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The Design Principles of 3D-Virtual Reality Learning Environment (3D-VRLE) in Science Education

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ABSTRACT

Background: 3D-Virtual Reality Learning Environments (3D-VRLEs) have proven effective in stimulating student engagement in teaching and learning processes. However, some principles should be considered before introducing and implementing these learning environments in science education. This paper aims to document the principles that guide the design and development of the 3D-VRLE in science education and to draw the implications for the Omani educational context.

Methods: A design-based research (DBR) methodology was conducted to gather data using two instruments: literature review and semi-structured interviews. One specialist developer and two Subject Matter Experts were selected for interviews using purposeful sampling. The in-person interviews consisted of seven questions and a three-hour discussion. The questions were centered on the technological features of 3D-VRLE applications, the instructional design process used to develop these educational applications, and the design principles used in their development. Keywords used for the literature review included biology, physics, chemistry, science, DBR, 3D-virtual reality, lab, and learning environment. Inductive thematic analysis was used as a technique for analyzing the interview data.

Results: The findings pointed to a systematic and planned design process for 3D-VRLE in accordance with the ADDIE model. It was found that the design principles of the 3D-VRLE should include authentic and instructionally grounded systems, a collaborative and motivating environment, and student-centered instruction.

Conclusion: 3D-VRLEs may have significant implications for the teaching of science in terms of the physical arrangement of classrooms, the way the teacher delivers the topic, the number of students in the classroom, and the type of technology that needs to be adopted in schools. This study presented the blueprints required by Omani science curriculum designers for the design/development of 3D-VRLE. This allows them to take the initiative in design and production of relevant learning materials and products and use them effectively in the educational context of Oman.

Keywords: 3D-virtual reality learning environment, Design principles, Design-based research, Science education, Oman

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Introduction

Researchers may interpret the 3D-virtual reality learning environment (later, 3D-VRLE) in different ways (1). It can be defined as a humanoid computer environment that creates an authentic immersive experience by altering objects and digital data into a displayable and even tangible three-dimensional world (1-3). Matsui & Terence (4) demonstrate the use of 3D-VRLE by adapting it to their purposes or measuring its impact utilizing current infrastructure and platforms. They believe that using 3-D simulations, games, and virtual environments (VEs) for teaching and learning, has enormous promise. Furthermore, researchers have also identified numerous conceivable advantages of applying virtual reality in classrooms (5). For example, Sarac (6) and Alper et al. (7) argue that virtual environments set the stage for increased performance and a higher level of learning. Bonner et al. (8) indicate how virtual reality provides learners with a special learning experience by enabling them to interact with numerous situations at any time and in any place. Another area of interest in 3D-VRLE research is the ability to physically explore objects that are not accessible in reality, allowing learners to better understand and memorize them while also reducing learning transfer issues (9). Although employing a 3D-VLE to encourage and engage students in learning is an appealing and valuable endeavor, there are some principles that must be considered when introducing and implementing these types of learning environments in the teaching and learning processes (1). The basic principles as presented in many studies are discussed in this paper (6, 10-12). Therefore, this paper documents the principles used to guide the design of 3D-VRLE and draws implications for the Omani context.

Design Strategies and Principles of 3D-VRLE

Design Strategies: Kapp (13) contends that designers must choose the correct strategy as a good starting point for creating meaningful instruction with Virtual Reality. He suggests that three instructional strategies must be considered when creating a 3D-VRLE experience: conceptual orienteering, critical incident, and operational application. These strategies are elaborated as follows:

1. The first design strategy is conceptual orienteering, which entails building a virtual reality scenario wherein learners are given examples to help them understand fundamental concepts.

2. The critical incident is the second design strategy, which requires students to learn how to plan or conduct activities that are unexpectedly risky when implemented in the actual world.

3. The operational application is the third design strategy, which entails interacting with and manipulating objects in order to achieve competency in functionality and performance.

Design Principles: Kapp (13) outlines seven fundamental principles that need to be designed in any 3D-VRLE to enable learners to have tangible learning results (Figure 1).

