Effects of Virtual Reality on Mental Rotation Ability of Science Students at Elementary Level

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Abstract

Recent research has shown that the use of Virtual Reality (VR) can induce many cognitive capacities in science learners. This research explored the effects of virtual reality on mental rotation abilities, which are recognized as one of the significant sub-factors of spatial abilities. This study aimed to explore the effects of virtual reality on the mental rotation abilities of learners at the elementary level. The research was carried out employing experimental methodology, in which a pre-test post-test control group design was used. The hypotheses of the study were to compare the mental rotation abilities of the science students in the experimental group while learning through VR and the control group while learning as usual. The population consisted of 7th grade students from the Islamabad Model School for Girls. Sample of study was conveniently selected i.e. 62 students through random selection. The standardized measure was used for a mental rotation test consisting of 24 multiple choice questions. Over the course of three weeks, virtual reality was used for the intervention purpose of learning various science topics that required mental rotation abilities for full comprehension. The results showed that VR had significant positive effect on mental rotation abilities of the science learners at elementary level. It is recommended to use virtual reality to enhance the learners' spatial abilities such as mental rotation abilities.

Keywords: *Virtual Reality, Spatial Abilities, Mental Rotation Abilities, Spatial Orientation, Spatial Visualization, Sciences.*

1. Introduction

Mental rotation ability is the foundational capability for understanding various scientific concepts (Delavar et al., 2018). The mental rotation ability is one of the important sub-factors of spatial abilities which involve mental manipulations of the object from spatial representation of visual stimulus (Borst, et al., 2011). The cognitive process which involves a person to imagine how the

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objects would appear after being rotated or turned around any point by any certain angle whether the object is two dimensional or three-dimensional is known as mental rotation (Shepard & Metzler, 1971). The most essential spatial thinking tasks were the mental rotation as argued by cognitive psychologists (Hegarty, 2010).

Studies in the field of mental rotation abilities showed evidence that using spatially presented stimulus through modern technologies like virtual reality has positively affected mental rotation abilities (Dunser et al., 2006; Kozhevnikov, 2008). This can be further understood by the model presented by Dalgarno and Lee, (2010) in which the researcher has discussed that VR has the potential to present the spatially knowledge in the most effective way that no other recent technology can presented due to its visual-immersive nature. Using virtual reality technology provided the learner to observe the image with spatial dimension displaying its spatial width, height and length allowing easily manipulating and rotating the spatial-visual image and thus training their spatial abilities including mental rotation ability (Jiang & Laidlaw, 2019). The spatial representation provided by virtual reality helps to understand various science concepts such as astronomical concepts (Cole, Wilhelm, & Yang, 2015; Gazit, Yair, & Chen, 2005; Plummer et al., 2022). Virtual reality is apt for representing spatial knowledge (Dalgarno & Lee, 2010) and sciences having spatial characteristics in nature can be best understood through it (Durukan, Artun, & Temur, 2020) through addressing spatial abilities.

1.1 Statement of Problem

Mental rotation ability is a significant factor of spatial abilities which is imperative for understanding various scientific concepts. According to the recent research of the decade for the present era, mental rotation abilities are strongly correlated with the academic performance in STEM subjects. The recent technological advances such as the virtual reality can opens up many possibilities to train the students in this respect because literature argued that the virtual reality technology uses three-dimensional visualization which provides the scope to enhance the mental rotation abilities. The problem is that in the context of Pakistan, mental rotation abilities are not focused and studied at large scale, however, it might be easily addressed through infusing VR with regular science teaching and learning (Baumgartner, 2020; Jiang & Laidlaw, 2019) which was not primarily in functional usage in regular science teaching and learning. Some of the stereotype topics from the basic science are Lunar Phases, Molecular Structure Bonding and Human Internal Organs etc. which demands high mental rotation abilities. The issue is that, there is no evidence in Pakistan to widely use virtual reality technology for practicing the mental rotation involving tasks in order to analyze the impact of VR on the mental rotation abilities. Therefore, this research was carried out to explore the effects of virtual reality technology on mental rotation abilities of the science learners in Pakistan.

