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Virtual Experimentation and Students' Biology Problem-Solving Skills

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Abstract

The study was focused to explore the use of virtual world of computer in Biology experiments to foster the students' problem-solving skills (PSS). The study was made on explanatory sequential mixed method design which included quantitative (true-experimental) approach was followed by qualitative (interview protocol) method. Population of the study included government schools of Punjab. The sample of the study included the government school of backward areas of south Punjab. With help of random sampling technique, the sample was taken and divided into two groups i.e., experimental and control group. The both groups were taught the concept of evolution. But the experimental group was taught with the non-immersive virtual reality program i.e., MEGA (Molecular Evolutionary Genetics Analysis) version 11. While, the control group was taught with the traditional lecture method. Two research instruments were prepared for the data collection. For the quantitative step of the study, a multiple-choice question paper was prepared to check students' problem-solving skills. This MCQ paper was used as pre and post-test (before and after intervention of experiment). For the qualitative step, the other research tool included interview protocol to check students' remarks regarding their experimentation of VR (virtual reality). Data analysis included independent sample t-test, (for quantitative study); while thematic analysis was made to explore the students' experience during the intervention. The findings revealed that virtual reality had significantly affected students' PSS of experimental group than that of the control group. The interview protocol further revealed the challenges and feasibility of the intervention of the experiment.

Keywords: Virtual environments, Biology Teaching, Problem Solving Skills

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Introduction

Surge of advanced computer technologies to the education and other fields, have raised up the demand of instruments, and gadgets in the education. Moreover, the sudden eruption of pandemics in previous decades (turning the traditional concept of face-to-face learning to online/blended learning), changed the face of education in such a way which could not be recovered to its previous phase even after the situation got normal (Fenech, 2021; Nasution et al., 2021).

The use of digital technology penetrated to the educational routine turning a paradigm shift from natural to virtual miraculous world (Alammary et al., 2014; Atwa et al., 2022). The concept of virtual laboratories and virtual experimentation is one link of that chain and has been proved as a blessing for the developing countries like Pakistan (Kintu et al., 2017; Zhao & Song, 2022). With the use of virtual environments, students of ignored areas which lacked sufficient laboratory facilities, and the students of online/ distance or blended mode of education, can get equal benefits (Thiong et al., 2014). The students while using virtual environments, systematically confronts to different situations which play vital role in their physical and mental development (Rehman et al., 2021a).As Vygotsky indicates that games play a vehicle for learning new concepts (Vygotsky, 1978; Vygotsky & Kozulin, 1986). Regardless of their complexity, the games aid learning process, especially for teaching cause and effect relationships.

In summary, VR technology has the potential to enhance problem-solving skills in biology by providing students with opportunities to engage in immersive, inquiry-based learning experiences, and by offering visualizations of complex biological systems and processes that are difficult to observe in the real world.

Research Objectives

Main research objectives of the study were:

- To investigate the change in level of problem-solving skills in the concept of genetics and evolution, with engagement in virtual environment MEGA (Molecular Evolution Genetic Analysis) version 11.13.
- To investigate the change in level of problem-solving skills in the concept of genetics and evolution, without engagement in virtual environment.

Research Questions

- What change in level of Problem-Solving skills is obtained by students while using virtual environment?
- What change in level of Problem-Solving skills is obtained by students without using virtual environments?

Literature Review

Historical Development of AVR in World and Pakistan getting Behind

Literature indicates that the invention of stereoscope in 1838(Martin, 1988; Woodward et al., 1987), put foundations of use of virtual imaging in the world. View-Master followed this next year, which is still being used today (de Jong, 2011). The start of 3D imaging in 1960s, in the form of "Sensorama" (Jong & Njoo, 1992), and "Ultimate Display" (Newell & Simon, 1961), and "Creation of Aspen Film Maps" (Huppert et al., 1998) put a new wave of innovation to this virtual world imaging.

However, the term "Virtual reality" in its real sense was first used by Lanier (Simmons & Lunetta, 1993), at the end of that decade. Till this time, the virtual reality just meant for symbolism of real world in the form of virtual images whether still or moving.

A novel and great advancement in the term started in 2001, as immersive and non-immersive environment, where the persons experienced themselves to be part of virtual world either by manipulating situations or not. Such displays were named as "SAS Cube rooms" by Z-A productions (Saiz & Klein, 2002), and Google Street View by Google offered stunning views of real world and made them accessible around the globe (Sahin, 2006). Afterwards a mass spread in scope and depth of VR technology was observed. Invention of games and simulations started and a new concept of AR and VR occupied the educational platforms till 2018 (Rehman et al., 2021a).

Standing of Pakistan

Pakistan having standing among the developing countries of world, is yet behind the world in its technological advancements. So, here the use of VR is very low. Only a few companies are providing services to implement technology in educational institutions. NED university was first to establish virtual labs in Pakistan named as "The Grid" (Iqbal et al., 2017) Among others EduSery, Haptica, and STYLY are prominent names who are presenting computer simulation services in Pakistan (Burns & Vollmeyer, 2020). Haptica, EduSery (Wikipedia, 2022), and STYLY are offering different educational simulation software, and laboratories services in Pakistan (Geven & Hasan, 2020; M. A. Nadeem, n.d.). STYLY even conducts various workshops in renowned Pakistani universities to provide awareness and information regarding VR technology.

Still in comparison with the world education systems, use of VR technology in Pakistan is just nominal (Hali et al., 2021). Following figure illustrates the standing of Pakistan with respect to developed counties.

Figure 1. Standing of Pakistan with developed countries w.r.t use of VR technology (A. Nadeem, 2019).