The following points address the above-mentioned principles:

1. Instructionally Grounded. It is critical for learning to be tailored to meet a proven educational need, and a learning solution should be the best and most cost-effective option to address any shortfalls. This premise is essential for any instructional intervention.

2. Participant Centered. In a 3D-VRLE learning experience, the students should be

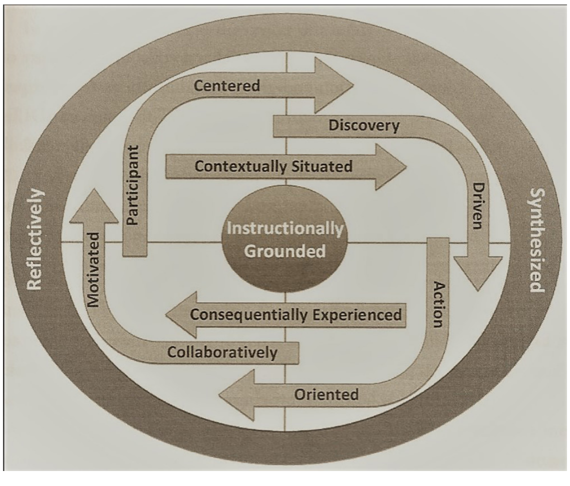

Figure 1: VR Design Principles (Kapp, 2017)

at the center of the learning experience and the locus of control should shift from the teacher to the learners. However, Kapp (13) argues that the designers must construct a learning experience that blends material and procedure to the point where the boundary between learning and doing is practically unnoticeable.

3. Contextually Situated. The context of the 3D-VRLE must be real and actionable. At the same time, it must be circumscribed in such a way that all students' learning objectives are accomplished without being too evident or difficult. The context of the 3D-VRLE experiences, in this study, is authentic and realistic because all the explained examples in the 3D-lessons are related to the daily life and learning experiences of students.

4. Action Oriented. 3D-VRLE experiences need to be centered on action. Designers must develop an environment in which the learning objectives are embedded in a real-world activity. The design suffers greatly if the student is merely exposed to a 3D environment without engaging in any interaction. One should, however, consider enhancing the VRLE experience with action and movement. This will encourage learners to take action and make the necessary and meaningful movements.

5. Consequentially Experienced. Both erroneous and correct actions in a 3D-VRLE experience should have direct, meaningful, and realistic implications. Students should be expected to demonstrate their ability to complete a specific task or challenge in these environments, and they should be given feedback on the activities so that they can improve their performance in future iterations.

6.Collaboratively Motivated. 3D-VRLE allows learners to connect and participate, and this technological achievement must be turned into a design capability. It should not be so organized that learners are unable to participate in learning and contribute to a collaborative sense-making activity.

7. Reflectively Synthesized. Learning is only an experience, and only a small amount of learning can be achieved without reflection. The design of a 3D-VRLE must provide time for reflection, whether instructor-led, peer-to-peer, or an exercise that requires learners to reflect at their own pace with an automatic debriefing.

Study Questions

1. What are the principles that guide the design of 3D-VRLE?

2.What do these principles imply for the Omani educational settings?

Study Objectives

The following objectives were pursued in this study:

A. To document the principles used to guide the design of 3D-VRLE.

B. To draw implications for the Omani context.

Methods

The DBR methodology was utilized in this investigation as described below.

Design-Based Research Approach

As cited in Shattuck and Anderson (14), DBR is defined by Wang and Hannafin as "a systematic but flexible methodology aimed at improving educational practices through iterative analysis, design, development, and implementation, based on collaboration between researchers and practitioners in real-world settings and leading to contextually-sensitive design principles and theories" (pp. 186-187). DBR is commonly used by researchers who conduct studies in real-world educational settings, such as classrooms, to create theory and design principles that are applicable to that environment (Figure 2). Conducting a rigorous and reflective investigation to test and enhance innovative learning environments as well as create new design principles is one of the key ideas of DBR.