1.2 Objectives of the Study

The study was attempted with the following objectives:

1. To explore the effects of virtual reality on the mental rotation abilities of the science students.

1.3 Research Hypotheses

The following research hypotheses were formulated to achieve the objectives of this study:

H_{01}: There is no significant difference between the scores of the students regarding mental rotation abilities at pre-test for control group and experimental group.

H_{02}: There is no significant difference between the scores of the students regarding mental rotation abilities at post-test for control group and experimental group.

H_{03}: There is no significant difference between the overall scores of students regarding mental rotation abilities for pre-test and the post-test.

1.4 Delimitations of the Study

By safekeeping the time and resources, the extension of the study was restricted in many domains that can be explained as following:

1. The study was restricted to Islamabad city only.
2. The VR-based learning was managed only in the subject of science.
3. The sample of the study was the students from grade 7^{th}.
4. The sample included only girls' students because the selected school was a girls' school in Islamabad city.

1.5 Significance of the Study

The findings of study will bring new perspective for science educationists by altering the "teaching and learning" of "science education" because virtual reality provides an interactive and immersive experience which can engage the learners in better way and gradually develop interest towards science. This study will serve as the baseline for dragging the consideration of the educationists to improve learning of spatially demanding subjects through integration of virtual reality technology.

2. Literature Review

Integrating Virtual Reality (VR) in educational setup is a novel area of research (Kavanagh et al., 2016). Baumgartner (2020) presented an experimental study in which it was concluded that the consumption of VR directed to a development in overall spatial reasoning ability for which mental rotation abilities were at the main focus. Literature showed that VR has demonstrated significantly positive potential benefits in elementary level classrooms (Kurtulus, 2013; Merchant et al., 2014; Piovesan et al., 2012). Now, VR is available in a cost-effective way due to rapid sophistication in VR (Brown & Green, 2016) offering for educational usage to make pleasing, enjoyable and interesting learning with increased motivation and attention span (Huang et al., 2010; Piovesan et al., 2012) needed at elementary level. A distinguished feature of virtual reality is that by providing immense visualization it bears the potential to develop spatial abilities among the learners (Jiang & Laidlaw, 2019; Plummer et al., 2022) particularly mental rotation abilities (Safadel & White, 2020). Spatial skills are considered as the 'building block' of scientific cognition (Gagnier & Fisher, 2016). Spatial abilities might be well-defined as "set of human mental skills" that encompassed 'manipulating and processing of visual-spatial information' (Lee et al., 2009). Domingueza et al. (2012) also concluded that spatial abilities of the students can be positively manipulated using VR.

Spatial abilities were mainly subdivided into 'Spatial Visualization, Spatial Orientation and Mental Rotation' (Ilic & Dukic, 2017). "Mental rotation" denotes the ability to revolve "mental representations" of objects within human mind. Sun et al. (2018), concluded in a research that virtual reality technology has significantly positive effects on spatial abilities of the learners. Ariali and Zinn (2021) also investigated the effects of virtual reality on spatial abilities particularly mental rotation abilities of the students with two conditions in which first condition is randomized control condition with regular learning pattern and the other was adaptive training condition through VR and concluded with the increase in mental rotation ability among VR training group.

Lei et al. (2018) also used Water Bears VR application which is another interesting application for engineering education providing a "3D environment" for training of comprehensive abilities among learners and the researcher concluded that "VR" significantly make "abstract knowledge of sciences" more feasible to grasp for learners when they visualize the virtual models/scenes, and VR supports in making abstract knowledge into concrete knowledge. It can sham any natural phenomena that enable the students to actively absorb useful knowledge from observation. According to Lei at al. (2018) VR might generate the situations that are near to real life, might be imitating real life phenomena, and make the students to obtain knowledge from "concrete examples". Moreover, VR can be helpful in teaching the learners "how to apply the same knowledge in different situations" that is called critical thinking and students can internalize scientific phenomenon very well. Ariali, (2020) also concluded that mental rotation abilities were significantly impacted by the use of virtual reality.