As described in the previous section, Pakistan is very far from world in use of this technology due to lack of resources, to afford supercomputing systems and the other add-ons. For example, Oculus Rift (Zubair & Zubair, 2020) and HTC Vive are two most widely used devices for creating AVR environments which cost 450-650 dollars each (Rehman et al., 2021b). Even then they require to support powerful PCs to run these devices. So, purchasing such systems to develop virtual laboratories for educational institutions is a big challenge for a developing country like Pakistan who has expenditure over education only 2.5 of total GDP (World Bank, 2018).

Therefore, some older low-cost versions or immersive technology (e.g., HMDs) or non-immersive computer simulations, are gradually getting fame in Pakistan (Ameerbakhsh, 2018; Fadi & Aoude, 2015). Different technology companies' sale reality software which requires cell phones instead of a PC or no extra attachments e.g., Gear AVR of Samsung, and Google Daydream require no additional devices as mentioned above (Mcgrath, 2022). These Samsung Gear or Google Daydream just require headphones and smart phones (Burns & Vollmeyer, 2020). But mostly this immersive simulator software is used in gaming instead of educational purpose such as PUBG (Desmeulles et al., 2014). However, the interactions and projections of smartphone display may not give real immersion due to their lower quality images, and limited collaborative powers.

In Pakistani classrooms (especially in secondary and higher secondary levels), the maximum use of technology is limited to the PCs only (Rahmawati et al., 2018). Other technological gadgets such as digital projectors, interactive whiteboards etc. are not used in the schools. Therefore, the use of immersive AVRs is not possible in Pakistani schools. Teachers are bound to perform conventional activities, and reluctant to embrace modern technological developments (Farrell et al., 1999; A. Nadeem, 2019).

Introduction of low-cost non-immersive AVRs considerably supported this mode of education. According to World Bank Report, inadequate education system is major cause of poverty in the small-income countries and the introduction of this AVR technology may enhance quality education for students in developing countries(OECD, 2016) and thus ultimately may lead to poverty eradication (World Bank, 2018). Further various organizations around the world (such as Harvard, and MIT) are providing training courses over the AVR technology.

Problem Based Learning Models (PBM)

Problem solving skills are always considered as base of the progress in science education, as they are itself based on the scientific attitude of investigation. (Syafii & Yasin, 2013) cited a recommendation made by College of Education, University of Washington (2001), according to which, the usage of problem-solving skills aid students to grasp essential knowledge and concepts in better ways.

Usually, PBM is considered as synonym to scientific learning approach including similar steps such as 1) identifying problem; 2) selecting all possible solutions to the problems; 3) identifying best possible solution to the problem; 4) trying out the selected solution; and 5) presenting the findings under the guidance of teachers (Annetta et al., 2010; Smith & Duncan, 2011). Getting through these steps, indulge students completely to their assignments. It indicates the ability to fully understand and master the fundamental concepts. Thus, the concept of constructivist learning is built up using the PBL environments.

Use of VR in Enhancing Problem Solving Skills

In the present era of technology, the use of AVR is proved to have multidimensional significance. Firstly, they provide a novelty of learning experience taking away from the old-fashioned classrooms. Thus, they are getting popular being more attractive and convenient for the young generations who are getting bored from the old fantasies. The novelty of the experiments enhances their motivation and enthusiasm towards learning. The tasks are practised as many times as the students want (Morimoto & Ponton, 2021). Further the specimens are not let to decay, or disrupt (Aseeri, 2013; Qayyum et al., 2024).

Secondly, the use of AVR stimulate heutagogic/constructivist learning atmosphere by making students independent learners as compared to traditional classrooms i.e., the students need to ask less questions and conversations with their teachers and fellows as they are expected to do otherwise (Tabassum et al., 2024; Youngblut, 1998).

Thirdly, the virtual world allows everyone to share and contribute in educational cycle making them free from the constraints of age, time or status. Thus, they are equally useful for the online, blended and face-to-face classrooms. They are equally useful for the students with some impairments (Dilshad et al., 2016; Tibola et al., 2019).

Fourthly, they provide completely unlimited access to records, books or posts. Sometimes these are only way to investigate real-life systems. These are useful to investigate peace of behaviour under controlled conditions (Hite, 2022). They help to compare alternative way of teaching. Instead of the various drawbacks of examination systems in Pakistan (which is not going to be discussed in detail here being irrelevant to the topic under study), the VR records the step-by-step progress of the learner (Mohammad Babateen, 2011; Rahman et al., 2022; Savvides, 2018). Thus, it provides better, unbiased and more valid assessment procedure. There is no need of invigilator to catch on senses of students.

Theoretical Background

The theoretical background of the AVR leads to the constructivist approach (main proponents: Piaget (1896-1980); Vygotsky (1896-1943); Dewey (1859-1952); and Bruner (1915-2016). The concept of Piaget, and Dewey, assert the importance of activity-based learning as the basis of science learning. Vygotsky adds the construction of new experiences over the previous concepts (zone of proximal development) (Chang et al., 2020).

The problem-based method is used as modern constructivist learning approach with which, some sort of understanding, and concept mapping is made while trying out different solutions to find answers of given problems (Rasheed et al., 2021). This approach focuses on the scaffolding to prompt cues, or tools to assist in learning.

The technology integration aids this scaffolding process and transforms the learning process from teacher-centred to the learner-centred (Duwain Brazley, 2018). Computer simulation, being one of the emerging technologies in Pakistan, allow learners to develop habits of self-monitoring and self-paced (heutagogy) (Marín Morales, 2020). Whereby, each step of given problem is monitored by computer program itself, which makes the teacher free from observing each student's work individually and where chance of human error of missing observation is always left (Bailey, 2017).