The first research question was about exploring the principles that guide the design of 3D-VRLEs and mapping out a blueprint for designing them in future. To address that

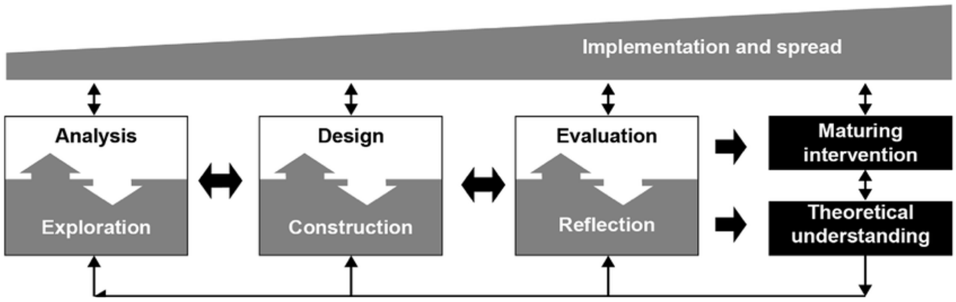

Figure 2: DBR Model (McKenney & Reeves, 2013)

question, the researchers followed the cycles below using the DBR methodology:

Phase 1 of DBR terative cycle: In this cycle, the researchers document and reflect on the process of designing, developing and modifying the 3D-VRLE using the available literature on the same topic. To meet the objectives of this research, an extensive search was carried out to locate journal articles, books, periodicals, and accounts in multiple relevant academic fields. The searched databases included Google Scholar, Springer, ERIC, EBSCO, Al Mahal, EduSearch and ProQuest. Search terms and keywords included biology, physics, chemistry, science, DBR, 3D-virtual reality, lab, and learning environment. The total number of search results stood at 95. These results were screened and focused, and finally 30 relevant sources were extracted using the following criteria:

1. Studies that were published in the 1990-2020 time period.
2. Studies that used samples from a population in K-12, corporates, or university settings.
3. Studies that used virtual reality-based instruction in the form of e-labs, games, simulation, or virtual worlds.
4. Studies that used DBR design.
5. Studies published in English or Arabic languages.
6. Studies conducted at school level with a particular focus on the teaching of scientific subjects.

Phase 2 of DBR iterative cycle: this cycle involved three distinct steps:

A. Studying different readily-made 3D-VRLE products in the local market and selecting one of them as the best to meet the instructional design standards and context as validated by the literary evidence in phase 1.

B. With the help of a panel of experts (one subject supervisor and four subject teachers) from the Ministry of Education (MOE), a simulation based instructional product, called Eureka© and the contained animated instructional physics units were reviewed and selected. The criteria for selecting this particular product were:

- Curricular similarity to the content presented in Omani physics subjects.
- Application of the global instructional design principles.
- Appropriateness for exploring and presenting the physics concepts interactively.
- Serving as a mini 3D-VRLE physics laboratory.
- Learners' ability to employ various experimental variables in physics and guess the findings

C. Then, the researchers went further to investigate this cycle. The 1st author traveled to India to interview one specialized developer and two Subject Matter Experts (SMEs) at a manufacturing company, to glean from their experiences and ensure that they also had followed a sound method in the design process of their products. The company's developers were asked certain questions concerning the recommended design principles and the ADDIE model in their production processes. The interview was conducted in person, and included 7 questions and around 3 hours of discussion. The questions revolved around the technological affordances of these 3D-VRLE applications, the instructional process that is followed in designing them, the applied design principles and the model employed to evaluate these educational applications. The following is a description of the study sample and instrument used in this phase:

I. *Population and Sample:* The population of this study was the specialized developers community at the Indian Eureka© company. However, only one instructional designer and two SMEs were interviewed to reflect on the design process of the 3D-VRLE learning environments. In order to obtain relevant and reliable data to support our work, the researcher selected the respondents in advance of the research. The purposeful sampling technique was applied, and the interviewees were selected based on their practical experience in developing the 3D-VRLE, as they played a critical role in the development of the 3D-VRLE product employed in this study. Using this sampling technique, the researcher was able to acquire a better insight into the activities on the ground, especially from the perspective of the people directly involved in the production of these kinds of educational products.