Hodgkiss et al. (2018) concluded that spatial abilities were predictive of science achievement for seven to eleven years old children and develop similar contribution towards science performance for each age group respective to elementary level students. Spatial abilities are important at elementary level students because elementary students with good spatial abilities are more likely to excel in Science, Technology, Engineering, and Mathematics (STEM) courses, and they are more likely to be interested in pursuing a STEM-related career (Carr et al., 2018). Elementary school is not only a prime time for learners to develop their spatial abilities but also a pivotal time for developing interest in STEM and learners' pathways in the future have been found to be influenced by the experiences one has in elementary school (Msall & Panther, 2020).

It has been observed that very little literature in the context of Pakistan was available to study the effects of VR. However, Ali et al. (2014) in Pakistan have studied the effects of virtual reality-based chemistry lab. But there was very scarce literature available in the context of Pakistan to explore the effects of VR. Also, the spatial abilities induced very significant role for understanding scientific concepts but it was found very much scarcity of literature from Pakistan context. Also, there were very scarce research through worldwide to date that have investigated the students' science concepts in direct relation to spatial abilities (Harris et al., 2018; Mayer et al., 2014) but studies were available to improve or develop spatial abilities through adaptive trainings and interventions. Therefore, this research was proposed to examine the effects of immersive virtual reality technology on spatial abilities primarily the mental rotation ability of the learners at elementary level regarding science concepts in the context of Pakistan.

It is evident from the literature that the mental rotation abilities are directly linked with the academic performance in sciences and using virtual reality technology, offers the possibilities to provide the chance of practicing this important spatial intelligence i.e., mental rotation abilities. But in the context of Pakistan, these very important abilities are often neglected in favor of many other verbal abilities. Therefore, this study is significant in the ways, it provides the chance to focus and analyze these important abilities through practicing with the potential of emergent virtual reality technologies with the opportunities to grasp the mental rotation involving tasks which are impossible in otherwise situations due to unique affordances of virtual reality.

3. Research Methodology

3.1 Research Design

For this research, experimental research design followed by pre-test posttest control group design was used. The first phase included the pre-test phase from the whole sample. The second phase was the intervention phase. Lastly, there was the post-test. Then comes the data analysis phase and interpretation of the results according to the objectives of the study respective to the hypotheses.

3.2 Population

The focus was on the 7th grade students from the Islamabad Model Girls School. However, due to large size of population, the researchers decided a conveniently selected sampling frame from the target population. Therefore, Islamabad Model School for Girls in the locality of Bani Gala was selected conveniently as the accessible population. The accessible population collectively for seventh graders was comprised of 170 students which were enrolled in the year 2019 and was actually present there. The convenience follows the ease of access to collect data and the intervention from the authorities.

3.3 Sample and the Sampling Technique

The sample of the study included 62 students in total which was randomly selected from the target population which served as the subjects for the study. The students were randomly distributed in either the control and the experimental group was shown as follows:

Table 1

Distribution of the Sample for the study

Group	Number of Students	Total
Control	31	31
Experimental	31	31
Total	62	62

Table 1 showed that the experimental group included 31 participants which were selected randomly from the accessible population from the grade 7th from the selected school of Islamabad city and 31 students were selected in the control group.