Thus, the concept of scaffolding through AVR computer simulations embraces the theoretical foundations of Dewey, Piaget and Vygotsky (Madden et al., 2020; Thompson et al., 2020). The problem-solving concepts completes their theories of accommodation, and assimilation built on the previous concepts of genetics and evolution.

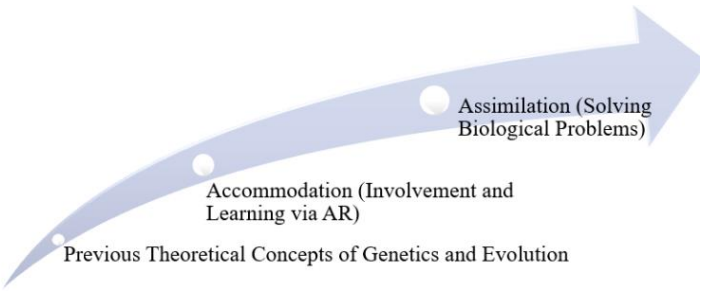

Figure 2. *Theoretical Foundations of the Study.*

The students were engaged in the previously taught concept of genetics and evolution in computer simulations program MEGA. This provided a platform for the students and even teachers to reflect their own learning and analyse different steps of genetics and evolutionary process. These reflective practices built metacognitive strategies within students and increased motivation for student learning (Annetta et al., 2009; Martínez Fernández, 2020).

Conceptual framework of the study

The conceptual framework of the study was based on comparison between two learning situations i.e., in-vitro where interaction between human and laboratory instruments is observed; and in-silico, where the interaction between human and virtual environment in the form of computer simulation MEGA was observed.

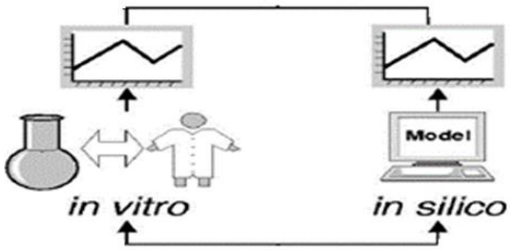

Figure 3. *The Conceptual Framework for the Study*

Delimitations of the study

- Secondary students of 10th class who already had studied the chapters of Darwinism and genetics.
- The government schools of south Punjab, who usually lacked laboratory facilities.
- An explanatory mixed method design, with quantitative experimental work, and qualitative interview protocols.

Research methodology

The study was mixed method explanatory research i.e., the quantitative method followed by the qualitative method. The quantitative step included pre-test post-test control group experimental design which is highly recommended design by the research experts (Gay, 2012) i.e.,

Table 1
Description of Study Design

Group	Pre-test(O1)	Treatment (X)	Post-test (O2)
Experimental Group (E)	Yes	Yes	Yes
Control Group (C)	Yes	No	Yes

While the qualitative part of the study included interview protocol, which included the students' feedback regarding the effectiveness, hurdles and feasibility of the study. Following figure gives a summary of complete study methodology.

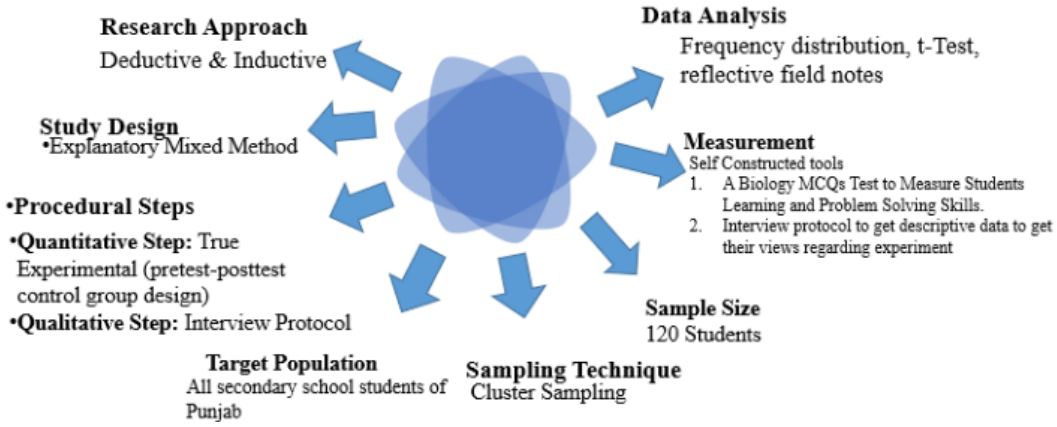

Figure 4. *Summary of Research Methodology*

Population and Sample

Population of study included all students from government schools in southern Punjab, who usually face various instructional issues regarding the facilities and competencies of laboratory work.

A sample of 120 students was selected using cluster sampling technique. The total sample was divided into two groups i.e., experimental and control group. The both groups were equated on their competence level, based on their previous results.

Description of Research Instruments

Brief description of the research tool is summarised in following figure.