II. *Research Instrument:* A semi-structured interview was used to interview the above sample. The following procedures were undertaken to design and conduct the interviews:

Before the actual interviews, an outline was drafted as a useful guide for the interview process. The questions were designed by the researchers with reference to the literature and reviewed by specialists in the areas of educational technologies and statistical measurements for the purpose of editing and error correction.

- The interviews were planned to investigate the experts' opinions about the design and development of 3D virtual products according to their experience. Moreover, the interviews implicitly addressed the design principles applied in developing 3D-VRLE product and discussed some of the technological features of the company's products.

- The interviews were recorded using a voice recorder application on a cellphone.

III. *Validity:* The present study, therefore, proposed a blueprint encompassing these principles and guidelines derived from the fieldwork based on the following validation measures:

- The fieldwork was thoroughly conducted by one researcher.

- The data provided by interviewees was checked through informal observation by this researcher.

- Information and principles were isolated during the interviews in an effort to triangulate data and ensure the results' validity.

- Similarity was previously established between the curricular content of the selected 3D-VRLE and the content of the Omani science curricula, which increased the results' transferability.

Phase 3 of DBR iterative cycle: This phase entails the method of analysis applied in this research. The SME and instructional designers' responses were analyzed using *inductive thematic analysis* which involved reading through the interview data and identifying patterns across the data. Data were first transcribed by the researcher (in the form of audio files), and then they were encoded and categorized through creating a set of initial codes that represented the meanings and patterns of the data. A codebook was created to keep track of the codes, identify excerpts and assign them appropriate codes. Then, the codes were collated with supporting data, grouped into themes, reviewed, and followed by the narrative writing. The narrative went beyond just describing the data and included the researcher's own interpretive analysis and made an argument for the claims that were presented. This process resulted in three themes: namely, the design process, affordances of 3D-VRLE products, and design principles of 3D-VRLE products.

Phase 4 of DBR iterative cycle: The researchers finally reflected on and suggested the implications that best highlight the 3D-VRLE design principles for the Omani educational context.

The outcome of the DBR approach as described earlier could be an exemplary blueprint for other designers, producers, or practitioners, in adapting the 3D-VRLE to their own contexts. In addition, it might have significant implications for Omani MOE's educational plans.

Results

To address the first research question, the thematic analysis gave rise to three major themes: a) The Design Process Steps, b) The Technological Affordances of 3D-VRLE Products and c) Design Principles of 3D-VRLE products. The discerned themes indicate some issues related to the virtual educational products: the design stages of 3D-VRLE products, the features of these products and the design principles guiding their development process. To present the findings of this study, the interviewees were referred to as the following: Subject Matter Expert-1 (SME1), Subject Matter Expert-2 (SME2) and the Instructional Designer (ID).

- Theme 1: The 3D-VLE Design Process.

Subtheme 1-1: Design process must focus on students' needs. When asked about the reason why it is important to design/develop such products, all the interviewees acknowledged that their 3D-VLE products are designed to address some educational problems which are either noticed in the field or derived from previous educational research. Both SMEs pointed out that the animated videos and simulations are content-rich resources. They serve as effective interactive tools for bridging the gap in areas where students face cognitive challenges and, thereby, provide them with a platform for interactive learning. The participants agreed that science subjects require strong visualization and exploratory tools to be understood. SME2 stressed that: "*We see which topic is important for the curriculum and from the point of students. Which topic is difficult for them to understand…*?" Similarly, ID contended: "*We look if there is any particular topic that is difficult to be absorbed from the learners' points of view...*".

