# VIRTUAL REALITY TECHNOLOGY AS A PEDAGOGICAL TOOL IN PHYSICAL SCIENCE EDUCATION: A CONCEPTUAL STUDY

**Pheello Vincent Makhele**

Supervisor
Dr Reuben Dlamini

A research report submitted to the Wits School of Education, Faculty of Humanities, University of the Witwatersrand in partial fulfilment of the requirements for the degree of Master of Education by combination of coursework and research.

Johannesburg

December 2021

# ABSTRACT

The existing literature on the pedagogical uses of virtual reality technology reveals inconclusive findings. This study synthesised the findings of primary research that investigated the effect of pedagogically integrating virtual reality technology in physical science education. Previously, research in this area was constrained by the high cost of accessing the technology and consequently, there is a paucity of empirical studies conducted on this subject. With the current advancement in digital technology, virtual reality is increasingly becoming affordable, accessible, and having much better representational fidelity. It appears that much of the research that is accumulating on the integration of virtual reality technology in education is driven by perceived technological affordances as opposed to the interplay between pedagogical affordances and the technological affordances.

The current study was guided by pragmatism and used a meta-analytic approach to investigate the pedagogical effectiveness of integrating virtual reality technology in physical science education. The initial literature search conducted on the University of the Witwatersrand's library electronic databases yielded 517 publications with potential for inclusion as identified by the study's keywords. A deduplication process to remove repeating articles and an exhaustive screening process to identify articles that met the study's inclusion criteria were conducted. Ultimately eight articles were identified as meeting the set inclusion criteria. Two more articles that were cited in some of the included studies were deemed appropriate for inclusion in the present study. Thus, a total of 10 articles was accepted for the current meta-analysis.

Viechtbauer's (2010) metafor package, Balduzzi, Rücker and Schwarzer's (2019) meta package and Harrer, Cuijpers, Furukawa and Ebert's (2019) dmetar package, which are all freely available in R for running meta-analyses, were used for data analysis. A pooled effect size estimate of $g = 0.7260$ in the range of *[95% CI: 0.2633, 1.1887]* and a p-value of $p = 0.0043$ were obtained from the analysis, albeit, with a substantial heterogeneity of $Q(df = 16)$

$= 355.19$, $p < 0.0001$ and $I^2 = 95\%$. Upon attending to the causes of this variability in the results and eliminating studies contributing to this heterogeneity, the results remained significant with a pooled effect size estimate of $g = 0.5879$ standard deviation units in the range of *[95% CI: 0.2938, 0.8820]* and a p-value of $p = 0.0011$. Nonetheless, heterogeneity persisted ($Q\ (df = 11) = 69.27$, $p < 0.0001$ and $I^2 = 84.1\%$), suggesting that about 84% of the variation in the results was possibly a result of between-study variation.

These results suggest that the pedagogical integration of virtual reality technology in physical science is significant and effective. Thus, the current study's conclusion is that the pedagogical integration of virtual reality technology in physical science presents promising results.

**Keywords**

Virtual reality; physical science; pedagogical affordance; technological affordance; meta-analysis; conceptual study; conceptual change

# DECLARATION

I declare that this research report is my own unaided work. It is being submitted in partial fulfilment for the degree of Master of Education at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

Pheello Vincent Makhele

Student Number: 765037

On this _02___ day of ___December____ in the year 2021

ACKNOWLEDGEMENTS

I would like to acknowledge and thank the following people who directly and indirectly played a significant role in helping me write this report.

I would like to convey my sincere gratitude to my supervisor, Dr Reuben Dlamini. Thank you for your guidance and being patient with me throughout this journey. Thank you for the generous support that you are always willing to offer me even when I sometimes hesitate to reach out.

I would like to thank Dr Nokulunga Ndlovu for persistently showing confidence in my capabilities and her continued mentorship. Thank you, Dr Ndlovu, for everything. Only you could never get tired of always hearing unending stories about why it was taking me this long to finish writing this report. And the ‘gigs’ kept me going.

I am also grateful to Dr Ian Moll for his influential Educational Psychology teachings. I am glad that our paths crossed just in time before your retirement.

I thank Alison Chisholm, the Wits School of Education’s librarian, for taking me through a telephonic training on accessing the library’s e-Resources, arranging for me to access the University of the Free State’s library and for always being there to answer my troublesome questions.

I thank Education International for funding my studies. Without their financial support, this report would not have been written.

Lastly, I would like to express my gratitude to my peer, Monas Allotey, for always being willing to offer a helping hand, reading my work and sharing ideas on academic discourse.

**TABLE OF CONTENTS**

# LIST OF FIGURES

# CHAPTER 1: INTRODUCTION

## 1.1 Introduction and Background to the Study

The adoption of technology in education should be necessitated by teaching and learning challenges that can be effectively addressed by the effective interplay between technological affordances and the pedagogical affordances, I claim. Think about the invention of a chalkboard or slate; one would imagine that prior to the invention of this educational tool, a teacher would be talking to their class and, at the same time, the learners would be listening and trying to visualize what the teacher is saying, while simultaneously trying to process such information and ensure it is retained in their memory. Consider, for instance, a lesson where a teacher asks learners to imagine creating, altering, or manipulating objects that are abstract or microscopic, such as particles, atoms, or electric fields, to understand how they behave under various conditions (Dede, Salzman, Loftin & Sprague, 1999). This example presents serious challenges for learners, as discussed later in this report. Such challenges do not only arise when imagining invisible objects as is shown by several historic misconceptions about most scientific concepts, such as erroneous past beliefs that the earth is flat, static and being orbited by the sun, the moon, and other celestial objects. See Carey (1991) for a comprehensive account of conceptual change challenges.

Experience shows that there are some tasks that would be cognitively overwhelming without technological tools to augment cognitive processing, resulting in undesirable consequences. For instance, it was only in 1609 with the invention of the telescope that Galileo Galilei confirmed Nicholas Copernicus' idea that only the sun was stationary and everything else orbited around it (Hawking, 1988). Muttappallymyalil et al. (2016) indicate that before the invention of the chalkboard, the task of making presentations to large classes was almost impossible as teachers would have to write lessons on every learner's slate. This would be a daunting task for an educator and one can only imagine how overwhelming it would be to teach a relatively large class, and having to go round writing instructions on each learner's slate. Furthermore, this would not be the only challenge in this scenario; it is likely that in a relatively large class, the learners on whose slates instructions would be written first would have had the privilege of processing and acting upon these instructions ahead of those learners on whose slates instruction would be written last. This could mean that those that had instructions written on their slates ahead of others could work through their task ahead of those learners who had instructions written on their slates last. This is assuming that the educator would not instruct learners not to look at the instructions until such time when all had instructions written on their slates.

It is these kinds of educational challenges that lead to innovative ideas which effectively enhance teaching and learning. James Pillans, headmaster and geography teacher at the Old High School in Edinburgh, was faced with the challenge of giving geography lessons on large maps to learners in 1800 when he connected several slates to form one board of slates to draw large maps on. In 1801, West Point mathematics teacher, George Baron, faced an almost similar challenge illustrating complex mathematics formulas to a large audience when he used a similar approach by connecting multiple slates to form one board to work on (Buzbee, 2014). It is this simple and yet so profound idea of connecting multiple slates that would later lead to the invention of the chalkboard. To this day, chalkboards are found in almost every teaching room, to the extent that Krause (2000) posits that "Chalkboards and blackboards seem like such primitive tools and a 'natural' part of classrooms at all levels that some readers may wonder how they might be considered a 'technology' at all" (p. 6). The chalkboards and blackboards have become so "natural" and common that they are rarely considered technological tools.

As advances in technology rapidly proliferate, the rationale for the integration of technology in education appears to derive from the interplay between pedagogical and technological affordances that are perceived to be inherent in some technological tools. Whereas the chalkboard was a tool specifically invented to address teaching and learning challenges, there are instances where some technologies are invented for specific uses and later repurposed for teaching and learning because of the pedagogical affordances that they may offer. An example of a technology initially intended for other uses that has since attracted popularity from researchers for teaching and learning purposes is Virtual Reality (VR) technology, an interactive, multisensory computer-generated simulation of the real-world to be perceived as if it were the natural world (Craig, Sherman & Will, 2009). The early use of this technology is traced to the Wright-Patterson Air Force Base in Ohio in the 1960s and 1970s where it was used to develop flight simulators and head-mounted displays for pilot training (McLallen, 1996; Pandelidis, 2010). The training of pilots is a high-risk activity and therefore, the safety of trainee pilots is a key priority. Simulations are used to mimic what would happen in reality had the trainee pilot been doing the actual task. The value of simulation is that it affords the trainee pilot opportunity to explore risky tasks without exposing themselves to real-life risks.

Similarly, VR technology has been used in mining and medical surgery for safety-related training. According to Tichon and Burgess-Limerick (2011), “Virtual reality simulation offers the opportunity to develop perceptual expertise, perceptuo-motor skills, and cognitive skills such as problem-solving, and decision-making under stress, without exposing trainees or others to unacceptable risks” (p. 33). The use of VR technology is common in the mining sector because of the high-risk nature of the industry, “with inadequate or insufficient training” often cited as the main cause of fatalities (van Wyk & de Villiers, 2008, p. 276).

This technology has, however, lately been utilized for teaching and learning purposes because of the affordances perceived to be inherent in it that could effectively address some of the current teaching and learning challenges. Some of these challenges include activities that carry high risks such as laboratory activities, activities that are too complex to explain and for learners to comprehend, concepts that are not in harmony with one’s worldview, and concepts that are difficult to visualize, to name just a few. An example of this is provided by Dunlop as cited in Chen, Yang, Shen and Jeng (2007) that “many children have difficulty understanding some concepts in astronomy such as the size and shape of the Earth; the cause of day and night; the cause of seasons, and the orbits of the Earth, the Sun and the Moon” (p. 289).

Because of the widely documented affordances of VR technology in the literature (see Winn & Jackson, 1999; Dalgarno & Lee, 2010; Mikropoulos & Natsis, 2011; Dede et al., 1999; etc.), one would hypothesize that this technology would effectively enhance learning under well-constructed learning conditions. To date, several empirical studies have investigated the interplay between VR technology and teaching and learning, though without evident pedagogies (Fowler, 2015; Johnston, Olivas, Steele, Smith & Bailey, 2018). Hence Johnston et al. (2018) took it upon themselves to conduct a content analysis study to ascertain and classify pedagogies that appear to be inherent when teaching and learning with virtual reality technology. Moreover, advances in the computing power of mobile technology devices have led to a surge in the accessibility of VR technology (Ray & Deb, 2016) thereby necessitating more research into the pedagogical value of this technology.

This study aims to systematically glean and statistically integrate the findings of empirical studies that have thus far been conducted on the interplay between virtual reality technology and the teaching and learning of physics and chemistry (physical science) in both basic and higher education.

## 1.2 Definition of Terms

**Virtual reality**: Virtual realities are interactive, multisensory computer-generated simulations of the real world to be perceived as if they were the real world (Craig, Sherman & Will, 2009). They are meant to be illustrations of the actual objects, though in a virtual form. As Terashima (2001) indicates, through VR technology, one can feel the presence of being in a virtual location as if it were a physical location, with all the sound and smells that are meant to be in the physical location. There are different virtual realities such as immersive virtual reality, desktop virtual reality, and mixed virtual reality. According to Sherman and Craig (2018), the key elements in experiencing virtual realities are virtual world, immersion, sensory feedback, and interactivity. Figure 1 shows the features that make up a typical VR system.