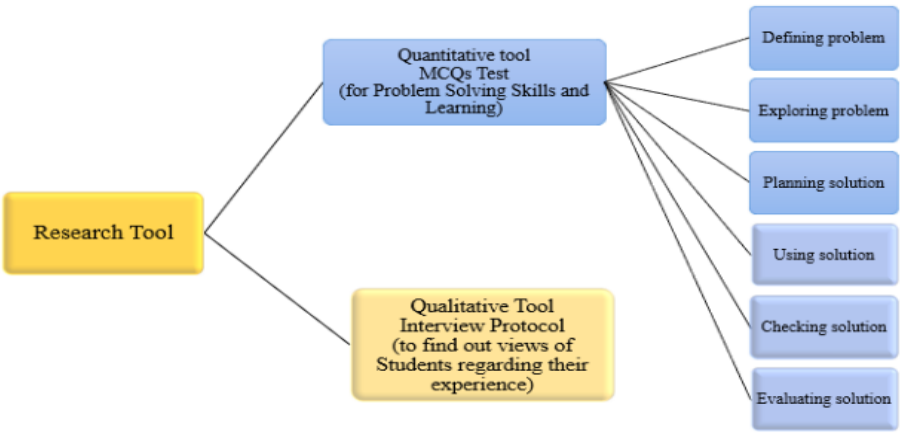

Figure 5. *Detailed description of the Study Tools*

Validation of Research Instruments

The tools were validated by content and construct validity i.e.,

- At first, both of the research tools were got validated by expert review. The content validity of the tool was found by the expert-review. The criteria for the validation were set as approval from 80% of the experts as described by (Fraenkel et al., 2012).
- The second tool comprised a paper designed on Multiple Choice items and was got validated by statistical analysis i.e., discriminant validity and reliability co-efficient.
- The construct validity of the tool was determined by Average Variance Extraction (AVE). Acceptance criteria as proposed by (Hair et al., 2018), was that each latent construct should be greater than that of the highest squared correlation of the other laten constructs. The values of the discriminant validity are stated in following table:

Table 2
Discriminant Validity of the Study Tool

	Defining Problem	Exploring Problem	Plan moderation	Selection of suitable plan	Implementation of selected solution	Self-evaluation of tried
Defining Problem	1.00					
Exploring Problem	0.03	0.65				
Plan moderation	-0.01	0.16	0.49			
Selection of suitable plan	0.02	0.42	0.07	0.68		
Implementation of selected solution	0.05	0.55	0.20	0.36	0.67	
Self-evaluation of tried method	-0.05	0.19	-0.07	0.21	0.10	0.71

The reliability analysis of the tool was found by Cronbach Alpha. Hair et al., (2018) further described the acceptance criteria for the Cronbach Alpha as acceptable in the range of 0.45-0.59; average in the range of 0.60-0.69; adequate in the range of 0.70-0.79; good in the range of 0.80-0.89; and excellent when above 0.90. The reliability analysis of the tool revealed value of Cronbach Alpha was found as 0.89 which was considered as good as per aforementioned criteria.

Execution of experiment

The concept of evolution was taught to the both groups. The experimental group was taught using most frequently used Mendelian genetics was selected for that purpose using MEGA (Molecular Evolutionary Genetics Analysis) software version 11. It provides user-friendly platform for analysing DNA and protein sequences, and exploring patterns of genetic change. Moreover, it is efficient as it can be run on the computer as well on the mobiles as well. Moreover, the software further aids those who adopts biology as major advancement in career as it leads to the bioinformatics as well. The version of MEGA taken for the present study was only free or trial version which was easily available for all students anywhere. The software was first created since 1990 and is widely used till now in various genetic studies (Kumar et al., 2016, 2024; Stecher et al., 2020; Tamura et al., 2013, 2021).

The program content was aligned with the curricular content. The concept of evolution to be run in the software involved two-step process i.e., multiple sequence alignment and phylogenetic tree construction. The exemplary data set was prepared by the researched which included the DNA sequences from three different genus's of sweet pea plant which is a subject of common interest in secondary classes.

The experiment was executed for two weeks. afterwards a MCQ test was constructed for the measurement of problem-solving skills and learning process. The same test was administered as pre-test and post-test. The indicators used in the test included: the ability to identify problem; ability to collect/ process data; ability to plan solution; ability to execute the plan and solve problem; and the ability to evaluate their own problem-solving process.

Data analysis plan

The results of the study were recorded in SPSS. Data analysis included frequency distribution and t-test. While, the interviews were summarised and themes were generated using those interviews.

Study Findings

For each study objective findings of the study are described by following tables:

The main objective of the study was to compare results of pre-test for each of the experimental and control group. T-test was used for that purpose. The results of this statistics are given in following table.

Table 3
Scores of the Experimental and Control Group on Pre-test

Groups	Mean	SD	Mean Diff	t-Value	Sig.	Effect size
Experimental Group	16.70	2.41	0.12	-0.67	0.51	.037
Control Group	16.58	2.07				

It is clearly described by the table that there was insignificant mean difference on t-test for the results of pre-test of experimental and control group. The mean difference value (.12), p-value (.51), and effect size (.037) indicated a negligible difference between both groups. This indicates that the both groups were of equal calibre on initial stage. After the introduction of treatment (X), the both groups were post-tested and the following tables describe the results of post-test for both groups.

Table 4
Scores of the Control Group on Pre-test and Post-test

Group	Mean	SD	Mean Diff	t-Value	Sig.	Effect size
Pre-Test	16.70	2.41	5.48	-8.70	0.00	.047
Post-Test	22.18	2.15				

The table indicates the difference of pre-test and post-test results of the control group. The mean difference (5.48), and p-value (0.00), indicated that the after the intervention of the experiment, control group gain was significant. However, the and effect size (.47) value indicated that the inclusion of traditional method to the students is still less applicable near to medium power of the data difference.

Next, the same was also determined for the experimental group on pre-test and post-test as well.

Table 5
Scores of the Experimental Group on Pre-test and Post-test

Group	Mean	SD	Mean Diff	t-Value	Sig.	Effect size
Pre-Test	16.58	2.08	17.67	-21.14	0.00	.078
Post-Test	34.25	2.85				

The table depicts the scores of experimental groups before and after the intervention of experiment. The results of mean difference (17.67); t-value (21.14) and p-value (0.00) indicate an obvious gain in the problem-solving skills of the experimental group. Moreover, the value of effect size (.78) indicates a good power to the statistical analysis. This indicates that the data is generalisable to the students' population of similar characteristics

Both of the above tables indicate that the both experimental and control group were showing significant gain after the intervention of the treatment. However, to find out net-gain, a comparison of both (experimental and control) groups on post-test was also determined.