Subtheme 1-2: Design process requires benchmarking/mapping. As for starting the design process of these products, participants stated that they figure out which of the topics are missing in various categories by looking for particular topics missed or needed globally through a special process called 'book or curricula mapping'. As the ID mentioned: *"... Actually, we design global products, so we look in different books and in different curricula around the world to ensure that this topic is missing"*. In addition, one of the SMEs indicated that the process of looking for topics helps them to find the coverage percentage for the defined topic and how much information a particular topic entails. In the search process, they usually go from macro level to micro level in looking for what they must produce and what is required. Their activities also encompass the mapping of topics according to the curricula to match them with customers' needs and expectations. As SME1 stated: "*We go from macro level to micro level in looking for what we have to produce and what is required. This process is called book mapping and it helps us to find the coverage so that we define how much information that particular topic has*". Moreover, the participants agreed that the mapping process happens according to the desired delivery range either for primary, middle, secondary, or high schools. Based on the level, they decide how much information they need to look for (coverage percentage). The ID said: "*We look for the topics in different sciences and in different books because we are designing universal products. We care about the percentage of coverage for each topic. We refer to different curricula and various examples are covered in them. This step is considered the theoretical line before starting the visualizing line"*.

Subtheme 1-3: Design process relies on teamwork and clear scripting. The SME2 confirmed that big teams of employees work to design and develop the 3D-VRLE products in the company. She said: "*We have a team of scriptwriters, designers, modelers, material guys, animators and programmers. Each member of this team takes a specific step in the process of developing the desired* *topic*". She mentioned that each member in this team is responsible for a specific role and task. Furthermore, scriptwriters develop the text materials, designers produce the graphics and drawings based on the scripts, modelers make the models, material guys prepare the materials and make them look real, animators work with the animation, and the programmers work with the simulations. All interviewees stressed that scriptwriting is the most important stage in the design process because the other stages depend on it; as SME1 maintained: *"After identifying the topics, basic script is the first step in the design process. It needs imagination and ideas. After it is written, then scenarios (storyboards) are prepared to help the animators and programmers whose work is based on these scripts".*

Subtheme 1-4: Design process requires field evidence. When asked about the approach that they employ in evaluating their educational products, the participants argued that they use customer feedback (Testimonials). This feedback will then receive permission to be reported and documented. They assured customers that they use all that feedback to measure their products' effectiveness in different educational contexts and levels around the world. They pointed out that all the products must be tested on a number of users in order to receive feedback about its efficiency, and thus, possible modifications have to be made. In addition, they conduct research and reports to collect some data that help them improve their products and measure its impact on students' performance and academic achievement. The SME2 said: "*We have two levels of getting feedback from our users. The first level is the students' level which we apply at the end of each product in short and interactive quiz form. These quizzes are used to test if the learners absorb the knowledge and concepts or not. Also, we use 3D simulations to assess their understanding of abstract concepts…In the second level, we have the customer feedback (Testimonials) to collect and follow what people are saying about the products. Different users around the world are trying our products and share their experience and feedback with us...".* Also, the SME1 assured that: "… *many research, reports and projects have been done to check to what extent the desired educational outcomes have been achieved, and this covers different schools globally. These studies have reported that these products influence the academic achievement and enhance the students' capacity to understand the concepts in science and math topics*…".

In summary, it could be stated that the design and development of the 3D-VRLE products at this company follow an organized and systematic process. In fact, these steps are similar to the steps prescribed in ADDIE instructional design model. First, an instructional problem is clarified, delivery options are identified, and the project's end date is already decided. Next, the designers design the user interface, create the prototype (models), and apply visual design (graphic design). Then programmers get to work on developing the products and debugging them. They perform two types of evaluations at the end of the process: formative and summative. Each stage of the design process includes formative assessment, and summative evaluation is accomplished by collecting feedback from end users using various technologies.

- Theme 2: The Technological Affordances of 3D-VRLE Products.