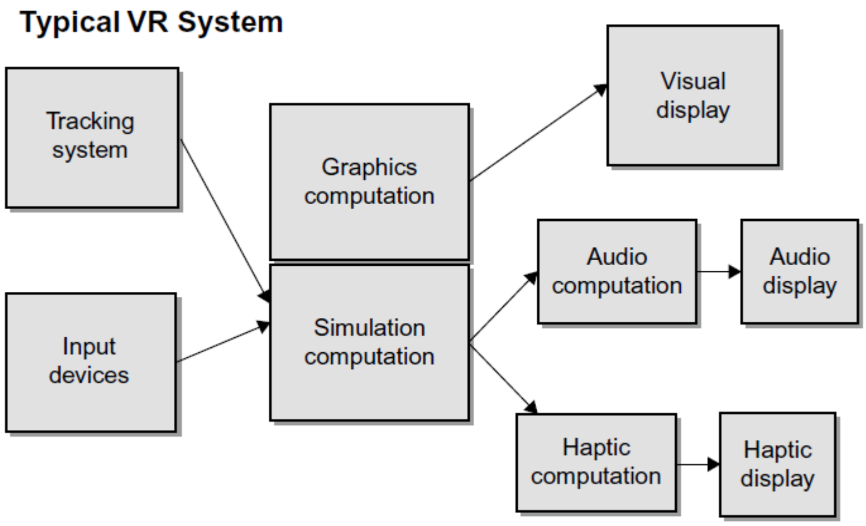


**Figure 1: Features that make up a typical VR system**

Source: Craig et al. (2009, p. 10)

Some widely known examples of virtual realities include Google Cardboard, Playstation VR, Samsung Gear VR, Google Expeditions, Hololens, Oculus Rift, to name a few. In South Africa too, there are some organizations that work on the development of virtual reality technologies; these include Sisanda Tech, The Naledi3d Factory, Sangari, among others.

**Immersion**: Immersion in virtual reality is regarded as an imaginary or psychological sense of being in a virtual world through the use of peripheral devices "such as Head-Mounted Displays (HMD), data gloves, and position trackers to provide sensory information and measure the user's response" (Bangay & Preston, 1998, p. 43). According to Sherman and Craig (2018), the best way to think about immersion is through imagining things that are beyond your reach; like thinking about the future. It is the degree of immersion that differentiates immersive virtual reality from other types of virtual realities. Those that are not fully immersive are either considered semi-immersive or non-immersive virtual realities (Lockwood, 2004).

**Sense of Presence**: From the notion of immersion arises the concept of sense of presence, which Fowler (2015) describes as a "psychological state [of being there] that can arise from an immersive system" (p. 416). In some instances, the two concepts, immersion and a sense of presence, are taken to mean the same thing (Sherman & Craig, 2018); however, it is in fact immersion that engenders the sense of presence (Winn, 1993). A user's involvement and interaction are deemed necessary to experience a sense of presence.

**Immersive virtual reality**: An immersive virtual reality is that which has no interface but a high level of immersion that is enabled by wearing Head-Mounted Displays (HDMs). Figure 2 shows a user wearing an HDM. Immersion is enabled by sensors that are built in Head-Mounted Displays to track the user's movements (Helsel, 1992; Winn, 1993).

**Figure 2: A user wears an HMD and a globe on as he explores a virtual world**

Source: Craig et al. (2009, p. 2)

**Desktop virtual reality**: Desktop virtual reality is virtual reality that is accessible on a desktop computer without the use of head-mounted displays and position-tracking sensors. The user interaction is like with any other computer program since it is enabled through the use of input devices such as keyboards, computer mouse, joysticks, etc., (Winn, 1993). Consequently, desktop virtual reality technologies are generally considered non-immersive.

**Digital pedagogy**: Digital pedagogy is concerned with the effective use of digital technologies such as computers for teaching and learning.

**Digital pedagogical affordances**: Digital pedagogical affordances are those benefits that are perceived to be inherent in the use of digital technologies for teaching and learning.

### 1.3 Problem Statement

Globally, there is extensive empirical research on the use of VR technology for skills training and teaching and learning (Mills & Madalena T de Araújo, 1999; Jarmon, Traphagan, Mayrath, & Trivedi, 2009; Huang, Rauch & Liaw, 2010; Dalgarno & Lee, 2010; Arya, Hartwick, Graham & Nowlan, 2012), with several systematic reviews (Mikropoulos & Natsis, 2011; Feng, González, Amor, Lovreglio, & Cabrera-Guerrero, 2018; Wang, Wu, Wang, Chi, & Wang, 2018; Concannon, Esmail, & Roduta Roberts, 2019; Di Natale, Repetto, Riva, & Villani, 2020; Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020) being conducted to investigate the overall effectiveness and elements of VR technology that might effectively enhance teaching and learning.

In the South African context, the research on virtual reality technology appears to be skewed towards the mining industry (Tichon & Burgess-Limerick, 2011; van Wyk & de Villiers, 2009; Squelch, 2001) and other disciplines (Recheis et al., 1999; Brown, Nunez & Blake, 2005; Bangay & Preston, 1998) other than education. In physical science education, learners have been shown to acquire conceptual knowledge mostly at quantitative level, with their qualitative conceptual understanding contradicting their conceptual understanding at quantitative level. The pedagogical adoption of an appropriate VR technology and its distinguishing features presents potentialities for the facilitation of effective conceptual knowledge acquisition.

Accessibility and affordability of VR technology have led to the slow adoption of the technology in education. However, advances in the computing power of mobile devices such as smartphones and laptops are increasingly making the technology affordable to the larger market, thus necessitating rigorous investigation into the associated pedagogical aspects that are likely to yield effective teaching and learning outcomes. There are already instances, particularly in South Africa, where technocentric figures have begun advocating for the integration of smartphone-based technologies like augmented reality technology in education (Sulaiman, 2020) despite insufficient academic research to back their advocacy.

It is therefore important to analyze the existing research globally to establish the techno-pedagogical VR aspects that significantly promote teaching and learning, if any, before considering integrating this technology into the curriculum. This is particularly so in the South African context where several ICT integrations in education initiatives have hardly met the proponents' expectations (Minty & Moll, 2020). Such an understanding would be useful, firstly in the design and development of virtual reality content, and secondly for training educators on the pedagogical uses of this technology.

In this study, the main focus will be on the pedagogical use of virtual reality technology for the teaching and learning of physical science. The rationale being that most concepts in physical science tend to be abstract, microscopic, or macroscopic; and there exists evidence to suggest that learners only have "a number of incomplete, part-understandings derived from different sources" when it comes to the learning of a concept in their early stages (Rowell, 1989, p. 149). If such concepts are macroscopic, sometimes learners' scientific explanations happen to be inconsistent with one's everyday experiences, the consequence of which is conceptual conflict.

Take, for instance, the rotation of the earth around the sun or the structure of atoms. In a descriptive study by Harrison and Treagust (1996), when students were asked about their perception of atoms and molecules, "Various students described atoms as being like a ball, a solar system, a plum, and even as a structure that is able to divide and reproduce like a cell" (p. 510). Merchant et al. (2012) argue that in chemistry, for a chemist "to know the shape of molecules" (p. 551), the ability to visualize how atoms are arranged in 3D space may be essential, a task that would arguably be difficult, if not impossible, to achieve without the means to aid such visualization since such particles are so small that their unit of measure is a nanometre, one billionth of a metre. The ability to bring to human senses that which would have naturally been beyond accessible (Winn & Jackson, 1999) is one reason that necessitates the integration of VR technology in education.

Cognitive overload on working memory is a potential consequence of not deploying educational VR technologies especially when teaching physical science. This is because learners are often left on their own with flawed mental models of these abstract concepts akin to the experience cited in Harrison and Treagust (1996). Consequently, this often leads to learners forming misrepresentations of the actual concepts or having misconceptions of the actual phenomena.

Based on the reviewed literature on the pedagogical affordances of VR technology in education (Winn, 1993; Winn & Jackson, 1999; Dalgarno & Lee, 2010; Mikropoulos & Natsis, 2011; Dede et al., 1999), there exists strong evidence suggesting that the pedagogical integration of

VR technology in education may effectively enhance teaching and learning. For instance, a study by Winn & Jackson (1999) outlines fourteen propositions relating to the educational uses of virtual reality technology and deliberately frames these claims as propositions because the authors were of the view that evidence to validate these statements was still insufficient or not yet conclusive.

This study is necessitated, firstly, by the conceptual change challenges that learners encounter when learning concepts in physics and chemistry that require them to form mental models of concepts that may either conflict with their worldviews or be impossible to mentally visualize, thereby leading to undesirable cognitive overload in learners. Secondly, the study rationale arises from the perceived pedagogical affordances that appear inherent in VR technology.

## 1.4 Research Questions

This research aims to address the following main question:

> *In what ways does the interplay between virtual reality technology affordances and digital pedagogical affordances contribute to teaching and learning?*

The main research question is answered by exploring the following sub questions:

1. In what ways can virtual reality technology be used for pedagogical benefits to effectively enhance learning?
2. Which virtual reality technological-pedagogical features significantly influence learning?

## 1.5 Objectives of the Study

The affordances of VR technology are widely documented in the literature (see, for example, Dalgarno & Lee, 2010; Mikropoulos & Natsis, 2011; Chen, Toh & Fauzy, 2004). How these affordances can effectively be utilized to enhance teaching and learning remains vague, despite an increase in the development of such technologies in the market and the decreasing cost of accessibility. Furthermore, there seems to be a paucity of research on the pedagogical approaches that can be used in conjunction with VR technologies (Fowler, 2015; Johnston et al., 2018).

Based on the stated research question and the background provided, the objectives of this study are:

1. To explore how virtual reality technologies enhance teaching and learning
2. To identify misconceptions that are addressed with virtual reality technologies
3. To explore virtual reality techno-pedagogical affordances that significantly promote learning
4. To determine the conditions under which virtual reality technologies enhance teaching and learning

## 1.6 Significance of the Study

It is imperative to establish a basis for incorporating the use of VR technology in teaching and learning in both higher education and basic education that is informed both by technological and pedagogical affordances. The effectiveness of using VR technology for safety-related training might be evident (Johnston et al., 2018), but that does not necessarily mean that when incorporated in teaching and learning for propositional knowledge, the technology will be equally effective. It is therefore important to attempt to thoroughly investigate the pedagogical benefits of using VR technology and the ways or conditions of use of this technology in the context of teaching and learning propositional knowledge.

It is anticipated that the findings of this study will corroborate the hypothesis that VR technology can effectively enhance teaching and learning, thereby justifying its integration in teaching and learning. It is also hoped that the findings of this study will reinforce the constructivist's views on learner-centredness since VR technology affords learners the opportunity to actively interact with the computer as they explore computer simulations. Moreover, it is the researcher's aim that the findings from this study will contribute to the existing literature on useful design and development aspects of VR technology for consideration by virtual reality technology developers in the development of the technology. The researcher also seeks to contribute to informing teachers, researchers, and educational technology funders on useful VR pedagogical aspects to consider when deciding to integrate virtual reality in education. Since this study is a conceptual study, the researcher's expectation is that the findings and conclusions made will contribute to new knowledge on the pedagogical use of virtual reality technology, and set a basis for future empirical studies to test the findings and ultimately lead to the building of a new theory.

## 1.7 Philosophical Assumptions of the Study

In research, the way an inquiry is approached can arguably be traced back to a researcher's pre-existing views and beliefs about the world. It is these beliefs and worldview that "influence how researchers select both the questions they study and methods that they use to study them" (Morgan, 2007, p. 49). These belief systems or worldview as Creswell (2017) prefers to call them, that shape the way researchers approach their research inquiry, are interchangeably known as *paradigms* or *philosophical assumptions*. Paradigms symbolize "the values and beliefs of a group …, such that one set of views and beliefs may be incommensurable with another, abiding by different philosophical assumptions, ontologies, epistemologies and axiologies" (Cohen, Manion & Morrison, 2017, p. 34).

Although Thomas Kuhn was the pioneer of the adoption of the use of paradigms to understand the nature of research inquiry and how a researcher sees the world (Lincoln & Guba, 2007; Morgan, 2007; Lapan, 2012; Stemhagen, 2014), he was of the view that working within a paradigm can actually impede research inquiry since relevant ideas that may not fall within that paradigm are discarded (Stemhagen, 2014; Saracho,2014). Nonetheless, paradigms play a crucial role in guiding researchers in their research inquiry.