Table 6
Scores of the Experimental and Control Group on Post-test

Group	Mean	SD	Mean Diff	t-Value	Sig.	Effect size
Experimental Group	34.25	2.85	12.07	9.35	0.00	.068
Control Group	22.18	2.15				

The table describes the comparison of post-test results of the both experimental and control group. It was indicated that a significant mean difference of both groups on post-test. Moreover, the mean value of the experimental group was clearly high than that of

the control group. The mean difference value 12.07 was taken as the net gain of the intervention. The effect size .68 indicated a medium strength to the statistical power analysis. Which indicated that the difference is moderately applicable to the population.

As, the study was designed on sequential explanatory mixed method approach, the next step was to explore the issues faced by the students during the intervention of the treatment. For that purpose, interview protocol was used with the students of both groups. The themes generated from the interviews i.e., the AVR is found to be very interesting for the students. However, the students needed a sufficient training session for the intervention of the treatment. It could also be proved good for further advancement in the field. It was also expressed by some students that, this AVR session would be more useful in higher classes rather than secondary level.

Discussion

Findings of study indicated interesting results i.e., the comparison of experimental and control group indicated insignificant mean difference which means that the both groups were equal at initial qualification. After the intervention of computer simulation, results were compared between both experimental and control groups. The results of post-tests indicated a significant mean difference from pre-tests in experimental group. But the results of control group also indicated significant mean difference on post-test than pre-test results. To observe main gain scores, the post-test results of both groups were compared. It indicated again significant mean difference in favour of experimental group.

Literature indicated mixed results on use of computer simulations i.e., the studies made by Iqbal et al. (2016), and Rehman et al. (2021) indicated positive outcomes from the use of computer simulated environments. However, the contrary results also were observed in the researches. Usually researchers who reached these findings, further supposed that the virtual world cannot compete the genuine handling of instruments in laboratory. Therefore, the students who got real-world experimentation scored better than that of those who used simulated environments (Aftab Alam, 2017; Falode & Gambari, 2017; Potkonjak et al., 2021; Scheckler, 2003).But a supposition for this difference can also be stated as, the present study was not meant for the academic performance, rather it was meant for the problem-solving skills in science experimentations. Meta-analysis made by Azizah and Aloysius (2021) also indicated that the problem-solving skills are raised by the use of repeated manipulation of simulated environments. Thus, many researchers even supported the fact that the virtual laboratories can become a good asset for school curricula in the present era of technological revolution (Almuqbil, 2020; Caratachea, 2021; Papaconstantinou et al., 2020).

Further probe into the matter was made by qualitative phase of study, which indicated that students raised the students' interest towards use of the simulated environments. But they had to face various challenges while learning computer simulations. They also were of the point, that the virtual world cannot replace real-world altogether. These findings were further discussed in the study made by Ngoyi (2013) where he asserted that in spite of challenges associated with the virtual laboratories, their benefits are more precious than that of the challenges. Researchers further asserted that the challenges can be overcome by various ways. Angel-Urdinola et al. (2021) asserted that the technology otherwise would remain inaccessible to the students, if not used via AVR or VR. Therefore, there is need to overcome challenges with its use instead of avoiding that. VR training trends as part of professional development of teachers, can be a right way towards and efficient instruction to develop students' technical, practical and socio-economical skills as well to enhance its generalisability. Similarly, Shin (2021) asserted that measures adopted to change teachers' behaviours towards empathy, collaboration can be helpful to overcome issues arising during VR class such as difficulty level, learning speed etc. Sundblad (2018) overviewed that work on VR programming, can be helpful in making it easier and user friendly. (Trentsios et al., (2020) concluded that the issues of control and immersive sickness created with the HTC Vive system and Head Mounted Display (HMD, VR glasses), can be overcome by using alternative ways such as WebGL (Web Graphic Library) applications. The access to 3D atmosphere in web browsers (such as LabVIEW) in this way leads to the direct integration of student with the e-learning environment.

Conclusions

The findings and discussion of the study, led to conclude that the virtual reality can be a good but not best alternate for the physical laboratories. However, they are more preferrable to stimulate problem solving skills among the students. The issues faced by students for learning computer simulation programs, can be resolved easily by competent teachers and staff development in this regard. Single computer lab, can become a science lab for the students as well.

Recommendations

1. For administration and students
    - Incorporating the AVR in science teaching especially in Biology course.
    - Getting different forms of non-immersive or semi-immersive AVR in the Biology labs, and mobile apps.

2. For future researchers
    - Using experiments with different varieties of AVR to check its further feasibility.
    - Making a replication study on demographic differences to determine widened generalizability of the study findings.

References

Aftab Alam. (2017). *A Student Friendly Framework for Adaptive 3D-Virtual Learning Environments* [PhD Dissertation]. University of Malakand.

Alammary, A., Sheard, J., & Carbone, A. (2014). Blended learning in higher education: Three different design approaches. *Australasian Journal of Educational Technology*, *30*(4), 440–454. https://doi.org/10.14742/ajet.693

Almuqbil, N. S. M. (2020). A Proposal for Virtual Laboratories in Learning Biology for Secondary School Curriculum. *Journal of Educational and Social Research*, *10*(6), 323–331. https://doi.org/10.36941/jesr-2020-0130

Ameerbakhsh, O. (2018). *Towards the Use of Interactive Simulation for Effective e-Learning in University Classroom Environment* [PhD Thesis]. University of Stirling.