Subtheme 2-1: 3D-VRLE design supports learning. When the interviewees were asked about the features and characteristics of their virtual educational products, they concurred that their products make the learning process clearer and easier for the students because they are designed to explain the abstract and difficult concepts and present the knowledge in an interactive fashion. This view was supported by SME2 who simply stated*:" … Our reports proved that all these features increased intrinsic motivation and engagement for students. Actually, we can see that* when *we use our products in learning, the students perform* *and absorb it easily".*

Subtheme 2-2: 3D-VRLE design enhances science lab activities. The interviewees claimed that the 3D simulations, which are usually accompanied with each video they produce, help students to practice, interact and learn in groups or with peers. As a result, they enhance collaboration among learners during the learning process. The teachers can also perform these simulations as a replacement for difficult or dangerous scientific experiments in classrooms. In addition, SME1 argued that these products are modelling the concepts and facilitate the application of acquired knowledge and skills by making the learning process realistic and applicable. She said: "*We prepare 3D simulation in each product which helps students to practice, interact and learn in groups, and encourage the collaboration principle in the learning process…The quiz, also, helps students to check their understanding and assess their achievement...*". Furthermore, ID declared that their 3D-VRLE products can be used in learning physics because they allow the full physics concepts to be modelled for easier understanding of such concepts. He added: "*Actually, we can see when we use our product in learning, the student performs and absorbs the instructional assignment easily. Also, knowledge can remain in their memory for longer time, and they can perform better in tests*"

- Theme 3: Design Principles of 3D-VRLE Products.

Subtheme 3-1: 3D-VRLE must be authentic and needs driven. It was agreed in the interviews that the topics were produced in response to the educational needs of the target field, which in turn reflect the students' needs. That way, the company follows a sound design principle as required in developing such products. This principle ensures that the virtual products are authentic and instructionally grounded. In SME1's words: "*The contexts of all our topics that were produced are authentic because they are real and noticeable in the educational field and that makes them related to the student's needs.*

Subtheme 3-2: 3D-VRLE supports students' collaboration and motivation. The company is working to create virtual products with attributes that encourage collaboration and motivate learners to gain knowledge with interest in their learning endeavors. The SME1 mentioned that: *"We also care a lot that our products should encourage collaboration and motivation among learners*".

Subtheme 3-3: 3D-VRLE promotes student-centered learning. One SME explained that these educational products promote student independence by assigning them responsibilities and enabling them to use independent problem-solving skills. This feature points to another design principle which is student-centered instruction.

Subtheme 3-4: 3D-VRLE provides continuous self-assessment. The interviewees illustrated that 3D-VRLE products require students to assess their learning by completing a given task or activity and providing them with related feedback in order to help them improve their performance in an appropriate manner. These activities/ tasks help fulfil some learning objectives in an indirect way. Also, in reply to a question, ID asserted that these products force learners to reflect at their own pace with automatic debriefing, where some sort of reflection is required; in this respect, he stated that: "*The learners can control their learning using the 3d-videos… They can think about their learning and reflect; so, they are able to get the knowledge by themselves while using the simulations... They practice and repeat the process again and again until they absorb the knowledge."*

In summary, the above design principles reflect a combination of basic learning theories such as cognitive perspectives, social interdependence, and constructivist learning. These principles are considered fundamental to designing 3D-VRLE because they integrate with each other to improve the effectiveness of such environments.

Discussion

It is evident that the interviewees referred primarily to the instructional design procedures, vis-à-vis the ADDIE model in particular, when describing the 3D-VRLE design process followed at their company. There was consistency between the participants' description of the design process and what is reported in some studies (15-17) about the steps involved in the instructional design process, starting with a search for the topics to be designed and ending with the processes of deployment and evaluation. These studies confirmed that developers must first investigate key educational issues and set a pedagogical outcome before designing learning environments that solve such issues (15). Furthermore, the Agile Learning Design can be used to meet the requirements for 3D-VRLE, because it incorporates numerous cycles. Each cycle begins with an issue analysis and ends with the creation of the final product. Developers can start testing and analyzing the efficiency of this part after it's finished. If the results are satisfactory, a new iteration is started; if not, the designer must take a step back, figure out what went wrong, and fix it (17).

Further, the characteristics of the 3D-VRLE products appear to be similar to the affordances and features mentioned in different previous studies. The participants identified a set of characteristics of 3D-VLEs which included: the facilitation of tasks that result in enhanced representation of spatial knowledge, more opportunities for experiential learning, increased motivation/engagement, efficient collaborative learning and enriched contextualization of learning. Indeed, the participants' responses were consistent with what was presented in the literature review in this study (2, 3, 15, 16, 18, 19). These accounts report that 3D-VRLEs create interactive and realistic learning, encourage collaborative and practical activities, and set the stage for performing unsafe experiential learning tasks in a safe environment.