The research paradigm underlying this study is *pragmatism*, a paradigm that does not subscribe "to a particular set of rules or theories but rather suggests that different tools may be useful in different research contexts" (Leavy, 2017, p. 14). The researcher is of the view that issues of their research inquiry can be better understood when they pursue them with "freedom of inquiry" (Dewey as cited in Morgan, 2014, p. 1050). The researcher's interest in pragmatism is a result of its thesis being rooted in what works, "rather than philosophical claims" (Morgan, 2014, p. 1051). The discussion on pragmatism and other paradigms is further developed in Chapter 3.

## 1.8 An Overview of Research Design and Methodology

Even though research on the pedagogical benefits of virtual reality for teaching and learning is increasing exponentially, the actual integration of the technology for teaching and learning purposes, both in basic education and higher education remains sluggish at present, a sign that more research or consensus on the pedagogical use of virtual reality is still needed. The current study uses conceptual research to systematically establish where research on the pedagogical use of virtual reality comes from, where it currently is, what the gaps are and where it is heading (Shalley, 2012).

Using meta-analysis, the researcher synthesized and statistically analysed the pooled findings of existing empirical studies on the pedagogical uses of virtual reality technology for the teaching and learning of physical science in both basic education and higher education. One of the reasons put forward by Shalley (2012) in advocating for conceptual studies is that "conceptual analyses can be used to think broadly about issues and play with different ideas that could eventually lead to one or more empirical pieces" (p. 260). Further, Shalley (2012) is of the view that using meta-analyses, "the relationships between theoretical constructs and empirical evidence" (p. 261) can be uniquely explained, thereby contributing towards theory building. As a result, it is the researcher's hope that the findings from this research will be used as a basis for future empirical studies (Xin, 2017), advance existing knowledge and ultimately lead to new theory building.

## 1.9 Limitations of the Study

Initially, it was intended that this research would be an empirical study using a virtual reality technology facility at one of the universities in South Africa. However, after the exchange of the Memorandum of Understanding (MoU) and engaging with it, it became complicated to go ahead with the empirical study as data collection became a challenge. The researcher then changed the study from empirical research to conceptual research.

Because this study is conceptual research, the data was collected from existing studies that used different virtual reality technologies. Each virtual reality technology has a unique design and technological elements. For instance, others may be highly immersive while others may not. A limitation of this study, therefore, relates to the fact that because not all virtual reality technologies are the same their impact on teaching and learning will differ depending on the combination of the instructional methods employed and the design and technological features of the tool. Having said that, it is these same different design and technological features related to the instructional methods that the researcher was particularly interested to investigate in order to be able to establish ways in which techno-pedagogical affordances contribute to teaching and learning.

Meta-analytic research is quantitative in nature. For the purposes of this study, the researcher focused on the interplay between virtual reality technology affordances and digital pedagogical affordances in the teaching and learning of physical science education. The data analysed was collected from multiple databases and comprised peer-reviewed published articles on empirical studies conducted in the period 1990 to 2020. Results from studies that may have been conducted towards theses or presentation at conferences were not included in the collected data. As a result, there is a likelihood that the data collected and analysed may not have been wholly representative of all the studies that have been conducted on the pedagogical use of virtual reality technology.

In addition, studies that have focused on subjects other than chemistry and/or physics were not of interest to the researcher since the present study focused on the pedagogical use of virtual reality technology as a cognitive tool for the scaffolding of the teaching and learning of abstract, microscopic, and macroscopic concepts that are not in harmony with one's worldview.

There are two more key limitations that are naturally inherent in meta-analysis studies or literature reviews, namely, publication bias and the language of written literature (Card, 2015). Publication bias is a bias that arises when the reviewer is unable to have access to studies that may have negative or unfavourable effects as there is a high likelihood that such studies may not have been published (Boden, 1992; Card, 2015). Furthermore, reviewers can only review the literature published in a language that they understand.

## 1.10 Ethical Considerations

When research entails interaction with human subjects, there are ethical considerations that are put in place to minimize or eliminate the possibility of causing harm to the participants. In other words, such research must be ethical. Ethical considerations principles require that participants in a study are given sufficient information prior to taking part in the study, outlining what the research project is about, their rights as participants in the study, any foreseeable physical risks associated with the study, the provision of any benefits that participants may be entitled to (Vanderstoep & Johnson, 2008; Lapan, Quartaroli & Riemer, 2012; Terrel, 2015) and giving participants assurance that their responses will be treated confidentially, keeping their identities anonymous and ensuring that their privacy is maintained throughout the research journey. In addition, permission to collecting such data needs to be obtained prior to the collection of data.

Since the nature of this research was conceptual, there was no interaction with human subjects. The research involved collection and analysis of archival data, thereby excluding concern about ethical issues as outlined above.

## 1.11 Outline of the Research Report

**Chapter 1** introduced the study and outlined the relevant background, citing some of the educational challenges that led to the invention of some of the educational technologies in existence to date, in particular, the chalkboard. The Chapter defined and clarified key terms that will be encountered throughout this study. It presented the problem statement from which the research question and related sub-questions arose, the objectives of the study and the significance of the study. Furthermore, the chapter briefly located the philosophical assumptions guiding the study, gave an overview of the research design and methodology, and discussed the limitations of the study and ethical considerations in research.

**Chapter 2** deals with the theoretical framework underlying this study and interrogates what is known about pedagogical benefits of ICT integration in education, and by extension, virtual reality, in the relevant literature and identifies what is missing. The researcher considers cognitivism and constructivism as the two frameworks informing this study. The literature review section begins with some of the widely cited debates on media use for learning. It considers discussions around ICT integration in education and its digital pedagogical affordances, and reviews definitional issues relating to virtual reality technology. The Chapter delves into conceptual change issues in science education and affordances attributed to virtual reality technology, deliberates on VR technology for teaching and learning, and concludes by discussing accessibility of the technology.

**Chapter 3** delves into the research design and methodology envisaged for the current study. It begins with a discussion on the role of philosophical assumptions in scientific research and justifies the choice of paradigm that underpinned this study. As indicated in sections 1.7 and 1.8, respectively, the current study is conceptual research that uses meta-analysis. The Chapter also discusses the data collection method used, the literature search process followed, and the eligibility criteria used for the inclusion and exclusion of studies.

**Chapter 4** focuses on the analysis of the collected data. Meta-analysis is conducted in R to compute the overall effect size estimate of the included studies to establish the effect of pedagogically integrating virtual reality technology in physical science education. The results of the data analysis process are discussed and the implications of these results in relation to the research question is deliberated.

The conclusions and recommendations from the study are discussed in **Chapter 5**.

# CHAPTER 2: THEORETICAL FRAMEWORK AND LITERATURE REVIEW

## 2.1 Introduction

This chapter is split into two sections. The first section locates the theoretical framework underlying this study and the second section reviews the relevant literature. Two frameworks are considered to guide this study: cognitivism and constructivism. The literature review section begins with a review of some of the prominent debates on the use of media for learning. It then reviews the discussions around the pedagogical integration of ICT in education and affordances derived from the digital pedagogy. Subsequent discussions of this section dwell on the definitional issues pertaining to VR, conceptual change issues in science education, VR technological affordances, VR for teaching and learning, and issues of VR technology accessibility.

## 2.2 Theoretical Framework of the Study

How one comes to know that which they know is fundamental in creating the necessary conditions that will afford them the opportunity and the means to effectively know what they seek to know. It has been discussed in the previous chapter how challenging and cognitively overwhelming it is to comprehend abstract, microscopic, or macroscopic concepts that conflict with what one sees without the means to support this endeavour. It was also briefly stated that VR technology has the potential to address these challenges. The argument that the task of relying on mental models when learning abstract concepts is cognitively overwhelming is based on our knowledge of the architecture of human cognition, as taken from Atkinson and Shiffrin (1968). According to them, human cognition can be broken down into:

> ... the sensory register, the short-term store, and the long-term store. Incoming sensory information first enters the sensory register, where it resides for a very brief period of time, then decays and is lost. The short-term store is the subject's working memory; it receives selected inputs from the sensory register and also from the long-term store ....

> The long-term store is a fairly permanent repository for information, information which is transferred from the short-term store. (p. 14).

### 2.2.1 Cognitivism

From the perspective of cognitivists, understanding how learning takes place entails understanding how a learner processes information. Cognitivists look "at learning from an information processing point of view, where the learner uses different types of memory during learning" (Anderson, 2008, p. 9). They take the "structure and process of the human mind as [their] subject of study" (Floden, 1981, p. 79) and attempt to understand how the learner processes information.

The foundation of their theory is the architecture of human memory which is split into short-term memory (also commonly known as working memory) and long-term memory. Atkinson and Shiffrin (1968) suggest that there are two key dimensions to the human memory system, namely the physical memory structure and the control processes. The physical memory structure, together with its built-in processes are those fixed permanent features of the memory, whereas control processes "are selected, constructed, and used at the option of the subject and may vary dramatically from one task to another" (Atkinson & Shiffrin, 1968, p. 14). As shown in Figure 3 below, control processes function within the capabilities of the working memory.

Moreover, one can see in Figure 3 that information from the environmental input travels to the working memory through different sensory registers. This provides the basis for the advocacy by cognitivists that different media forms be incorporated in teaching and learning to activate various sensory organs because given information in different media forms has the capability to trigger off different mental processes (Salomon, 1976).

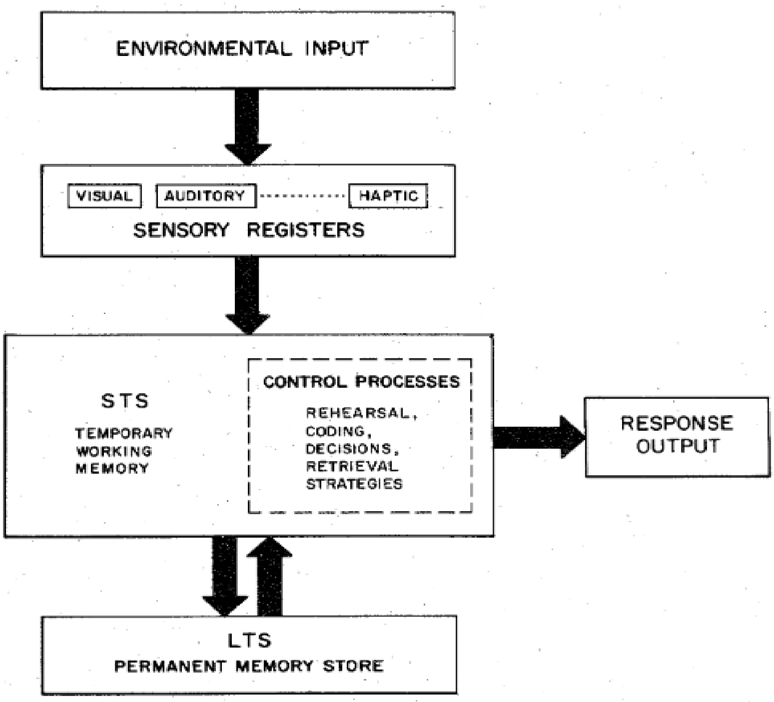


**Figure 3: Human Memory Information Flow**

Source: Atkinson & Shiffrin (1971, p.3b)

Information processing from the sensory register takes place in the working memory, which is limited in duration and capacity (Kirschner, Sweller & Clark, 2006; Anderson, 2008), particularly when dealing with novel information. This working memory can be considered the backbone of the structure of human cognition because it is in here that incoming information from the sensory register is meaningfully processed before it is passed on to the long-term memory. It is also the working memory that works hard to retrieve information from long-term memory for recall. Through control processes, it is the working memory that "facilitates planning, comprehension, reasoning, and problem-solving" (Cowan, 2014, p. 197). It is therefore worth mentioning that the consequences of ignoring the working memory's limitations and how the information processing process takes place are dire on learning.

The information that is processed and learned is permanently stored in long-term memory, which is why long-term memory is also referred to as the "knowledge base". Once the information is stored in long-term memory, it is the working memory that is used to retrieve that information for recall. This relationship between working memory and long-term memory is one crucial aspect of learning.