3.4 Instrumentation

Two forms of the instruments were used for the study to collect information about the performance of the learners. These instruments were both the measuring instruments and the instructional instruments. The measuring instrument was consisted of a standardized measure for the mental rotation ability of the learners developed by Peters et al. (1995) based on the original test by Shepard and Metzler (1971) consisted of 24 items. Each question carried 2 marks as a whole which made 48 marks in total i.e., one item demanded two responses and each correct response carried 1 mark and 0 mark for each wrong response or no response. This test contained 0-48 range of marks for each participant. The measuring instrument was used in two equivalent forms which was the pre-test and the post-test for the study and either form can be used. The internal consistency was measured using equivalent forms of the test. The recommended time span for completing the test was 6 minutes but during the pilot study, it was seen that majority of the students were unable to complete the test in this time. Therefore, it was decided to give 10 minutes to complete this test, after observing the majority of the students get completed the test items. Its content validity was also ensured by the experts and the reliability was satisfactory using Kuder Richardson reliability co-efficient value of 0.746. Although, the tool was already validated by the National Testing Service but to test for the adjustment to the socio-demographic purpose the tool was sent for the validation from the experts in the educational setup. After accomplishing and ensuring the necessary formalities regarding the measurement instrument, the tool was administered on the participants of the study. The instructional tool was consisted of guided VR-based learning with the contents from the general science book recommended as course book for grade 7th students. The sample item was illustrated as follows:

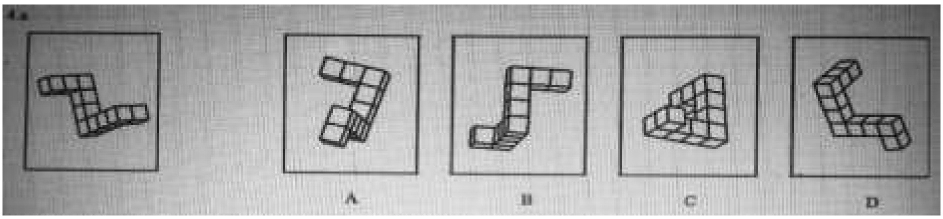

Fig 1. *Sample Item from the Mental Rotation Test*

3.5 Intervention

Students were exposed to virtual reality by watching, engaging and interacting in three sixty-degree immersive videos through head-mounted-display VR devices. The topics for the intervention were aligned with the regular syllabus for the students. The videos were searched from the YouTube and carefully selected for the students. The selected videos were sent for the experts' opinion. After getting the experts' opinion, 18 videos were finalized for the treatment purpose. These videos comprised each strand of the science curriculum, i.e., from biology section the intervention included immersive videos containing spatial information of human internal organs, from the physics section the intervention contained the content from astronomy section such as lunar phases etc., and from the chemistry section there were content regarding molecular representation. The selection of the videos was based on the requirement of the mental folding ability of the students. These topics were selected after the recommendation from many studies from the review of literature. The selected videos were downloaded before intervention to the students to the experimental groups. The time span of these videos ranged from 5-9 minutes per video. The lesson plans were developed for intervention. The duration of the intervention was 3 weeks with 40 minutes each period for 4 days in a week. The control groups were taught as usual. Both the groups were initially briefed about the content.

3.6 Data Collection

The data of the pre-test and the post-test were collected and used for the data analysis purpose.

4. Data Analysis and Interpretation

The descriptive as well as the inferential statistics were used for the analysis of the data. For the descriptive statistics, the mean scores, standard deviation and gain scores were computed. For the inferential statistics, the t-test was applied for drawing inferences and to test the hypotheses.

Table 2

Comparison of the mean scores regarding mental rotation abilities at pre-test for control group and experimental group

Test	Group	Mean	SD	Df	t-value	Sig.
Pre-test	Control	28.129	1.875	60	0.297	0.813
	Experimental	28.258	1.526			

Table 2 showed the comparison of mean scores regarding the pre-test for the control group and experimental group regarding mental rotation abilities of the students. The mean scores of the control group at pre-test was 28.129 with standard deviation scores of SD=1.875 and the mean scores of the experimental group was 28.258 with standard deviation scores of SD=1.526. The t-value was 0.297 at the significance level $p<0.05$ which was the critical value. The calculated value was $p=0.813$ which is greater than the critical value. It means that both the groups were not significantly different from each other at pre-test. From this table it can be concluded that both the groups were at the same level at pre-test phase. Therefore, H_{01} was accepted in this regard.

