlike the conventional theory test set by the Road Transport Department, which showed two-dimensional images, each of the questions in the VR-based test showed a three-dimensional simulation of a virtual road scenario and the learners were instructed to identify an observable traffic rule error, if any. Both pretest and posttest were similar in content but the order of the questions was different to avoid the set response effect.

Scoring

The total score of each test was 15. For each question, participants received a score of either 1 (correct answer) or 0 (incorrect answer), and a total score ranging from 0 to 15. This total score was multiplied by 100 to convert it to percentage.

Test Validity

Content validity of the VR-based test was determined by expert judgment (Gay & Airasian, 2003). Subject matter expert from the Road Transport Department was requested to review the process used to develop the test as well as the test itself, and then made a judgment about how well these items represent the intended content area.

Test Reliability

A pilot study was carried out after the test items were designed and validated. An item analysis was performed to obtain the item difficulty index, the item discrimination index, and the pattern of responses to the various distracters in order to improve the test. The Cronbach's reliability coefficient of the test was 0.83, depicting a satisfactorily reliable test.

Bennett, Seashore and Wesman Space Relations Test

This instrument was chosen to test the spatial visualization ability of the participants. It consists of 60 patterns that could be folded into figures. A feature inherent in these items is that they required mental manipulation of objects in three-dimensional space. It tests the ability to visualize a constructed object from a picture of pattern, which is illustrated in two-dimensional. This is consistent with the spatial skill needed to reconstruct the three-dimensional view of the road scenario from the two-dimensional plan view.

The test is to be completed in 25 minutes. This test has a reliability of 0.91 (Bennett, Seashore, & Wesman, 1972). In this project, participants who scored above 50% were classified as having high spatial visualization ability and participants who scored 50% or below were classified as having low spatial visualization ability.

Procedures

Prior to the implementation of the study, permissions were obtained from a number of different parties for conducting the pilot study and the experimental study. Permissions were sought from the Penang State Education Department and the participating schools' principals.

Pilot Study

A group of Form Four students from a selected school served as the participants or learners of this evaluation. These learners were not involved in the experimental study. After informing the learners on the purpose of this evaluation, they were given a training to familiarize themselves to the navigation of the virtual environments. Then, they were requested to explore the VR-based learning environment and to answer the posttest of the VR-based test. Item analysis was then conducted on the learners' answers to the posttest.

Experimental Study

Two weeks before the treatment, the learners were given the Bennett, Seashore and Wesman Space Relations Test and the VR-based pretest. Then, just before the treatment, the experimental groups were given training on the navigation of the virtual environment. Immediately after the treatment, which took an hour, the learners were given the VR-based posttest.

Results

Pilot Study

The evaluation involved 30 Form Four students. Sixteen students were randomly selected from a Science stream class while the others were randomly selected from an Arts stream class to obtain greater variability. The posttest scores ranged from the lowest, 13.3%, to the highest, 100%. Based on guidelines by Hopkins (1998), question 1 and question 5 were classified as having good discrimination or good ability to measure individual differences while all the other questions provided excellent discrimination. The difficulty indices ranged from 0.3750 to 0.7500, which indicated that all the questions were of moderate difficulty. The Cronbach's alpha reliability coefficient was 0.83, which depicted the test questions were satisfactorily reliable. In addition, the responses to each question were well distributed.

Experimental Study

Distribution of Learners

The 184 learners were divided into three groups. Each group was assigned to one of the three learning modes. Table 1 shows the number of learners assigned to each learning mode.

Table 1: Learners distribution across the learning modes

Learning mode	Number of learners
Non VR	64
Guided VR	62
Non-Guided VR	58
Total	184

Testing of Hypotheses

ANCOVA was used to analyze the data. In this analysis, the pretest scores served as the covariate. However, before ANCOVA was conducted, a series of test to check the assumptions for this type of analysis was performed and this type of analysis was found appropriate to be employed.

Testing of null hypothesis for research question 1

H_{01}: There is no significant difference in the gain score for the VR-based test between low spatial visualization ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR).