To enhance learning, cognitivists advocate for efficient organization and meaningful chunking of information for effective processing by the working memory. Due to the limitations of working memory, careful consideration should be given to either cognitive scaffolding or technical scaffolding, during the teaching of abstract concepts. This is where VR technology comes in handy. According to McLellan (1994), "Virtual reality (VR) is a cognitive tool" and the technology "was devised to enable people to deal with information more easily" (p. 175). However, one potential challenge to look out for when learning with virtual reality, just like when learning with any multimedia, is cognitive overload.

#### 2.2.1.1 Cognitive Load Theory and its consequences

Cognitive Load Theory (CLT) is concerned with the efficient use of cognitive processes during information processing. It is "mainly concerned with the learning of complex cognitive tasks, where learners are often overwhelmed by the number of information elements and their interactions that need to be processed simultaneously ..." (Paas, Renkl, & Sweller, 2004, p. 1). The theory utilizes what is known about the structure of human cognition to come up with better and efficient instructional techniques, such that, information processing by the working memory is facilitated. The reader will recall the role and limitations of working memory as discussed in the previous section. Failure to recognize the limitations of working memory is likely to lead to cognitive overload in learners, which happens when "the learner's intended cognitive processing exceeds the learner's available cognitive capacity" (Mayer & Moreno, 2003, p. 43). For instance, this could happen in the case where learners are taught abstract or microscopic concepts in physics or chemistry, which are complex to mentally visualize without the means to aid visualization.

For cognitivists, the working memory serves as an engine for any information to be learned because all that there is to learn is processed in the working memory. However, in addition to its already mentioned limitations, working memory is also susceptible to two different categories of cognitive load, *intrinsic* cognitive load and *extraneous* cognitive load (Sweller, van Merrienboer & Paas, 1998; Sweller, Ayres & Kalyuga, 2011). For effective learning to be facilitated, it is these two different working memory loads that should be managed because they are likely to hinder the process of learning if ignored.

*Intrinsic* cognitive load is inherent in the nature of the information to be learned, whereas *extraneous* cognitive load comes with the way the material to be learned is presented to learners (Paas et al., 2004; Sweller et al., 2011). Because intrinsic cognitive load resides in the nature of learning tasks to be undertaken, one way to manage working memory load is to reduce extraneous cognitive load (Sweller et al., 2011). With virtual reality, for instance, the burden on learners to imagine abstract and microscopic concepts in physical sciences is mitigated; VR serves as a "mediation of mental processes" (Salomon, 1976, p. 26).

### 2.2.2 Constructivism

Two prominent figures widely associated with the constructivism theory of learning are Jean Piaget (1896 -1980) and Lev Vygotsky (1896 -1934). Even though they both worked towards a common concept, their points of departure differed significantly. As Valsiner (1996) puts it, "They [Piaget and Vygotsky] developed their respective thought in parallel ways. Piaget took progressive equilibration and assimilation/accommodation notions as the core of his perspective. Vygotsky tried to make sense of dialectical synthesis of higher psychological functions" (p. 296). Piaget's constructivism is biologically rooted, positing that children learn concurrently with their biological developmental stages, whereas Vygotsky's constructivism is grounded in sociocultural activities (Moll, 1999; Goodman, 2008; Selepe & Moll, 2016). Vygotsky's constructivism is grounded in the internalization of social interactions by learners (Salomon, Globerson & Guterman, 1989). Nonetheless, they both believe that children are active participants and construct their own knowledge as they act upon and interact with their environment.

Constructivists view knowledge as being "individually constructed and socially co-constructed" (Jonassen, 1999, p. 217) by learners through their experiences and interaction with the environment. Learners hold on to this knowledge of their constructed world until such time that it does not fit in with new knowledge (Magadla, 1996; Ackermann, 2001). Constructivists' emphasis is on active participation by learners who are deeply "thinking about what they do" (Papert, 1972, p. 245) as they strive to make meanings for themselves in pursuit of constructing knowledge. It follows from this perspective that learners should be provided with conducive learning environments that will afford them the opportunity to learn by doing, to collaborate, and to reflect on what they are engaged in, so that they can internalise their learnings (Jonassen, 1999). Figure 4 shows a constructivist learning environment model conceptualized by Jonassen (1999) illustrating the components that are central to constructivist learning environments.

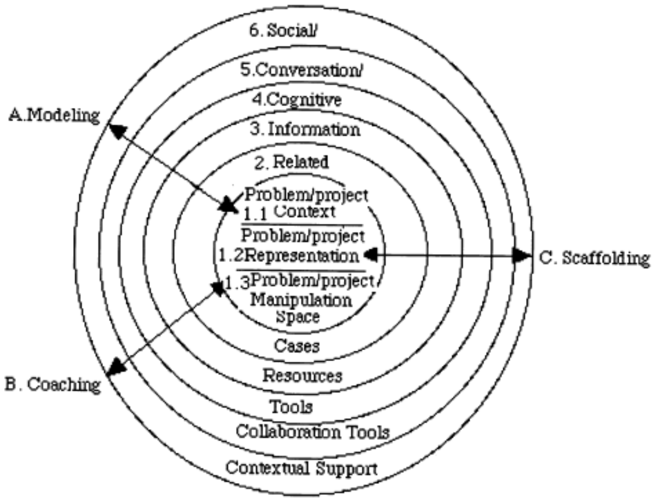


**Figure 4: Jonassen's Constructivist Learning Environment (CLE) model**

Source: Jonassen (1999, p. 218)

Why this model of constructivist learning environment is pertinent for this study will become apparent later in a discussion on the affordances that virtual reality technology offers; the generic reason though, is that most of the model's essential components appear to be intrinsic in most educational virtual realities. In addition, not only does this model embrace constructivists' ideas, but it incorporates those of cognitivists too in the form of "cognitive tools" for scaffolding learning. At the centre of the model is an ensemble of three key integrated facets, which form the focus of the learning process: problem or project context, problem or project representation, and problem or project manipulation space. Piaget's idea of an *operation* is salient in this regard. According to Piaget (1964),

> Knowledge is not a copy of reality. To know an object, to know an event, is not simply to look at it and make a mental copy, or image of it. To know an object is to act on it. To know is to modify, to know is to understand the process of this transformation, and as a consequence to understand the way the object is constructed. An operation is thus the essence of knowledge; it is an interiorised action which modifies the object knowledge. (p. 8).

The three integrated components at the centre of Jonassen's model clearly appear to present a conducive learning environment, which is indispensable for the realisation of Piaget's conception of knowledge construction. According to this model and Piaget's conception of learning, it is the centre of this model that the researcher conceives as an *operation space* which serves as what Piaget (1964) views as "the essence of knowledge" (p. 8). This is because it is what resides here that needs to be pursued or acted upon and drives learners to embark on constructing knowledge. It is what is provided here that drives learning and determines the degree of engagement by the learners. The surrounding components serve as nothing but learning support tools. Related cases serve to scaffold student memory and enhance cognitive flexibility; information resources serve to help learners understand and make sense of the problem; cognitive tools facilitate the processing of cognitive thinking tasks such as the visualization of abstract phenomena; conversation and collaborative tools serve to enable "learners to collaboratively construct socially shared knowledge" (p.28), and, social or contextual support serve to incorporate the learners' sociocultural aspects into the learning environment (Jonassen, 1999).

### 2.2.3 Conclusion

Virtual Reality presents itself as a capable educational technology tool that should be incorporated in constructivist learning environments such as the one espoused by Jonassen. The technology "has several characteristics that make it promising as a constructivist tool for learning science" (Dede et al., 1999, p. 8) because of its distinctive features that are able to address some of the challenges discussed above. The researcher views VR technology the same way Papert (1980) and Jonassen, Carr and Yueh (1998) viewed the computer; it is the researcher's view that as learners manipulate virtual reality technology to make sense of either what they think or their experiences, they themselves get to think about how they think as conceptual conflicts are triggered by results that the learners did not anticipate (Rowell, 1989). VR technologies are heavily interactive in nature, providing the sort of *operation space* highlighted above, and they appear to symbolize the sociocultural interactions that are embraced by social constructivists. Further, the technology is commended for its learner-centredness, its ability to promote collaborative and experiential learning, and the ability to enhance active participation amongst learners. As McLellan (1996) puts it:

> It [VR] is also a tool for model-building and problem solving. VR is potentially a tool for experiential learning. The virtual world is interactive; it responds to the user's actions.

> Virtual reality evokes a feeling of immersion, a perceptual and psychological sense of being in the digital environment presented to the senses. (p. 461).

It, therefore, suffices to consider cognitivism and constructivism as the two theoretical frameworks best suited to guide this study. These two frameworks are selected for their potential to address some of the limitations that are encountered by learners when learning without the use of virtual reality technologies. At the same time, the frameworks will enable the identification of some of the VR technology affordances that may have an impact on learning, such as active participation by learners, collaborative learning, experiential learning, and many others. The utility of these two frameworks in investigating the use of virtual reality technology for teaching and learning purposes derives from the fact that as learners are encouraged to act upon their environment (*operation space*), careful consideration should be made to effectively manage cognitive overload on learners' working memory.

## 2.3 Literature Review

### 2.3.1 Introduction

The basis of Lev Vygotsky's notion of internalization derives from the interplay between the external and the internal. Accordingly, internalization is "the internal reconstruction of the external operation" (Vygotsky, 1978, p. 56). Moreover, for this process of internalization to be effectively realized, argues Vygotsky (1978), it needs to consist of a series of three transformations: an initial external activity must be reconstructed to occur internally; interpersonal processes must be transformed into intrapersonal ones; and consequently, developmental events unfold. This brings rise to the use of technology (in particular, virtual reality technology) as "auxiliary means" to be internally reconstructed for effective knowledge construction, and secondly, as cognitive tools for scaffolding learning.

Sufficient literature (see Salomon, 2002; Minty & Moll, 2020; Kim & Reeves, 2007; Salomon, 1976; Hokanson & Hooper, 2000; Hokanson & Hooper, 2004) suggests that despite the hype around the potentialities of ICT integration in education, these expectations are yet to be realized. One obvious explanation for this failure that frequently shows up in the literature relates to the adoption of a technocentric approach (Salomon, 2002; Kim & Reeves, 2007; Papert, 1980; Papert, 1987; Salomon, 1998; Hokanson & Hooper, 2004) that appears to – implicitly or explicitly – justify the integration of technology in education instead of deriving from a knowledge construction approach, and by extension, from a pedagogic approach. The *tail seems to be wagging the dog*; "Often there is a tendency to focus on the technological features without understanding the instructional need" (Merchant, 2012, p. 4). It can be argued, for example, that Clark's (1983) conclusions on media use for learning: "media as simple vehicles of instructional methods" (p. 446), were influenced by the technocentric approach that underpinned his study.

Kozma (1991), Fowler (2015) and Jonassen, Campbell and Davidson (1994) arguably make a valid point when they suggest that the best approach to adopt when it comes to media use in learning and, in general, ICT integration in education, is to look at the pedagogical affordances that inform the design of technologies, and which, in conjunction with the instructional methods and "the learning activity within which learners [will] make use of the tool" (Kim & Reeves, 2006, p.207), can effectively enhance teaching and learning.

Mikropoulos and Natsis (2011) attest that "the essential contribution of ICT(s) to the learning process comes indirectly through their pedagogical exploitation and certain features that arise from technological characteristics" (p. 769). Below, is a review of ICT integration issues and digital pedagogical affordances that promote pedagogical benefits of ICT. The discussion unpacks the definitional connotations of virtual reality and its pedagogical affordances in relation to the teaching and learning of physical sciences (physics and chemistry) and the issues relating to the technology's accessibility and affordability.

### 2.3.2 ICT pedagogical integration and digital pedagogy affordances

According to Hammond (2010), the notion of an affordance was coined by James J. Gibson to "describe what an environment offers the animal, what it provides or furnishes, either for good or ill" (p. 205). It is, however, Donald Norman who refined the concept to more general objects (Hammond, 2010; McGrenere & Ho, 2010). Norman's affordance, as cited in Hammond (2010), "refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (p. 208). Burden and Atkinson (2008) suggest that it is the individual user of the tool who defines the pedagogical usefulness of the tool as per the challenges being faced or the intended goals. Therefore, different users may perceive different affordances from the same tool and, consequently, the manner in which that tool is used determines its success (Hokanson & Hooper, 2000). An affordance is thus a potential inherent in an object awaiting the user to perceive it. That being said, it does not necessarily mean that once perceived, “all that glitters becomes gold”.