With regard to the design principles applied in designing 3D-VRLE products, the interviewees highlighted some of the points that they considered fundamental in creating effective learning with their 3D-VR products. They mentioned that they apply similar principles to those listed by Kapp (13) including: authentic and instructionally grounded materials, collaborative and motivating elements, student-centered instruction, and reflectively synthesized factors.

In reply to the second study question, the researchers attempted to reflect on the conclusions drawn from the literature and interviews to provide guidance for designing and developing Oman-specific 3D-VRLEs. As stated by McKenney & Reeves (20), one of the key outputs of any educational DBR is to come up with design principles that indicate how to solve specific difficulties in a variety of settings (p. 19). These guidelines are considered valuable to practitioners in the Omani MOE if they plan to adopt 3D-VRLE labs for sciences and other subjects in schools. If there is a plan to integrate 3D-VRLE technology in the Omani schools, MOE should first apply the specific design principles by reviewing the current science curricula and redesigning them commensurate with these new technologies. Second, it needs to align the curricular content with the learners' needs and desired objectives of employing these technologies within the educational processes. Third, the focus should be placed on a learner-centered approach, interaction between learners and teachers, cooperation and communication, flexibility, improving learning through feedback, and reliance on technology to improve learners' learning performance during the learning period in a virtual learning environment. Fourth, automated feedback and assessments tools should be appropriately integrated into the 3D-VRLE to gauge student's learning based on what they are experiencing in the VR settings. Fifth, one needs to consider learner responses and provide opportunities to help the learning process through timely and relevant feedback as well as a variety of formative assessment techniques. Finally, reinforcing student's newly acquired skills through interactive and practical demonstrations should also be given consideration.

The Omani schools, as any educational setting in the world, are striving to create technology-rich environments, but these must be deliberate and planned for, with a focus on learning and the curriculum. We therefore recommend that Oman's MOE adopt 3D-VRLE and its design principles using the blueprints proposed in this study. However, we think that efforts have yet to be made to investigate the effectiveness of this technology and its impacts on the Omani learners' achievement and attitudes towards science. The results of this research cannot be generalized to other contexts due to the limited sample size and specific context and conditions. They can be only applied in the educational context/institutions of the Sultanate of Oman whose working environments are similar to that of the institutional case studies in this research, in terms of the number of employees, their specializations, and the technical capabilities available to them.

Ethical Considerations

In this study, the following ethical issues were considered: After obtaining permission from the College of Education officials, the research began in March/2017. At the beginning of the research interviews, after the researcher had introduced herself, she explained the objectives of the study and the need to implement them to the interviewees. They were also assured that all information collected will remain confidential. This study was approved by the Ethics Committee of Sultan Qaboos University.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author on request.

Authors' Contributions

A.A. designed the study, supervised the intervention, collected data, and performed the analyses. M.T.O. contributed to the design and analysis of the study data and drafted the manuscript. A.M. critically revised the manuscript and followed up on its publication.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

1 Lin MT, Wang JS, Kuo HM, Luo Y. A study on the effect of virtual reality 3D exploratory education on students' creativity and leadership. Eurasia Journal of Mathematics, Science and Technology Education, 2017;13(7), 3151-3161. doi:10.12973/eurasia.2017.00709a

2 Borsci S, Lawson G, Broome S. Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training operators of car service maintenance. Comput Ind. 2015 Feb 1;67:17-26. doi:10.1016/j.compind.2014.12.002

3 Alqahtani AS, Daghestani LF, Ibrahim LF. Environments and system types of virtual reality technology in STEM: A survey. Int J Adv Comput Sci Appl (IJACSA). 2017;8(6). doi:10.14569/IJACSA.2017.080610