Table 2: One-way ANCOVA of gain score by learning mode with pretest score as covariate for low spatial visualization ability learners
Dependent variable: Gain score

Source	**Type III *SS***	***df***	***MS***	***F***	***Sig.***	**η2**
Covariate						
Pretest score	9648.421	1	9648.421	42.080	0.000	0.334
Main effect						
Learning mode	**5862.301**	**2**	**2931.150**	**12.784**	**0.000**	**0.233**
Error	19620.045	84	229.286			
Total	63955.556	88				

$p < 0.05$

A one-way analysis of covariance was conducted to examine if there was significant difference in adjusted mean of the dependent variable (gain score) between the low spatial visualization ability learners of each of the three learning modes, while controlling the pretest. After adjusting for the pretest scores, there was a significant difference between the low spatial visualization ability learners of the three learning modes on the gain scores, $F(2, 84) = 12.784$, $p = 0.000$ (see Table 2). These statistical results rejected the null hypothesis, H_{01}. This means that the learning mode had a main effect on the low spatial visualization ability learners' gain scores. The effect size, calculated using η^2, was 0.233, which in Cohen's (1988) terms would be considered a large effect size. Table 3 depicts the adjusted mean of each learning mode.

Table 3: Adjusted means for each learning mode

Learning Mode	**Adjusted mean**
Guided VR	28.985
Non-Guided VR	9.765
Non VR	14.568

Pair wise comparisons for one-way ANCOVA

As the one-way ANCOVA yielded statistically significant result, follow-up post-hoc pair wise comparisons were conducted to evaluate pair wise differences among the adjusted means as presented in Table 4. The Holm's sequential Bonferroni procedure was used to control for Type I error across the three pair wise comparisons. Table 4 also indicates two comparisons that were found significant using bold typeface.

Table 4: Summary of post hoc pair wise comparisons between low spatial visualization ability learners across the three learning modes

	Gain score	
Comparison groups	**Adj. Mean difference**	**Sig.**
Guided VR vs. Non-Guided VR	**19.220**	**0.000**
Guided VR vs. Non VR	**14.417**	**0.000**
Non VR vs. Non-Guided VR	4.803	0.235

Note: The adjusted mean difference shown in this table is the subtraction of the second learning mode (on the lower line) from the first learning mode (on the upper line); for example, 19.220 (adjusted mean difference) = adjusted mean of Guided VR mode – adjusted mean of Non-Guided VR mode

In summary, the findings of this hypothesis testing are represented mathematically as follows.

For low spatial visualisation ability learners

Guided VR > Non-Guided VR	**S**
Guided VR > Non VR	**S**
Non VR > Non-Guided VR	**NS**

S: significant **NS: not significant**

Testing of null hypothesis for research question 2

H_{02}: There is no significant difference in the gain score for the VR-based test between high spatial visualization ability learners of each learning mode (VR (guided exploration, Non-Guided VR, and Non VR).

Table 5: One-way ANCOVA of gain score by learning mode with pretest score as covariate for high spatial visualization ability learners

Dependent variable: Gain score

Source	Type III SS	df	MS	F	Sig.	η2
Covariate						
Pretest score	6174.636	1	6174.636	42.997	0.000	0.319
Main effect						
Learning mode	**3844.545**	**2**	**1922.273**	**13.386**	**0.000**	**0.225**
Error	13211.857	92	143.607			
Total	59911.111	96				

$p < 0.05$

A one-way analysis of covariance was conducted. The statistical results rejected the null hypothesis, H_{02}. There was a significant difference between the high spatial visualization ability learners of the three learning modes on the gain scores, $F(2, 92) = 13.386$, $p = 0.000$ (see Table 5). This means that the learning mode had a main effect on the high spatial visualization ability learners' gain scores. The effect size was 0.225, which in Cohen's (1988) terms would be considered a large effect size. Table 6 depicts the adjusted mean of each learning mode.

Table 6: Adjusted means for each learning mode

Learning Mode	Adjusted mean
Guided VR	28.085
Non-Guided VR	17.295
Non VR	13.209

Pair wise comparisons for one-way ANCOVA

As the one-way ANCOVA yielded statistically significant result, follow-up post-hoc pair wise comparisons were conducted as presented in Table 7. This table also indicates two comparisons that were found significant using bold typeface.

Table 7: Summary of post hoc pair wise comparisons between high spatial visualization ability learners across the three learning modes

	Dependent variable (gain score)	
Comparison groups	**Adj. mean difference**	**Sig.**
Guided VR Vs. Non-Guided VR	**10.790**	**0.001**
Guided VR vs. Non VR	**14.876**	**0.000**
Non-Guided VR vs. Non VR	4.086	0.177

Note: The adjusted mean difference shown in this table is the subtraction of the second learning mode (on the lower line) from the first learning mode (on the upper line); for example, 10.790 (adjusted mean difference) = adjusted mean of Guided VR mode – adjusted mean of Non-Guided VR mode

In summary, the findings of this hypothesis testing are represented mathematically as follows.