Digital technologies promote ubiquitous teaching and learning in multimodal representations, afford learners collaborative learning that is not confined only to the classroom, enable hypermedia learning, (Kreijns, Kirschner & Jochems, 2002; Oliver & Herrington, 1995; Eze, Adu & Ruramayi as cited in Padayachee, 2017), and “engage learners in problem-solving and critical thinking” (Kurt, as cited in Mlambo, Rambe & Schlebusch, 2020, p. 1). However, to derive benefits from these technological affordances, the integration of such technologies into pedagogy must be substantiated by sufficient evidence (Helsel, 1992) and incorporated into conducive learning environments that embrace learner-centredness for effective knowledge construction.

As advances in technology continue to make significant impact in industries such as medicine, communication, commerce (Salomon, 1976; Hokanson & Hooper, 2004), to name a few, the thinking that the same impact can be realised in education intensifies. There exists a wealth of empirical research on the integration of various ICTs (radio, television, media, computers, etc.) in education, and the evidence suggests that their impact on education remains debatable (Salomon, 1984; Hokanson & Hooper, 2000; Hokanson & Hooper, 2004; Dede, Jacobson & Richards, 2017). As previously indicated, sufficient research attributes this failure to the “technocentric trap” (Papert, 1987, p. 23) that frequently invades most studies pertaining to ICT integration in education. According to Helsel (1992), the issue is that “when the technology becomes the primary focus, the emphasis is placed on the mechanical, i.e., software capabilities, system architecture, eye physiology, etc., rather than upon the student” (p. 38). This is exacerbated by the incorporation of existing instructional methods into these new technologies (Hokanson & Hooper, 2000). If ICTs are going to be repurposed to address challenges in education or accomplish educational goals, it is important to first think about them from a pedagogical perspective, as opposed to a technological one. Indeed, the rationale for ICT pedagogical integration is to enhance “what the teacher has already been doing effectively” (Ndlovu & Moll, 2016, p. 125) in order to promote learning.

Progressively, as new technologies are being developed, the pedagogical benefits of ICT integration in education continue to be investigated (Mlambo et al., 2020). The same applies in the South African context, particularly since the publication of the 2003 white paper on e-

Education (Wilson-Strydom, Thomson & Hodgkinson-Williams, 2005). There is evidence of a surge in research into ICT pedagogical integration (Conole & Dyke, 2004), with multiple publications by education policymakers from country to country focused on leveraging the power of technology to transform teaching and learning. These include South Africa's 2003 white paper on e-Education and subsequent publications building on the 2003 white paper (Department of Education, 2004), the United States' National Education Technology Plan 2010 and its subsequent associated publications (U.S. Department of Education, 2010), and many others.

However, scrutiny of most research publications reveals that it is the technological affordances that initiate ICT adoption, with potential pedagogical affordances lagging technological affordances. This is despite the existence of sufficient evidence suggesting that it is pedagogically grounded integration of ICT in education that is likely to promote teaching and learning (Mereku & Mereku, as cited in Padayachee, 2017; Dalgarno & Lee, 2010; Minty & Moll, 2020). Furthermore, Conole and Dyke (2004) suggest that what is known about the affordances of a diverse range of technologies and how to utilize them for different pedagogical contexts is insufficient. Hokanson and Hooper (2000) further suggest that ICT integration in education can be used "along the continuum from representative to generative uses" (p. 543), where the representative use entails the transmission of information, while the generative use is located within both Piagetian (at the individual development level) and Vygotskian (sociocultural level) constructivist conceptions (Wilson-Strydom et al., 2005). As Hokanson and Hooper (2000) argue, it is the representative use of ICT integration that has commonly been used in education, yielding disappointing results.

At this moment, it is worth stressing that the imperative of knowledge construction by learners does not necessarily imply that educational technologies should be indiscriminately thrown at learners. The role of the teacher remains indispensable in the setting up of conducive learning environments that are compatible with the use of technology (Johnston et al., 2017). Equally crucial in this discourse is the appropriate pedagogy and teacher pedagogical beliefs or perceptions (Ndlovu & Moll, 2016). ICT integration in education itself presents new challenges to teachers, further complicating the nature of teaching, suggest Koehler and Mishra (2009). To reap the potential pedagogical benefits of what is afforded by ICT integration, it is critical to use well-established pedagogies, train educators sufficiently and offer them the necessary support.

The early adoption of ICT in education was first meant to develop and equip learners with computer literacy or skills (Wilson-Strydom et al., 2005; Mpehle, 2011). There was no emphasis on using ICTs to effectively promote teaching and learning; they were intended for representative use. But there has been a shift from that initial phase towards a generative use of ICT integration, which focuses on the learner constructing their knowledge (individually and socially); whose emphasis is on teaching and learning *with* technology to effectively enhance teaching and learning (Jonassen, 1995; Hokanson & Hooper, 2000; Wilson-Strydom et al., 2005). A technology which is rapidly gaining popularity amongst researchers for generative uses is virtual reality technology. However, evidence on how this technology can be pedagogically integrated in education is still scattered.

### 2.3.3 Virtual Reality technology

Steuer (1992) discusses several definitional issues pertaining to virtual reality, with many of the definitional challenges attributed to the technological approach that is adopted. To date, there is still no single universal definition of virtual reality (Winn, 1993; Hedberg & Alexander, 1994; Pratt, Zyda & Kelleher, 1995; Helsel, 1992; Liu, Bhagat, Gao, Chang & Huang, 2017; Sherman & Graig, 2018; Kardong-Edgren, Farra, Alinier & Young, 2019; Han, 2020; Makransky, Andreasen, Baceviciute & Mayer, 2020). Further, different types of virtual reality technology exist, with immersive virtual reality and desktop virtual reality being the most common (Makransky, Borre-Gude & Mayer, 2019). The key distinguishing feature between these two being that desktop VR is considered non-immersive whereas immersive virtual reality is classified as high-immersive (Makransky & Petersen, 2019; Dalgarno & Lee, 2010; Makransky et al., 2020). In addition, an interface between the user and the computer does not exist in an immersive virtual reality (Winn, 1993; Hedberg & Alexander, 1994).

Although different definitions of virtual reality technology exist, there are, however, several common elements that can be extracted from these various definitions towards a comprehensive and unified definition. Sherman and Craig (2018) suggest virtual world, immersion, sensory feedback and interactivity as the four key elements of immersive virtual realities, while immersion is an absent feature amongst desktop virtual realities (Winn, 1993; Limniou, Roberts & Papadopoulos, 2008; Slater, 2018). In fact, desktop virtual realities are not that different from most computer applications as interaction is similar with any other computer program, with the user utilising a mouse, keyboard or joystick to display the virtual environment on the desktop monitor (Winn, 1993; Makransky & Lilleholt, 2018; Makransky et al., 2020).

Pandelidis (1993) defines virtual reality "as a highly interactive, computer-based, multimedia environment in which the user becomes a participant with the computer in a 'virtually real' world" (p. 23). Pan, Cheok, Yang, Zhu and Shi (2006) define VR as "the use of computer graphics systems in combination with various display and interface devices to provide the effect of immersion in the interactive 3D computer-generated environment" (p. 20). An almost similar definition is provided by Mikropoulos and Strouboulis (2004); they define VR as "a combination of high-end computing, human-computer interfaces, graphics, sensor technology and networking which allows the user to become immersed in, interact and experience in real-time a three-dimensional (3D) artificial environment representing realistic or other situations" (p. 583).

Helsel (1992), on the other hand, breaks down the definition of virtual reality into two categories: conceptual orientation and technological orientation. The conceptual orientation of virtual reality is defined as "a process that enables users to become participants in abstract spaces where the physical machine and physical viewer do not exist" (p. 38), whereas the technological orientation of the definition "is seen as a form of human-computer interface characterized by an environmental simulation controlled only in part by the user" (p. 39). Craig, Sherman and Will (2009) view virtual reality as "a means of letting participants physically engage in some simulated environment that is distinct from their physical reality" (p. 1).

It is not possible to list all existing definitions of VR, but perhaps what is more helpful, anyway, is to deduce and consolidate those aspects of VR technology that frequently show up in most conceptions so as to construct a singular cogent definition. To this end, the researcher suggests that,

> virtual reality technology is about human-computer interaction in which there exists some computational representation of the real world which affords participants in the virtual environment to be immersed in two different places at once, the virtual environment and the real-world environment, and simultaneously feel as if they are in the real-world environment.

This is particularly relevant in physical sciences education where concepts are mostly abstract and microscopic. From a pedagogical standpoint, having the means to experience virtually what one would otherwise not be able to experience in reality should afford the learners opportunity to have enhanced assimilation of this information into their existing mental models and, consequently, better address some of the counterintuitive concepts that stand in the way of effective knowledge construction.

A most crucial question arises regarding what makes the integration of virtual reality technology in physical sciences education any different from other technologies. Three key features that distinguish VR technology from other technologies are *interaction, immersion,* and *presence*. Commenting on the nature of interaction provided by virtual reality technology, Bricken (1991) states, "We can create, modify, and manipulate them [virtual objects] in much the same way we do physical objects, but without those pesky real-world limitations" (p. 178). Indeed, according to Schubert, Friedmann and Regenbrecht (1999), the effect of an affordance of an interaction as learners act upon an environment in a virtual environment was known as far back as the 1960s by Heinz von Foerster.

Interacting with virtual objects the same way as with physical objects in the process of knowledge construction serves as what Jean Piaget (1964) considered "the essence of knowledge" (p. 176). Schubert et al. (1999, 2001), Murray and Sixsmith (1999) and Lui, McEwen & Mullally (2020) further locate virtual reality within an *embodied cognition framework* and suggest that it is the user's bodily interaction that serves as "the true source of presence" (Schubert et al., 1999, p. 270), that is, feeling as if you are actually in the virtual environment.

According to Slater (2018), "the fundamental element of any VR system must include a computer-generated world … but ideally one that" warrants immersion (p. 432). Immersion in a VR system is made possible by the system's display capabilities, body tracking and the actions that one can perform within the system (Winn, 1993; Hedberg & Alexander, 1994; Slater, 2009; Dalgarno & Lee, 2010; Dede et al., 2017; Liu et al., 2017; Makransky et al., 2019). Essentially, in order to feel immersed, bodily movement and interaction with "the physical properties of the system" (Slater, 2009, p. 3551) are necessary. Consequently, it is the degree of immersion in a VR system that triggers the degree of presence, that is, feeling as if one is interacting with the virtual world (Schubert et al., 1999, 2001; Winn, 1993; Dalgarno &

Lee, 2010). Three different types of immersion are stipulated in Fowler (2015): conceptual immersion, task immersion and social immersion. Conceptual immersion in a virtual reality environment entails exploring different representations of phenomena. Task immersion involves manipulating and acting upon VR activities (experiential learning), and social immersion is about interacting with one's peers in a virtual environment.

There are many conceptualizations of presence (Lombard & Ditton, 1997), but broadly speaking, presence entails the subjective feeling of being in the virtual world when, in fact, you are in the physical world (Hendrix, Brandt & Barfield, 1995; Lombard & Ditton, 1997; Witmer & Singer, 1998; Schubert et al., 1999, 2001; IJsselsteijn, De Ridder, Freeman & Avons, 2000; Slater, 2009; Mikropoulos & Strouboulis, 2004). Slater (2009) regards presence as "the strong illusion of being in a place in spite of the sure knowledge that you are not there" (p. 3551). Furthermore, presence is a function of immersion since a change in the degree of immersion triggers a change in the feeling of presence (Moreno & Mayer, 2002). It is a psychological feeling.