Angel-Urdinola, D. F., Castillo-Castro, C., & Hoyos, A. (2021). *Meta-Analysis Assessing the Effects of Virtual Reality Training on Student Learning and Skills Development* (9587; Policy Research Working Paper Series). http://www.worldbank.org/prwp.

Annetta, L. A., Cheng, M., & Holmes, S. (2010). Assessing twenty-first century skills through a teacher created video game for high school biology students. *Research in Science & Technological Education*, *28*(2), 101–114. https://doi.org/10.1080/02635141003748358

Annetta, L. A., Minogue, J., Holmes, S. Y., & Cheng, M. T. (2009). Investigating the Impact of Video Games on High School Students' Engagement and Learning about Genetics. *Computers and Education*, *53*(1), 74–85. https://doi.org/10.1016/j.compedu.2008.12.020

Aseeri, S. A. (2013). *Virtual Reality Interaction using Mobile Devices* [MS Thesis]. King Abdullah University of Science and Technology.

Atwa, H., Shehata, M. H., Al-Ansari, A., Kumar, A., Jaradat, A., Ahmed, J., & Deifalla, A. (2022). Online, Face-to-Face, or Blended Learning? Faculty and Medical Students' Perceptions During the COVID-19 Pandemic: A Mixed-Method Study. *Frontiers in Medicine*, *9*(February), 1–12. https://doi.org/10.3389/fmed.2022.791352

Azizah, N., & Aloysius, S. (2021). The Effects of Virtual Laboratory on Biology Learning Achievement: A Literature Review. *Advances in Social Science, Education and Humanities Research: Proceedings of the 6th International Seminar on Science Education*, 1–10.

Bailey, J. (2017). *Perceptual and Social Realism in Virtual Reality: The Effect of Immersion on Children's Psychological Responses* [PhD Thesis, Stanford University]. http://purl.stanford.edu/pn714rr1906

Burns, B. D., & Vollmeyer, R. (2020). *Problem Solving: Phenomena in Search of a Thesis*.

Caratachea, M. X. (2021). *Immersive Virtual Reality as a Tool to Make in K-12 Environments* [PhD Thesis, Virginia Commonwealth University]. https://scholarscompass.vcu.edu/etd/6811

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual Reality Sickness: A Review of Causes and Measurements. *International Journal of Human-Computer Interaction*, 1658–1682. https://doi.org/10.1080/10447318.2020.1778351

de Jong, T. (2011). Instruction based on computer simulations. *Handbook of Research on Learning and Instruction*, *3*, 446–466.

Desmeulles, G., Querrec, G., Redou, P., Kerdelo, S., Misery, L., & Jacques, T. (2014). The Virtual Reality Applied to the Biology Understanding: the in Virtuo Experimentation. *Expert Systems with Applications*, *30*(1), 82–92. https://doi.org/10.1016/j.eswa.2005.09.051

Dilshad, M., Malik, ana, & Ijaz Latif, M. (2016). Impact of Computer Simulation on the Achievement of Biology Students at Secondary Level. *Pakistan Journal of Social Sciences (PJSS)*, *36*(2), 1205–1214.

Duwain Brazley, M. (2018). Architecture, Virtual Reality, Spatial Visualization, Learning Styles, and Distance Education. *International Journal of Architecture, Arts and Applications*, *4*(2), 10. https://doi.org/10.11648/j.ijaaa.20180402.11

Fadi, M., & Aoude, N. (2015). *The Impact of Integrating Computer Simulations on the Achievement of Grade 11 Emirati Students in Uniform Circular Motion* [PhD Thesis, United Arab Emirates University College of Education]. https://scholarworks.uaeu.ac.ae/all_theses

Falode, O. C., & Gambari, A. I. (2017). Evolution of Virtual Laboratory Package on Nigerian Secondary School Physics Concepts. *Turkish Online Journal of Distance Education (TOJDE)*, *18*(2), 168–178.

Farrell, G. M., Type, P. U. B., & Price, E. (1999). *The Development of Virtual Education: A global perspective*.

Fenech, R. (2021). Blended learning: Honouring students' Psychological Contract. *Cogent Education*, *8*(1), 1–13. https://doi.org/10.1080/2331186X.2021.1914286

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to Design and Evaluate Research in Education* (8th ed.). McGraw Hill.

Geven, K., & Hasan, A. (2020). *Learning Losses in Pakistan due to Covid-19 School Closures: A Technical Note on Simulation Results*.

Hair, J. F., Babin, B. J., Anderson, R. E., & Black, W. C. (2018). *Multivariate Data Analysis* (8th ed.). Pearson.

Hali, A. U., Aslam, S., Zhang, B. H., & Saleem, A. (2021). An Overview on STEM Education in Pakistan: Situation and Challenges. *International Transaction Journal of Engineering*, *12*(1), 1–9. https://doi.org/10.14456/ITJEMAST.2021.20

Hite, R. (2022). Virtual Reality: Flight of Fancy or Feasible? Ways to Use Virtual Reality Technologies to Enhance Students' Science Learning. *American Biology Teacher*, *84*(2), 106–108. https://doi.org/10.1525/abt.2022.84.2.106

Huppert, J., Yaakobi, J., & Lazarowitz, R. (1998). Learning Microbiology with Computer Simulations: students' academic achievement by method and gender. *Research in Science & Technological Education*, *16*(2), 231–245. https://doi.org/10.1080/0263514980160210

Iqbal, M. A., Islam, M. A., Aleem, M., & Murtaza, H. (2016). *Computer Network Simulation Using OMNET++*. https://doi.org/10.1201/9781315367286