Table 3

Comparison of the mean scores regarding mental rotation abilities of the students at post-test for control group and the experimental group

Test	Group	Mean	SD	Df	t-value	Sig.
Post-test	Control	28.322	2.300	60	4.543	0.044
	Experimental	30.483	1.313			

Table 3 showed the comparison of mean scores at post-test regarding the mental rotation abilities of the students for the control group and the experimental group. The mean scores of the control group at post-test was 28.322 with standard deviation scores of SD=2.300 and the mean scores of the experimental group at post-test was 30.483 with standard deviation scores of SD=1.313. The t-value was 4.543 at the significance level $p<0.05$ which was the critical value. The calculated value was $p=0.044$ which was less than the critical value. It means that both the groups were significantly different from each other at post-test. From this table it can be concluded that both the groups differed from each other at post-test phase. Therefore, H_{02} was rejected in this regard. This provided evidence in favor of the treatment which was given with virtual reality to the experimental group and has significantly positive effect on the mental rotation abilities.

Table 4

Overall difference of mean scores regarding mental rotation abilities of the students at pre-test and the post-test

Test	Mean	SD	Df	t-value	Sig.
Pre-test	28.193	1.697			
Post-test	29.403	2.153	61	3.545	0.001

Table 4 showed the overall difference of the mean scores between the pre-test and the post-test regarding the mental rotation abilities of the students. The mean scores of the pre-test were 28.293 with standard deviation SD=1.697 and the mean scores of the post-test were 29.403 with standard deviation SD=2.153. The t-value was $t=3.545$ which was significant at $p<0.05$ because the calculated $p=0.001$ which was less than the critical value. Therefore, it can be concluded that both the groups were significantly different from each other at pre-test and the post-test. This means that both the groups performed better at post-test but from the table 3 it was concluded that the experimental group was better at post-test which is evidence in favor of the treatment. Therefore, H_{03} was rejected.

5. Discussion and Conclusion

The findings of this study were in-line with the findings of Ariali (2020) that virtual technologies tap the mental rotation ability of test persons and results showed a significant improvement of mental rotation ability after the virtual phase, which indicated the effectiveness of VR in this respect. The results were also in-line with the findings of Jiang and Laidlaw (2019) that practicing with VR improved the mental rotation abilities of the experimental group and this was supported with the evidence that the research compared VR and non-VR medium of instruction. However, the results of the study were contrary to the findings of Grassini et al. (2020) that VR alone is not responsible for the improvement of certain task but the sense of presence which was the basic characteristic of VR learning. However, the affordances of VR were established from the literature due to which the use of VR is claimed as innovative pedagogical tool with unique characteristics.

Findings of this study concluded a significant positive effect of virtual reality on the mental rotation abilities of science students for the experimental group rather than that of control group with usual teaching method. Furthermore, the analysis of results was drawn with the extended time allocation for the completion of the measure for the mental rotation. Conclusively, it can be stated that the use of VR positively affected the mental rotation abilities of the science students. Both the groups differed from each other in which experimental group was taught with the use of virtual reality technology.

6. Recommendations

This research provided limited view of capabilities of VR with respect of science subjects regarding mental rotation abilities of the students. Therefore, following were some of the recommendations for further studies.

1. From this study, it is recommended to use VR technology for teaching and learning sciences as the result of the study reflected that use of VR technology has significantly positive impact on mental rotation abilities of science students.
2. This study has included limited number of students and the sampling frame was conveniently selected however, the students were randomly assigned in each group but it was recommended to replicate the study with different methodology and with large number of students with diversified topics.
3. For this research, the time utilized for the completion of mental rotation test was ten minutes but the recommended time was six minutes therefore, further studies should also furnish the strict formalities for the administration of the instrument which may be responsible for altering the expected results

though this study could not have fully control this factor due to small number of participants.

4. This research used the already available digital content which was suitable and appropriate and aligned with the context of Pakistan in regards to science standards. However, the selection needs meticulous improvision as it may not appropriate and suitable to the certain demographics condition in terms of science learning standards. Therefore, it is recommended to generate and produce newer three-dimensional content for using virtual reality in Pakistan with better adaptability.

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