Although, there has been some research (see Hendrix et al., 1995; Schubert et al., 1999; IJsselsteijn et al., 2000; Moreno & Mayer, 2002; Mikropoulos & Strouboulis, 2004) conducted on the interplay between learning and some of these three features identified above as distinguishing features of VR, such studies have not investigated the effect of these affordances in relation to the teaching and learning of physical sciences. For instance, the study by Moreno and Mayer (2002) was conducted on botany and investigated the impact of instructional design methods implemented in virtual reality environments and the impact of the degree of immersion on learning across different types of virtual realities.

### 2.3.4 Revisiting conceptual change issues in science

In addition to agreeing that knowledge is constructed, one other crucial thing that both Piaget and Vygotsky agreed on, despite their different approaches, is the role of prior knowledge in promoting learning. What a child learns at school can always be traced back to their pre-school experiences (Ausubel, Novak & Hanesian, 1968; Vygotsky, 1978; Moll, Bradbury & Winkler, 2002). The current study draws on Piaget's view regarding the role of prior knowledge in learning, because Piaget looked at prior knowledge through the lens of an *operation,* as discussed previously, and secondly, because the present researcher considers Piaget's view useful in explaining the relevance of integrating virtual reality technology in education.

According to Piaget (1964), there are these four factors that are crucial in explaining cognitive development: maturation, experience, social transmission, and equilibration. Further, Piaget (1964) breaks down the second factor, experience, into the physical experience and logical mathematical experience. The distinction between the two being that "Physical experience consists of acting upon objects and drawing some knowledge about objects by abstraction from the objects", while logical mathematical experience "is drawn by the actions effected upon the objects" (p. 179).

Judging learners' understanding of scientific concepts that conflict with one's everyday intuitive experience through a performance test when at the same time learners cannot integrate these scientific concepts in their everyday life experiences is insufficient for effective knowledge construction. This is demonstrated in a study by Whitaker (1983) in which in some cases, learners could provide correct answers to multiple-choice questions but also provide incorrect explanations for the same correct answer. Alternatively, when the same question was asked differently, learners could not consistently answer it correctly, evidence that points to confounding mental models held by learners (Rudmann, 2005). In a different study by Vosniadou, Skopeliti and Ikospentaki (2004), children indicated that, despite knowing the earth to be round, "the earth has an end/edge from which people can potentially fall off" (p. 204). This further suggests that understanding scientific concepts at a quantitative level (manipulating formulations) is inadequate without a qualitative understanding (Reif, 1995; Loftin, Engleberg & Benedetti, 1993; Buteler & Coleoni, 2014). Winn (1999), for instance, is of the view that students in chemistry, may pass balancing equations in learning about how chemical reactions occur without really understanding how chemical reactions take place.

Conceptual change entails the "reorganization of existing knowledge structures" into rationally and scientifically accepted knowledge (Vosniadou, Ioannides, Dimitrakopoulou & Papademetriou, 2001, p. 383). Most learners find it difficult to assimilate new scientific knowledge into their intuitive ideas (Whitaker, 1983; McCloskey, 1983; Vosniadou, 1994; Loftin et al., 1993; Buteler & Coleoni, 2014) with evidence suggesting that "with conventional approaches to instruction" (Loftin et al., 1993, p. 68), learners are reluctant to give up their intuitive beliefs (Rudmann, 2005), even after successfully completing the course. This is partly because most of the concepts in physical science are either not directly observable, abstract, or counterintuitive to one's everyday experiences (Loftin et al., 1993). According to Mayes and Fowler (1999), conceptual learning is an iterative, cyclic, process that entails three phases: conceptualization, construction, and dialogue. This implies that to develop an advanced conceptual understanding, concepts need to be presented to learners in ways that can enable them to explore their different behaviours, provide learners with opportunities to manipulate and act upon these concepts, and provide learners with opportunities to integrate these conceptual learnings in their social context through collaborative learning or discussions (Mayes & Fowler, 1999; Fowler 2015).

At a glimpse, intuitive experiences appear to obstruct effective learning in physical sciences, particularly in a learning environment that does not provide an *operation space* to counter learners' preconceptions. However, evidence suggests that intuitive ideas are necessary and useful for learning (Posner, Strike, Hewson & Gertzog, 1982; Buteler & Coleoni, 2014; Rudmann, 2005) since even experts have them, except that theirs are refined and well assimilated into their existing knowledge (Buteler & Coleoni, 2014). Interestingly, Vosniadou (1994), suggests that it is, in fact, this refinement of mental models that appears to be difficult to overcome for conceptual change to happen particularly when the new information "is inconsistent with existing beliefs or presuppositions, or a relational structure of a theory" (p. 49). Moreover, from a constructivist viewpoint, it is this refinement and transformation of flawed observational knowledge into scientifically accepted concepts that comprises learning. The present researcher reasons that if given a conducive constructivist learning environment that affords learners opportunity to interactively investigate these scientific phenomena, their preconceptions could efficiently be addressed and consequently, learning be promoted (Vosniadou et al., 2001).

### 2.3.5 VR technological affordances

As previously argued, the inherent appeal of VR technology is in its technological affordances that relate to interaction, immersion and presence which could potentially be pedagogically exploited to tackle the conceptual change issues reviewed above for the purposes of promoting teaching and learning of physical science. To not fall for the "technocentric trap" (Papert, 1987, p. 23), the report discusses these affordances in relation to teaching and learning of physical science, particularly as they relate to conceptual change. VR technology is considered the only medium that allows participants to virtually interact with microscopic elements and allows the user to virtually enter the computational space and interact with it (Helsel, 1992; McLellan, 1994; Winn & Jackson, 1999).

Dalgarno and Lee (2010) provide a comprehensive account of the affordances of educational virtual learning environments as they relate to teaching and learning. The authors argue that these affordances comprise enriched spatial knowledge representation, enhanced opportunities for experiential learning, improved motivation/engagement, enriched contextual learning, and richer collaborative learning. These affordances are particularly significant in this study because, for instance, challenges to the meticulous understanding of the motion of celestial objects in astronomy are a result of difficulties that learners encounter when it comes to spatial knowledge representation (Rudmann, 2005; Cole, Cohen, Wilhelm & Lindell, 2018).

Plummer (2014), therefore, argues that the “foundation for students’ ability to improve their understanding of astronomy” (p. 2) is spatial thinking; that is, the ability to mentally process, visualize and manipulate the motion of heavenly bodies in 3D from multiple reference frames. Research by Rudmann (2005), Heyer, Slater and Slater (2013), Plummer (2014) and Cole et al. (2018) indicates that spatial thinking is a stumbling block for most learners as it is cognitively overwhelming on learners’ working memory. Interestingly, in a study by Wilhelm, Cole, Cohen and Lindell (2018), it was found that even teachers are confronted by spatial thinking challenges in the same way as their learners, which by implication exacerbates the already ineffective instructional methods on spatial knowledge representation.

According to Dalgarno and Lee (2010), it is the representational fidelity and learner interaction enabled by the virtual environment that ultimately yield the sense of presence in virtual environments. Immersion and presence are not “a unique property” of virtual environments since they are borne by the fidelity of representation and the interactivity levels within the virtual environment (Dalgarno & Lee, 2010, p. 13). Figure 5 shows a model of learning affordances of 3D virtual environments as conceptualised by Dalgarno and Lee (2010).

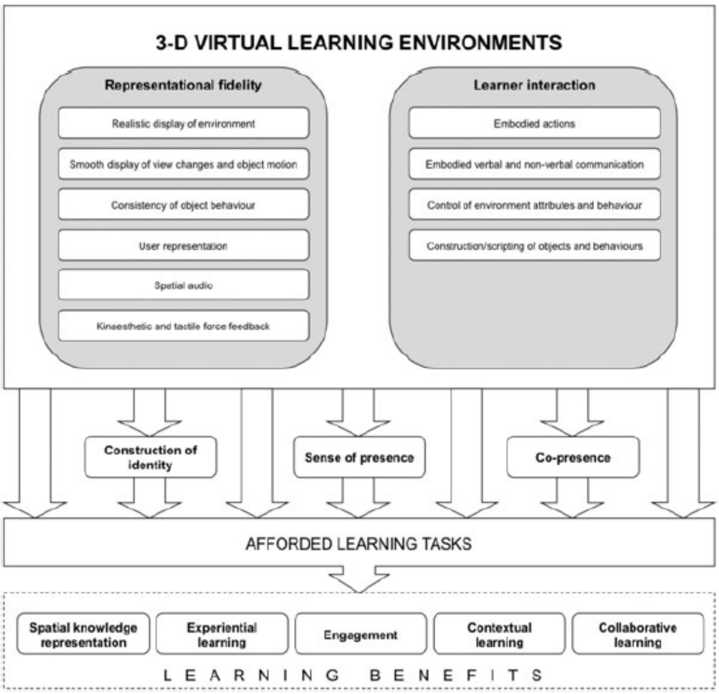


**Figure 5: Dalgarno and Lee's model of 3D virtual learning environments**

Source: Dalgarno and Lee (2010, p. 24)

As can be seen from the bottom of the model, five learning benefits emanate from the learning tasks affordances as exhibited by what is derived from the fidelity of representation and learner interaction. In the light of the nature of most concepts in physical science, virtual reality appears to have technological affordances that when pedagogically exploited could effectively enhance teaching and learning. For instance, Winn (1999) suggests that learners can effectively construct their chemical reactions knowledge in a virtual environment when they are afforded the opportunity to directly interact and manipulate the atoms to establish the behaviours that they exhibit as opposed to using symbols to balance equations. It is these 'first-person experiences' that make virtual reality profound as participants in a virtual environment can naturally interact with objects and phenomena in the virtual world the same way they do in the physical world and even beyond (Winn, 1993, 1999; Winn & Jackson, 1999). This is because VR technology "is, in effect, a transducer. … a device that detects data that is beyond the range of the human senses and converts into something we can see, hear, or touch" (Winn & Jackson, 1999, p. 7).  Key questions at this juncture are:

- how are these technological affordances pedagogically transformed to address some of the conceptual change issues discussed and to effectively promote teaching and learning of physical science? and

- can there be an affordance that actually does the opposite, that is, hinder students' learning?

As is suggested by Mikropoulos (2006) and Mikropoulos and Natsis (2011), it is not yet clear which of the unique features of virtual reality technology have pedagogical significance. What is of more importance to this study is to establish which of the virtual reality technology affordances are significant in promoting learning as there is research that suggests "that the case for how these technologies support learning remains equivocal" (Dalgarno & Lee, 2010, p. 12).

### 2.3.6 Virtual Reality research for teaching and learning

The effectiveness of virtual reality technology in training for the execution of procedural tasks in mining, medical surgeries, aviation, and other related sectors is well known (Burdea, 2004; Dede et al., 2017). Indeed, as outlined earlier, the early use of this technology, according to Pandelidis (2010) and Dede et al. (2017), is traced to the training of flight simulations. The learning tasks for which virtual reality technology has traditionally been utilized have predominantly entailed the acquisition of specific competence skills for performing certain procedures (Dede et al., 2017). The emphasis on its primary use was to enable the mastery of practical knowledge without exposing trainees to risks (Tichon & Burgess-Limerick, 2011; Makransky et al., 2019) that they would otherwise have been exposed to had they trained with the actual equipment. Thus, it does not come as a surprise that most of the existing research on the use of virtual reality has mainly focused on its effectiveness in the training for the performance of procedural tasks.

In mining, for instance, VR is used as an effective training medium that can give workers exposure to an "artificial", almost similar, tense, underground working environment without exposing them to undesirable risks (van Wyk & de Villiers, 2008). It is a tool that enables mining trainees to frequently experience, as would not be the case in the real world, "simulated hazardous situations without putting them in any danger", and to do experiments with potential incidents that might not have previously happened (van Wyk & Callaghan, 2007, as cited in van Wyk de Villiers, 2008, p. 54). It is touted for being a medium which offers "the opportunity to develop perceptual expertise, perceptuo-motor skills, and cognitive skills such as problem-solving, and decision-making under stress, without exposing trainees or others to unacceptable risks" (Tichon & Burgess-Limerick, 2011, p. 33). Moreover, virtual reality is considered useful in training for the use of expensive, unavailable, or inaccessible equipment (Squelch, 2001).