For high spatial visualisation ability learners

Guided VR > Non-Guided VR	**S**
Guided VR > Non VR	**S**
Non-Guided VR > Non VR	**NS**

S: significant **NS: not significant**

Testing of null hypothesis for research question 3

H_{03}: In the Guided VR mode, there is no significant difference in gain score for the VR-based test between the high spatial visualization ability learners and the low spatial visualization ability learners.

Table 8: ANCOVA of gain score by spatial visualization ability with pretest score as covariate for Guided VR mode

Dependent variable: Gain score

Source	Type III *SS*	*df*	*MS*	*F*	*Sig.*	η2

Covariate						
Pretest score	6054.738	1	6054.738	23.589	0.000	0.286
Main effect						
Spatial visualization ability	**47.176**	**1**	**47.176**	**0.184**	**0.670**	**0.003**
Error	15143.781	59	256.674			
Total	72311.111	62				

$p < 0.05$

A one-way analysis of covariance was conducted. It was found that there was no significant difference between the low spatial visualization ability learners and the high spatial visualization ability learners on the gain scores, $F(1, 59) = 0.184$, $p = 0.670$ (see Table 8). The adjusted mean for the high spatial visualization ability learners was 29.561 and the adjusted mean for the low spatial visualization ability learners was 27.801. The adjusted mean difference of 1.76 was not significant.

In summary, the findings of this hypothesis testing are represented mathematically as follows.

For Guided VR mode

high spatial visualisation ability > low spatial visualisation ability	**NS**

NS: not significant

Testing of null hypothesis for research question 4

H_{04}: There is no interaction effect between the learners' spatial visualization abilities and the learning modes (Guided VR, Non-Guided VR, and Non VR), related to gain score of the VR-based test.

Table 9: Two-way ANCOVA of gain score by learning mode and spatial visualization ability with pretest score as covariate

Dependent variable: Gain score

Source	**Type III SS**	***df***	***MS***	***F***	***Sig.***	**η2**
Covariate						
Pretest score	15666.427	1	15666.427	84.986	0.000	0.324
Main effects						
Learning mode (LM)	9003.031	2	4501.515	24.419	0.000	0.216
Spatial visualization ability (SVA)	844.345	1	844.345	4.580	0.340	0.025
2-way interaction						
LM SVA	**769.898**	**2**	**384.949**	**2.088**	**0.127**	**0.023**
Error	32628.530	177	184.342			
Total	123866.667	184				

$p < 0.05$

Table 10: Means, standard deviations, adjusted means, and standard errors of gain score by learning mode and spatial visualization ability

		Gain score			
Learning mode	**Spatial visualization ability**	***M***	***SD***	Adjusted ***M***	***SE***
Guided VR	**Low (N=30)**	29.1111	21.6898	27.653[a]	2.484
	High (N=32)	28.3333	15.6118	29.287[a]	2.402
VR(non-guided exploration)	**Low (N=28)**	7.8571	16.8316	8.252[a]	2.566
	High (N=30)	17.7778	12.1716	18.471[a]	2.480
Non VR	**Low (N=30)**	16.2222	16.2059	13.373[a]	2.498
	High (N=34)	12.5490	15.1103	14.515[a]	2.338

Note: [a] Evaluated at covariate appeared in the model: pretest = 58.1160

A 3 by 2 two-way ANCOVA was conducted to examine the effects of the learning modes on the performance in the VR-based test for low spatial visualization ability learners and high spatial visualization ability learners. The two-way ANCOVA results, as shown in Table 9, indicate that the interaction between learning modes and spatial visualization abilities was not significant, $F(2, 177)=2.008$, $p < 0.127$. This means the differences in the adjusted means of the gain score among the three learning modes did not vary as a function of learners' spatial visualization abilities. Although the effect of the learning modes on the gain scores of the VR-based test did not depend on the spatial visualization ability levels, there were differences in gain scores among the learning modes for learners of different spatial visualization abilities. The Guided VR mode had higher gain score than both the other two learning modes for both the low and high spatial visualization ability learners. In fact, the earlier statistical analyses for H_{01} and H_{02} revealed that these differences were significant.

The results in Table 9 also shows that there was a statistically significant main effect due to spatial visualization ability, $F(1, 177)=4.580$, $p < 0.034$. The adjusted mean of the gain score for the high spatial visualization ability learners, averaged across the three learning modes, 20.758, was higher than the adjusted mean of the gain score for the low spatial visualization ability learners, 16.426. However, the effect size was small, η^2 was 0.025. Table 10 presents the means, standard deviations, adjusted means, and standard error of the gain score by the learning mode and the spatial visualization ability.