Iqbal, M. A., Islam, M. A., Aleem, M., & Murtaza, H. (2017). *Computer Network Simulation using OMNET++ (A Practical Approach)*. www.hec.gov.pk

Jong, T. De, & Njoo, M. (1992). *Learning and instruction with computer simulations: Learning processes involved* (pp. 411–427). http://doc.utwente.nl/27111/1/K27111__.PDF

Kintu, M. J., Zhu, C., & Kagambe, E. (2017). Blended learning effectiveness: the relationship between student characteristics, design features and outcomes. *International Journal of Educational Technology in Higher Education*, *14*(7), 1–20. https://doi.org/10.1186/s41239-017-0043-4

Kumar, S., Stecher, G., Suleski, M., Sanderford, M., Sharma, S., & Tamura, K. (2024). MEGA12: Molecular Evolutionary Genetic Analysis Version 12 for Adaptive and Green Computing. *Molecular Biology and Evolution*, *41*(12). https://doi.org/10.1093/molbev/msae263

Kumar, S., Stecher, G., & Tamura, K. (2016). MEGA7: Molecular Evolutionary Genetics Analysis Version 7.0 for Bigger Datasets. *Molecular Biology and Evolution*, *33*(7), 1870–1874. https://doi.org/10.1093/molbev/msw054

Madden, J., Pandita, S., Schuldt, J. P., Kim, B., Won, A. S., & Holmes, N. G. (2020). Ready student one: Exploring the predictors of student learning in virtual reality. *PLoS ONE*, *15*(3). https://doi.org/10.1371/journal.pone.0229788

Marín Morales, J. (2020). *Modelling Human Emotions using Immersive Virtual Reality, Physiological Signals and Behavioural Responses* [PhD Thesis]. Universitat Politècnica de València.

Martin, A. (1988). Out of the Screen: Computers and Simulation. *Simulation/Games for Learning*, *18*(1), 21–29.

Martínez Fernández, Á. (2020). *GeneNet VR: Large Biological Networks in Virtual Reality Using Inexpen-sive Hardware* [PhD Dissertation, The Arctic University of Norway]. http://github.com/egraff/uit-thesis

Mcgrath, M. (2022). *An Evaluation of Virtual Reality (VR) as a Learning Tool for Students with the Aid of an Interactive VR Simulation Program* [MS Thesis]. Galway-Mayo Institute of Technology.

Mohammad Babateen, H. (2011). The role of Virtual Laboratories in Science Education. *5th International Conference on Distance Learning and Education*, *12*, 100–105.

Morimoto, J., & Ponton, F. (2021). Virtual Reality in Biology: Could we become Virtual Naturalists? *Evolution: Education and Outreach*, *14*(1). https://doi.org/10.1186/s12052-021-00147-x

Nadeem, A. (2019). Virtual Reality Educational Transforms and Prospect for Pakistan. *Muslim Perspectives*, *IV* (2), 79–101.

Nadeem, M. A. (n.d.). *Virtual Reality Educational Transforms and Prospect for Pakistan 79 Virtual Reality Educational Transforms and Prospect for Pakistan*.

Nasution, A. K. P., Surbakti, A. H., Zakaria, R., Wahyuningsih, S. K., & Daulay, L. A. (2021). Face to Face Learning vs Blended Learning vs Online Learning (Student Perception of Learning). *Journal of Physics: Conference Series*, *1783*(1). https://doi.org/10.1088/1742-6596/1783/1/012112

Newell, A., & Simon, H. A. (1961). Computer simulation of human thinking. In *Science* (Vol. 134, Issue 3495, pp. 2011–2017). https://doi.org/10.2307/1708146

OECD. (2016). *Skills for a Digital World*.

Ohn, M., Souza, U., & Ohn, K. (2020). A qualitative study on negative attitude toward electrocardiogram learning among undergraduate medical students. *Tzu Chi Medical Journal*, *32*(4), 392–397. https://doi.org/10.4103/tcmj.tcmj_91_19

Papaconstantinou, M., Kilkenny, D., Garside, C., Ju, W., Najafi, H., & Harrison, L. (2020). Virtual Lab Integration in Undergraduate Courses: Insights from Course Design and Implementation. *Canadian Journal of Learning and Technology*, *46*(3), 1–18. https://www.labster.com/

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2021). *Virtual Laboratories for Education in Science, Technology, and Engineering: A Review*. http://www.edleader21.com

Qayyum, A., Tabassum, R., Fatima Kashif, M., & Professor, A. (2024). The Digital Divide in Early Childhood Education: A Study of ECE Teachers' Perceptions. *Journal of Development and Social*, *5*(2), 2709–6262. https://doi.org/10.47205/jdss.2024(5-II-S)52

Rahman, F., Feekra, R., Baishakhi, B., & Kishor Morol, M. (2022). A Systematic Review on Interactive Virtual Reality Laboratory. *Interactive Learning Environments*, *1*(1), 1–10.

Rahmawati, D., Sajidan, S., & Ashadi, A. (2018). Analysis of problem-solving skill in learning biology at senior high school of Surakarta. *Journal of Physics: Conference Series*, *1006*(1). https://doi.org/10.1088/1742-6596/1006/1/012014

Rasheed, G., Khan, M., Malik, N., & Akhunzada, A. (2021). Measuring learnability through virtual reality laboratory application: A user study. *Sustainability (Switzerland)*, *13*(19). https://doi.org/10.3390/su131910812

Rehman, N., Zhang, W., Mahmood, A., & Alam, F. (2021a). Teaching physics with interactive computer simulation at secondary level. *Cadernos de Educação Tecnologia e Sociedade*, *14*(1), 127. https://doi.org/10.14571/brajets.v14.n1.127-141

Rehman, N., Zhang, W., Mahmood, A., & Alam, F. (2021b). Teaching Physics with Interactive Computer Simulation at Secondary Level. *Brazilian Journal of Education, Technology and Society (BRAJETS) Br. J. Ed., Tech. Soc*, *14*(1), 127–141. https://doi.org/10.14571/brajets.v14.n1

Sahin, S. (2006). Computer simulations in science education: Implications for distance education. *Turkish Online Journal of Distance Education*, *7*(4), 132–146.