Knowledge that entails "knowing how" to do tasks is known as procedural knowledge. Procedural knowledge relates to being skilled and competent in "knowing how" to perform tasks (Winch, 2010) and builds on tacit knowledge, which implicitly entails knowing how to perform tasks without necessarily being able to convey in words how that happens (Moll et al., 2005). However, the type of knowledge that is supreme in education "encompasses knowledge about a wide range of matters: scientific knowledge, geographical knowledge, mathematical knowledge, self-knowledge, and knowledge about any field of study whatever" (Truncellito, 2007). It entails theoretically knowing, in detail and with sound explanations, what one knows. This type of knowledge is known as propositional knowledge. A theoretical grounding is indispensable when it comes to propositional knowledge. A physicist, for instance, may not only know how to ride a bicycle but may even cite the mechanics and physics laws that make riding a bicycle possible. In this domain of knowledge, evidence suggests that virtual reality research is still in its infancy (Merchant, 2012; Dede et al., 2017; Dawley & Dede, as cited in Lamb, Lin and Firestone, 2019). In a study by Mado et al. (2022) which aimed to explore children's remote education using VR technology during the early days of the shutdown effected SARS-CoV-2 virus that caused the Coronavirus disease (Covid-19) pandemic, one of the findings was that currently VR educational content is lacking.

As virtual reality technologies become increasingly affordable with advances in computing power, they are becoming accessible and increasingly investigated for classroom teaching and learning purposes (McLellan, 1994; Liu et al., 2017; Lamb, Lin & Firestone, 2020), as opposed to the training of performing procedural tasks. The technology appears to have affordances that can be pedagogically exploited to effectively tackle propositional knowledge related phenomena in education, particularly in the physical sciences. This is because the nature of some of the phenomena, such as atoms and molecules, and the solar system, appears to be mentally laborious on learners' working memory (Heyer et al., 2013), thereby necessitating the integration of the means in an effort to augment learners' cognitive processing of phenomena. Thus Dede et al. (1997) are of the view that:

> ... to master complex scientific concepts, pedagogical tools and strategies should (1) provide learners with experiential metaphors and analogies to aid in understanding

abstractions remote or contradictory to their everyday experience and (2) enable students to participate in shared virtual contexts within which the meaning of this experience is social constructed. (p. 8).

However, little is known about the pedagogical frameworks that can be used to enhance learning with VR technology (Lee et al., 2010; Fowler, 2015; Liu et al., 2017; Richter & Dawley, 2009; Hu-Au & Okita, 2021), leaving educators and researchers with little "evidence base they need to determine the "when", "why" and "how" of using IVR [immersive virtual reality] for learning and teaching" (Bower & Jong, 2020, p. 1981). This became evident with the sudden transition to Emergency Remote Teaching and Learning (ERTL) as schools and universities shutdown in 2020 to curb the spread of Covid-19 pandemic. Thus, more research needs to be done on the pedagogy and techno-pedagogical affordances of VR technology in order to establish ways to use it to effectively promote learning (Bricken, 1991).

### 2.3.7 Virtual reality technology accessibility issues

There are several reasons for the slow integration of virtual reality in education observed in the past, among them, the associated costs of the technology (Roussos et al., 1999; Bricken, 1991; Kim, Park, Lee, Yuk & Lee, 2001; Abulrub, Attridge & Williams, 2011; Ray & Deb, 2016; Kavanagh, Luxton-Reilly, Wuensche & Plimmer, 2017). Affordability has always been the main challenge restricting accessibility and adoption of virtual reality for educational purposes (Merchant et al., 2014; Luo, Li, Feng, Yang & Zuo, 2021), leading to several commercial failures, with many VR systems being discontinued in the past (Kavanagh et al., 2017). *Google Expeditions* is the latest in this trend as Google announced the end of its smartphone-based virtual reality (Mullaney, 2020).

However, rapid advances in technology and high-performance computing power, has rendered the technology more affordable and accessible (Winn & Jackson, 1999; Abulrub et al., 2011; Kim et al., 2001; Merchant, 2012; Merchant et al., 2014; Slater, 2018; Fransson, Holmberg & Westelius, 2020; Pan & Hamilton, 2018; Araiza-Alba, Keane, Chen & Kaufman, 2021; Hamilton, McKechnie, Edgerton & Wilson, 2021), along with the emergence of smartphone-based virtual realities. Not only have these advances led to an increase in affordability and accessibility, but they have also resulted in "more compelling, immersive virtual experiences" (Blascovich et al., 2002, p. 106). It is, however, the greater affordability due to advances in computing power that seems to be the likely driving force behind the widespread enthusiasm for the pedagogical use of VR technology at present, and not the appreciation of the potential pedagogical benefits of the technology (Merchant, 2012; Bower & Jong, 2020).

Advances in the computing power of mobile devices such as laptops and smartphones appear to have a direct influence on the affordability and accessibility of virtual realities. Nonetheless, accessibility still appears to be relatively lower in South Africa and Africa where the 'digital divide' still exists. According to the IQbusiness report (2018) on VR technology, 60% of the adult population in South Africa has access to smartphone usage and only 24% has access to laptop/desktop computers as shown in Figure 6. In addition, internet connectivity in the country remains a challenge; an issue that partly derives from the 'digital divide' (Reece, 2008; Mouton, 2018). Nonetheless, the IQbusiness report suggests that the rate at which virtual reality technology is being adopted in the country is promising.

That South Africa and the continent are lagging behind developed countries in the accessibility of VR technology, is not necessarily negative because research on the pedagogical effectiveness of this technology is still inconclusive (Winn, 1999; Salzman, Dede, Loftin & Chen, 1999; Roussos et al., 1999; Mikropoulos, 2006). The present researcher is of the view that the current lack of accessibility in South Africa could be a positive from a research standpoint, as it allows for generation of more evidence on the effectiveness of this technology for educational purposes prior to advocating for its pedagogical integration in education.

DEVICE USAGE OF ADULT POPULATION

| | South Africa |
|---|---|
| Smartphone | 60% |
| Laptop/Desktop Computer | 24% |
| Tablet | 12% |
| Television (any type) | 82% |
| Device to stream Internet content to television | 3% |
| Average daily time spent using the Internet via any device | 8H32M |
| Average daily time spent viewing television, Broadcast streaming, or Video on Demand | 3H00M |

**Figure 6: Type of technology device and duration usage by adult population in South Africa**

Source: IQbusiness (2018, p. 5)

### 2.3.8 Conclusion

This chapter reviewed and identified gaps in the existing literature relating to the integration of ICT in education, VR technology, in particular. A prominent issue from the literature was the misguided technocentric approach that has been utilised in most studies on the adoption of ICT for teaching and learning purposes. Ultimately, such studies have often found ICT integration in education to be ineffective in promoting learning. This is despite knowing that, as Salomon (2002) states, "It is not the [technology] *per se* that makes the difference, for it only offers affordances and opportunities; *it is the pedagogical way in which it is used that makes the difference*" (p. 75). The researcher agrees that the primary focus of ICT integration in education should be on learning and not on the technology.

While, from a constructivist perspective, prior knowledge plays a fundamental role in knowledge construction, the Chapter has argued that there are some cases, for instance in the physical sciences, wherein learners' mental models emanating from their everyday experiences stubbornly conflict with new scientific knowledge (Vosniadou, 1994). Consequently, it has been argued in concurrence with Piaget and Papert, that if learners are presented with conducive constructivist learning environments that enable them to act upon new scientific knowledge, learning will be effectively enhanced.

To the best of the present researcher's knowledge, this study is different from previous meta-analytic studies in many ways; the focus is limited to the generative uses of virtual reality technology for the teaching and learning of physical science; and specifically, the researcher aims to identify those techno-pedagogical affordances of VR technology that seem to enhance or impede learning in the physical sciences and the associated pedagogies, to establish the nature of learning conditions that appear to be conducive for teaching and learning with virtual reality technology and also to determine the effectiveness of virtual reality in addressing conceptual change issues amongst learners. Unlike most meta-analytic studies that have broadly investigated the effectiveness of VR technology, it has been argued that the abstract and microscopic nature of some concepts in the physical sciences is cognitively overwhelming on learners' working memory and, as a result, the pedagogical integration of VR technology presents potentialities that can be exploited to effectively promote learning. Consequently, it has been argued in the preceding sections that broadly examining the effectiveness of VR technology amounts to trivialising the potentialities of this technology.

# CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

## 3.1 Introduction

This section begins with a brief review of the literature on research paradigms that underlie research studies, and it locates and discusses the research paradigm that guides the present study. Justifications of the research design, methodology, sampling strategies/techniques, data collection methods, and data analysis approaches are then provided, with reference to how the approaches adopted are best suited to tackle the research question.

## 3.2 Philosophical assumptions (Research Paradigms)

According to Creswell (2017), identifying and making explicit, the philosophical assumptions that guide one's research is essential as it helps explain the choices of the research design one makes. Nonetheless, even if these philosophical assumptions may not be made explicit, the researcher's underlying philosophies are still inherent in their research approach (Yvonne Feilzer, 2010). Philosophical assumptions "constitute the abstract beliefs and principles that shape how the researcher sees the world, and how s/he interprets and acts within that world" (Kivunja & Kuyini, 2017, p. 26). They shed light on the thought processes that the researcher embraces and hence reveal the research direction the researcher takes with respect to their research design, methodology and data collection methods. Philosophical assumptions, also commonly referred to as *paradigms*, are viewed by Guba and Lincoln (1994) as basic beliefs accepted on faith, without a way of establishing "their ultimate truthfulness" (p. 107). They include:

> … how we look at the world, the conceptual frameworks in which we work in understanding the world, the community of scholars who are working within that framework and who define what counts as worthwhile knowledge and appropriate methodology in it, how we research the world, what the concepts are, what counts as relevant knowledge and how we validate and consider that knowledge. (Cohen et al., 2017, p. 34).

That said, some researchers contest the aforementioned usefulness of research paradigms (Cohen et al., 2017). Nonetheless, this section eschews these debates here, and focuses on discussing the paradigms and locating the one that underlies this study and is appropriate for responding to the research question and objectives. This is in unison with the views of Cohen et al., (2017) that research must be guided by 'fitness for purpose' as the guiding principle. Three of the many paradigms; postpositivism, constructivism and pragmatism, are discussed below and justification of the paradigm guiding this study made.

### 3.2.1 Postpositivism

Postpositivists build on the traditional, objective, view of positivists which is rooted in absolute truth and certainty, and recognizes that "human knowledge is conjectural, probabilistic, influenced by the researcher and the theoretical lenses being used ..." (Cohen et al., 2017, p. 174). By extension, their philosophical assumptions do not entirely rest on quantifiable knowledge, and to some extent, qualitative knowledge is of use to them (Thomas, 2010). Their assumptions as articulated in Creswell (2017) are that knowledge is theory backed and verifiable, there exists a cause-effect relationship, knowledge derives from objective observation and measurement, and that knowledge is reductionist. For that reason, "evidence established in research is always imperfect and fallible" (Phillips, Phillips & Burbules 2000, as cited in Creswell, 2017).

### 3.2.2 Social Constructivism

The philosophical views of social constructivists are grounded in the subjective views of individuals as they interact with the world. They view phenomena as "complex 'wholes' that are inextricably bound up with historical, socioeconomic, and cultural contexts in which they are embedded" (Lodico, Spaulding & Voegtle, 2010, p. 8). Research as viewed by social constructivists is interpretive as research answers are influenced by the researcher's experiences (Lodico et al., 2010; Cohen et al., 2017). Social constructivists' "approach(es) make an effort to 'get into the head of the subjects being studied' so to speak, and to understand and interpret what the subject is thinking or the meaning s/he is making of the context" (Kivunja & Kuyini, 2017, p. 33). What the researcher does is explain the sense-making, interpretations, and viewpoints of the individual subjects.

Because the premise of social constructivists is on subjective meanings that are individually constructed from the social interactions that are made and first-person experiences, their approach to research design is qualitative in nature in an effort to make wide-ranging interpretations of the subjects' worldviews (Lodico et al., 2010; Creswell, 2017). Unlike quantitative research where responses are predetermined, qualitative research affords space for the subjects to express their experiences or worldviews without any boundaries.