The following summarizes the main finding of this hypothesis testing.

Interaction Effect

spatial visualisation ability learning mode	**NS**

NS: not significant

Discussion

Effects of the Learning Mode on Learning Based on Spatial Visualization Ability Levels

The finding that both high and low spatial visualisation ability learners benefited most from the Guided VR mode and the difference between the performances of these two groups of learners was not significant was rather inconsistent with the studies by Mayer and Sims (1994) and Toh (1998). All these studies provide preliminary evidence that high spatial ability learners benefit more from improved instruction design than the low spatial ability learners. There are several possible explanations to this finding.

First, the use of virtual environments that explicitly present the three-dimensional representations and dynamics of the road scenarios and the use of additional navigational aids to help learners to stay oriented in the Guided VR mode greatly reduce the learners' need to use their existing spatial processing schema. This reduces the extraneous cognitive load, which subsequently enables the high spatial visualisation ability learners to spare most of the cognitive resources for comprehending the content of the learning environment. This possibly explains the significant positive effect of this learning mode on the high spatial visualisation ability learners. Second, in this learning mode, the lack of spatial processing schema among the low spatial visualisation ability learners also does not negatively affect the learning of this group of learners. The explicit presentation of three-dimensional representation and dynamics of the road scenarios and the use of additional navigational aids keep the need for using this schema to very minimum. Thus, the low spatial visualisation ability learners of the Guided VR mode significantly outperform their Non-Guided VR as well as their Non VR counterparts as they are able to use their cognitive resources for comprehending the content rather than using these resources for supporting additional cognitive activities that are necessary in the effort to comprehend the content, such as those occur in the other two learning modes.

The finding that the low spatial visualisation ability learners of the Guided VR mode significantly outperformed their Non-Guided VR and Non VR counterparts may also be explained by Messick's strategies to match individual differences to learning task (1976). Messick (1976) proposes three strategies: the challenge match, the capitalisation match, and the compensatory match. The challenge match uses a deliberate mismatch between task demands and learner capabilities to force a learner to change and become more flexible. The capitalisation match aims to tailor task demands to match the learners' strengths and the compensatory match aims to offset learners' deficiencies by providing cognitive tools that learners cannot readily provide for themselves. The Guided VR mode that produces significant positive effects to both high and low spatial visualisation ability learners employs the compensatory matching technique. The use of additional navigational aids that are unavailable in the Non-Guided VR mode compensates the learners' ability to stay oriented in the virtual environments and the use of virtual environments, which are unavailable in the Non VR mode, compensates the need to mentally construct and maintain the three-dimensional representation and dynamics of the road scenarios. The non-significant difference between high spatial visualisation ability learners and low spatial visualisation ability learners of the Guided VR mode proves the success of the compensatory match. Stanney and Salvendy (1995), in their study, also found that the performance gap between high spatial individuals and low spatial individuals disappear with the use of interface design that can avoid the need of mentally structuring embedded information. This interface improves the performance of low spatial ability learners due to the compensatory match of their abilities.

The significant positive effect of the Guided VR mode over the Non-Guided VR mode also implies the importance of providing VR-based learning environment with proper instructional design in order to achieve the desired learning outcomes. This section, however, does not include the discussion of this finding.

Interaction Effect

Another finding of this study was that the interaction effect between the learners' spatial visualization abilities and the three learning modes was not significant. This means the effects of the learning modes on learning do not depend on the learners' differences in terms of spatial visualization ability. However, among the three learning modes, Guided VR mode provided the most positive effect to both low spatial visualization ability learners and high spatial visualization ability learners. Indeed, both low spatial visualization ability learners and high spatial visualization ability learners benefited equally from this learning mode. This implies that the learners benefit most from the Guided VR mode, irrespective of their spatial visualization abilities.

Conclusion

The vast majority of the research into virtual environments for instructional use is technology-driven, rather than taking into account the human factor. There has been little study on how learner characteristics interact with the features of virtual environments either to aid or inhibit learning. The ATI study that has been conducted provides more understanding of this aspect. The findings of this study have shown the learners benefit most from the Guided VR mode, irrespective of their spatial visualization abilities. This shows that the VR-based learning environment offers a promising medium in accommodating individual differences in terms of this aptitude. In addition, the significant positive effect of the Guided VR mode over the Non-Guided VR mode also implies the importance of providing VR-based learning environment with proper instructional design in order to achieve the desired learning outcomes.

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