Saiz, L., & Klein, M. L. (2002). Computer simulation studies of model biological membranes. *Accounts of Chemical Research*, *35*(6), 482–489. https://doi.org/10.1021/ar010167c

Savvides, P. (2018). *Teaching Science Lab Safety: Are Virtual Simulations Effective?* [PhD Thesis]. Arizona State University.

Shin, D. Bin. (2021). *Exploring the Role of Virtual Reality Perspective Taking on Teachers' Cognitive Empathy: An Action Research Study* [PhD Thesis, The Faculty of the School of Education, The College of William & Mary in Virginia]. https://doi.org/10.25774/w4-56nt-qs91

Simmons, P. E., & Lunetta, V. N. (1993). Problem-solving behaviours during a genetics computer simulation: Beyond the expert/novice dichotomy. *Journal of Research in Science Teaching*, *30*(2), 153–173. https://doi.org/10.1002/tea.3660300204

Smith, V. A., & Duncan, I. (2011). *Descriptive Account: Biology Students Building Computer Simulations Using Star Logo TNG*. *18*(December).

Stecher, G., Tamura, K., & Kumar, S. (2020). Molecular Evolutionary Genetics Analysis (MEGA) for macOS. *Molecular Biology and Evolution*, *37*(4), 1237–1239. https://doi.org/10.1093/molbev/msz312

Sundblad, G. (2018). *Virtual Reality and its Impact on Programming Learning Process Designing VR-based Programming Learning Practices* [BS Thesis]. Malmo University.

Syafii, W., & Yasin, R. M. (2013). Problem Solving Skills and Learning Achievements through Problem-Based Module in Teaching and Learning Biology in High School. *Asian Social Science*, *9*(12), 220–228. https://doi.org/10.5539/ass.v9n12p220

Tabassum, R., Saleem, S., & Taj, S. (2024). Relationship between Multiple Intelligences and Digital Literacy Skills among University Students. *Journal of Social Research Development*, *5*(2), 70–83. https://doi.org/10.53664/jsrd/05-02-2024-06-70-83

Tamura, K., Stecher, G., & Kumar, S. (2021). MEGA11: Molecular Evolutionary Genetics Analysis Version 11. *Molecular Biology and Evolution*, *38*(7), 3022–3027. https://doi.org/10.1093/molbev/msab120

Tamura, K., Stecher, G., Peterson, D., Filipski, A., & Kumar, S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis Version 6.0. *Molecular Biology and Evolution*, *30*(12), 2725–2729. https://doi.org/10.1093/molbev/mst197

Thiong, J. K., Ndirangu, M., & Okere, M. (2014). *Effects of computer-based simulation module on secondary school students' achievement in understanding of magnetic effect of electric current*. *2*(8), 96–102.

Thompson, M., Wang, A., Bilgin, C. U., Anteneh, M., Roy, D., Tan, P., Eberhart, R., & Klopfer, E. (2020). Influence of Virtual Reality on High School Students' Conceptions of Cells. *Journal of Universal Computer Science*, *26*(8), 929–946. https://hdl.handle.net/1721.1/130512

Tibola, L. R., Herpich, F., Silva, P. F. da, & Tarouco, L. M. R. (2019). Experience in Teaching Science in Virtual Environment. *International Journal for Innovation Education and Research*, *7*(4), 23–43. https://doi.org/10.31686/ijier.vol7.iss4.1375

Trentsios, P., Wolf, M., & Frerich, S. (2020). Remote Lab meets Virtual Reality - Enabling immersive access to high tech laboratories from afar. *Procedia Manufacturing*, *43*, 25–31. https://doi.org/10.1016/j.promfg.2020.02.104

Vygotsky, L. S. (1978). *Mind in Society* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.; 3rd ed.). Harvard University Press, Cambridge, Massachusetts, London, England. http://ouleft.org/wp-content/uploads/Vygotsky-Mind-in-Society.pdf

Vygotsky, L. S., & Kozulin, A. (1986). *Thought and language: Vol. null* (null, Ed.).

Wikipedia. (2022, September 29). *Supercomputing in Pakistan*. Wikimedia Foundation.

Woodward, J., Carnine, D., & Gersten, R. (1987). Teaching Problem Solving through Computer Simulation. *American Educational Research Journal*, *25*(1), 72–86. https://doi.org/10.3102/00028312025001072

World Bank. (2018). *Ending Learning Poverty: What Will It Take?* https://doi.org/10.1089/pho.2018.4550

Youngblut, C. (1998). *Educational Uses of Virtual Reality Technology*.

Zhao, S., & Song, J. (2022). Unpacking the Emotional Experiences of Learners in a Blended Learning Context. *Frontiers in Psychology*, *13*(May), 1–10. https://doi.org/10.3389/fpsyg.2022.879696

Zubair, U., & Zubair, Z. (2020). Surgical resident training in Pakistan and benefits of simulation-based training. In *Journal of the Pakistan Medical Association* (Vol. 70, Issue 5, pp. 904–908). Pakistan Medical Association. https://doi.org/10.5455/JPMA.282116