4 Matsui H, Terence C. The affordances of 3d virtual learning environments: designing for learners' interpersonal and emotional connections. Virtual Reality in Education: Breakthroughs in Research and Practice, edited by Information Resources Management Association, IGI Global, 2019, pp. 106-123. doi:10.4018/978-1-5225-8179-6.ch005

5 Liu R, Wang L, Lei J, Wang Q, Ren Y. Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. Br J Educ Technol. 2020; 51(6), 2034-2049. doi:10.1111/bjet.13028

6 Sarac H. Benefits and challenges of using second life in English teaching: experts' opinions. Procedia Soc Behav Sci. 2014; 158. 326-330. doi:10.1016/j.sbspro.2014.12.095

7 Durukan A, Artun H, Temur A. Virtual Reality in Science Education: A Descriptive Review. Journal of Science Learning. 2020;3(3):132-42. doi:10.17509/jsl.v3i3.21906

8 Bonner E, Reinders H. Augmented and virtual reality in the language classroom: Practical ideas. Teaching English with Technology. 2018;18(3):33-53. Available from: https://files.eric.ed.gov/fulltext/EJ1186392.pdf

9 Freina L, Ott M. A literature review on immersive virtual reality in education: State of the art and perspectives. International Scientific Conference eLearning and Software for Education, 2015; Vol. 1, 133. https://www.researchgate.net/profile/Laura-Freina/A-Literature-Review-on-Immersive-Virtual-Reality-in-Education-State-Of-The-Art-and-Perspectives.pdf

10 Beaumont C, Savin-Baden M, Conradi E, Poulton T. Evaluating a Second Life Problem-Based Learning (PBL) demonstrator project: what can we learn?. Interactive Learning Environments. 2014 Jan 2;22(1):125-41. doi:10.1080/10494820.2011.641681

11 Beck D, Perkins R. Review of educational research methods in desktop virtual world environments: Framing the past to provide future direction. J Virtual Worlds Res. 2014 Jan 19;7(1). doi:10.4101/jvwr.v7i1.7077

12 Al-Azawi R, Shakkah M. Embedding augmented and virtual reality in educational learning method: present and future, Paper presented at the Information and Communication Systems (ICICS), 2018; 9th International Conference on (Irbid), 218–222. doi:10.1109/IACS.2018.8355470

13 Kapp KM. Principles for Creating a Successful Virtual Reality Learning Experience. 2017; January 7. Available from: https://karlkapp.com/principles-for-creating-a-successful-virtual-reality-learning-experience/

14 Shattuck J, Anderson T. Using a design-based research study to identify principles for training instructors to teach online. International Review of Research in Open and Distributed Learning, 2013; 14(5), 186-210. doi:10.19173/irrodl.v14i5.1626

15 Reeves TC, Herrington J, Oliver R. Design-based research: A socially responsible approach to instructional technology research in higher education. J Comput High Educ. 2005; 16(2), 97-116. doi:10.1007/BF02961476

16 Aldoobie N. ADDIE model. Am Int J Contemp Res. 2015; 5(6), 68-72. Available from: http://www.aijcrnet.com/journals/Vol_5_No_6_December_2015/10.pdf

17 Battou A, Baz O, Mammass D. Learning design approaches for designing virtual learning environments. Communications on Applied Electronics, 2016; 5(9), 31-37. doi:10.5120/cae2016652369

18 Ben Ouahi M, Ait Hou M, Bliya A, Hassouni T, Ibrahmi A, Mehdi E. The Effect of Using Computer Simulation on Students' Performance in Teaching and Learning Physics: Are There Any Gender and Area Gaps?. Educ Res Int. 2021 Mar 23;2021. doi:10.1155/2021/6646017

19 Homer B, Plass J. Level of interactivity and executive functions as predictors of

learning in computer-based chemistry simulations. Comput Human Behav. 2014; 36, 365-375. doi:10.1016/j.chb.2014.03.041

20 McKenney S, Reeves TC. Systematic review of design-based research progress: Is a little knowledge a dangerous thing? Educ Res. 2013; 42(2), 97-100. doi:10.3102/0013189X12463781