Through the use of open-ended questions, the goal of social constructivist researchers is to see the world through the participants' eyes (Lodico et al., 2010; Creswell, 2017; Cohen et al., 2017; Kivunja & Kuyini, 2017). Social constructivists construct meanings from the meanings of others. The social constructions that they make are the "mental and sensemaking processes and products which humans engage as they make sense of, and organize, the physical realities, sensory data, situations, contexts, experiences, attitudes, values, beliefs, expectations, and the likes which swirl around them" (Lincoln, 2007, p. 3162). Thus, social constructivists' views are entrenched in multiple realities which they seek to extract across subjects. Contrary to postpositivists' positioning, social constructivists' meanings and the interpretations they make lead to theory building, whereas what postpositivists do is theory backed.

### 3.2.3 Pragmatism

According to Kivunja and Kuyini (2017), it is important that as a researcher one demonstrates an understanding of the ethos of their chosen paradigm in order to uphold and be guided by it in their inquiry. The adopted philosophical assumption for this study is pragmatism, a paradigm that is not so easy to define (Biesta & Burbules, 2003). As Lodico et al. (2010) indicate, "pragmatism is not concerned with whether research is describing either a real or socially constructed world. Instead, for pragmatists, research simply helps us to identify what works" (p. 16). Pragmatism's core philosophical assumption is the use of any available approaches or methods that are best suited to address the research problem at that point in time (Lodico et al., 2010; Creswell, 2017).

Pragmatists do not see any differences in inquiry methods other than as mere "ways of helping us cope with aspects of the world" (Bradley, 2003, p. 300). Pragmatism is not restricted to any specific research method and literature (see Lodico et al., 2010; Creswell, 2017) largely links it with mixed-methods research. As argued by Morgan (2014), it does not matter which research method one uses; qualitative, quantitative, or mixed-methods research, pragmatism can serve as a philosophical assumption for whichever. The same can be said about "paradigmatic claims" that link qualitative research methods with constructivism and associate quantitative methods with postpositivism; there does not exist a "deterministic link that forces the use of a particular paradigm with a particular set of methods" (Morgan, 2014, p. 1043).

The present researcher's choice of pragmatism as the paradigm that guides this study is not suggestive of a rejection of postpositivism or social constructivism. The research question of this study as stated earlier indicates that the researcher set out to explore how virtual reality technology affordances might promote teaching and learning, and secondly, to statistically test those VR technology elements that might be pedagogically contributing to teaching and learning. The researcher was, therefore, of the view that the ethos of pragmatism is best suited to address this research question and provide the appropriate framework for the resulting research design.

## 3.3 Research Design

The study's objective was to establish ways in which virtual reality technologies can be used to effectively enhance teaching and learning. Although much of the research that has been conducted thus far on the pedagogical use of VR technology for teaching and learning indicates positive results (Mikropoulos & Natsis, 2011; Dalgarno & Lee, 2010; Duncan, Miller & Jiang, 2012), much of the evidence is anecdotal (Dalgarno & Lee, 2010). It is still unclear how these aspects of the technology can be exploited pedagogically (Mikropoulos, 2006; Dalgarno & Lee, 2010; Fowler, 2015; Johnston et al, 2018), whether there are aspects of the technology that may hinder learning, and under what circumstances learning is effectively enhanced or impeded. Furthermore, according to Merchant (2012), there is a need for more research which integrates the results of studies conducted on the effectiveness of this technology.

Although Mikropoulos and Natsis (2011) and Dalgarno and Lee (2010) highlight some of the distinctive aspects of the technology that may contribute to learning, they do not statistically establish how effectively these features may influence learning. It is, however, essential to collect and integrate the results of studies conducted on this technology and perform statistical analyses to establish the effectiveness of the characteristic elements of the technology. In this way, research will establish "…how much better or worse" (Kulik, Kulik & Cohen, 1979, p.323) VR technology influences learning.

The current study is conceptual research. It systematically and comprehensively interrogates the existing literature on the pedagogical use of virtual reality for the teaching and learning of physical science. In contrast to empirical research, conceptual research synthesizes and analyses existing literature in an effort to put forward new propositions or theories, provide a review of the literature over a particular period, or advance existing theories by filling in the gaps in the existing theories (Whetten, 1989; Gilson & Goldberg, 2015).

There are three key features of VR technology that emerged as the researcher extensively reviewed the existing literature on VR technology integration in education. These distinguishing features are:

1. Immersion – this feature arises from the degree of realistic display of the phenomena in a virtual environment coupled with the user's interaction as a participant in the virtual environment (Winn, 1993; Winn & Jackson, 1999; Witmer & Singer, 1998; Dalgarno & Lee, 2010; Schubert et al., 1999; Slater, 2018). This feature of VR technology is said to be useful for effective learning at conceptual, task and social levels (Fowler, 2015).
2. Learner interaction/involvement – the high level of interaction that is uniquely enabled by virtual reality environments is said to elevate learner control over manipulating and modifying phenomena. Moreover, the intrinsic level of involvement enabled by virtual reality technology is considered to endorse embodied knowledge (Dalgarno & Lee, 2010; Schubert et al., 1999). It is generally accepted that constructivists consider learner involvement a crucial component in the learning process, but there is also a view that claims that the interactivity afforded by virtual learning environments significantly influences learning (Winn, 1999). However, questions exist as to the extent to which this can be equated to the implicit learner interaction that the pioneers of constructivism advocated.
3. Sense of presence – similarly, the claims for the subjective experience of "being there" in the virtual environment in relation to learning are strong (see Witmer & Singer, 1998; Winn, 1999; Winn & Jackson, 1999; Mikropoulos, 2006). Witmer and Singer (1998) provide a comprehensive account of factors that influence presence in *Measuring presence in virtual environments*. Questions remain, however, on how one assigns a

measure to a subjective feeling and what level of this "illusion" effectively promotes learning.

The general challenge associated with identifying constructs of interest in meta-analysis is that different researchers may use different constructs to mean the same thing or use the same name for different constructs (Card, 2015). That said, the constructs of interest that would likely have to be studied to investigate the existence of some association between the constructs and the pedagogical use of VR technology are identified in this study as achievement, performance, spatial thinking, motivation, and conceptual learning. There may be a direct or indirect relationship between some of these constructs and the pedagogical use of VR technology. For instance, according to Merchant et al. (2013), Cole et al. (2018) and Oliver-Hoyo and Babilonia-Rosa (2017), there is evidence in the literature that suggests correlation between spatial thinking and academic performance. The present researcher posits that this relationship is indirect, since a change in a student's academic performance would be caused by a change in their spatial ability which is brought on by the unique features of VR technology. The researcher's goal in this study was to investigate whether there is a change in the aforementioned constructs of interest that is brought on by a change in the pedagogical integration of virtual reality technology.

## 3.4 Research Methodological Approach

As Bangert-Drowns (1992) and Glass (1976, 1977) indicate, the nature of research outcomes variability is such that generalizing research interpretations, particularly in education and the social sciences, is challenging for reasons that are inevitable. This could be as a result of differences in research designs, varying sample sizes, different methodological approaches, different analyses of the data and many other reasons (Bangert-Drowns, 1992; Glass, 1976, 1977; Kulik et al., 1977; Schmidt, Le & Oh, 2009). To address some of these challenges, various research integration methods have been proposed. However, despite the existence of these different research integration methods, debates and criticisms of these methods persist.

The purpose of this study was nonetheless not to adjudicate on these matters. This study used a meta-analytic approach on quantitative research studies empirically conducted globally between 1990 and 2020 on the pedagogical use of virtual reality technology for the teaching and learning of physical science in both basic education and higher education. The rationale for a period spanning three decades was to ensure rigorous analysis of past and current research on VR technology, as a way of looking into the evolution in research findings with respect to advances in VR technology. The reason for looking specifically into physical science was the conceptual change issues earlier explicated.

Meta-analysis, as conceived by Gene V. Glass in 1976, is a research synthesis of quantitative empirical studies using statistical techniques in the form of *effect sizes* to establish the overall effect of an intervention on the pooled results of independent studies that were conducted on the same research area or topic (Chow, 1987; Card, 2015; McKenzie, Beller & Forbes, 2016; Karadağ, 2017; Ahn & Kang, 2018). It is the “analysis of analyses” (Glass, 1976, p. 3; Kulik et al., 1979, p. 324) of results obtained from independent, empirical studies for the purpose of eliciting unanimous findings (Kulik et al., 1979) and it is widely touted when searching for results that indicate both direction and magnitude of interventions. Its main objective is to integrate findings from pooled individual studies using statistical techniques (Glass, 1976). Unlike with secondary analysis which requires access to the original data to make reanalyses (Glass, 1976), in a meta-analysis, there is no need to have access to the often difficult to access original data that were used in the empirical studies as the goal is to “identify some central tendency in the outcomes of a group of studies … without resorting to original data” (Bangert-Drowns, 1992, p.396). An effect size is a statistic indicating the direction and magnitude of an intervention.

As literature (see, for example, Glass, 1976; Glass, 1977; Card, 2015) indicates, extensive research in education is produced within a short time, using different research techniques, different data collection methods and instruments, different subjects of study, and yet on the same topic. Because of these differences in research design and methodology on the same issue, it becomes a challenge to distinguish between differences that arise in results due to research design and methodological approaches, and the actual differences in results across studies (Card, 2015). To establish the overall effect, research synthesis in the form of meta-analysis becomes essential in situations like these, where literature on the same research area is immense and yet there are ambiguities on the same topic (Abrami, Cohen & d’Apollonia, 1988). The good thing about meta-analysis, in contrast to narrative research synthesis methods that have intrinsic researchers’ subjectivity limitations (Card, 2015; Karadağ, 2017), is that it enables researchers to statistically establish the effects of the research results.

## 3.5 Data Collection Methods

Because of the nature of this research (conceptual study), data for analysis were collected from online research databases accessed through the University of the Witwatersrand library. Before using the university library to search for data from the electronic databases, the researcher was taken through telephonic training on how to do a literature search on the university's library databases by the Wits School of Education librarian. Ultimately, the population of the study comprised articles published between 1990 and 2020 on the pedagogical use of VR technology for the teaching and learning of physical science collected from the online research databases named later in this chapter.

**Sampling**: The purposive sampling technique was adopted for this research because the study had a narrow interest in the pedagogical use of virtual reality for the teaching and learning of physical science for reasons that have been articulated above. Though many studies exist relating to the use of this technology in other subjects, they were not of interest as discussed in section 2.2.4. Inclusion and exclusion criteria were also used to select subjects that fit the study's criteria. These are stipulated below. A search for multiple studies of interest was carried on the electronic databases focusing on studies that were based on the same topic, so as to gather their results for further analysis.

### 3.5.1 Literature search process

Transparency is a critical issue in meta-analysis which should always be ensured by a meta-analyst so that results are replicable and limitations of the review can be evaluated (Bangert-Drowns, 1992). It is therefore critical that the reviewer reports the literature search strategies and processes that were employed in searching for potentially relevant literature (Card, 2015). In this study, the researcher used both broad and narrow search criteria. The literature search was done on the following databases: EBSCOhost, ScienceDirect, SpringerLink, Wiley Online Library, Taylor & Francis Journals, SAGE Journals Online, JSTOR, Directory of Open Access Journals (DOAJ) and Google Scholar. Selection of relevant databases from which to search for subjects was informed by reading through the documentation on each database.

Based on the set inclusion and exclusion criteria, as detailed below, the researcher searched and identified the relevant data by initially reading through the articles' titles and abstracts. The initial search keyword used by the researcher was "*virtual reality"* with publication period and subject area specified as "*1990-2020*" and "*Education*" respectively. Even though terms like "virtual worlds" and "virtual environments" are considered distinguishing elements of VR technology by Sherman and Craig (2018), they are often interchangeably used by researchers in their studies to refer to virtual realities. For this reason, the researcher also considered such studies for inclusion in the sampling. As the results were displayed, the researcher would read the title of the research article and its abstract at face value to establish whether it was potentially relevant for the study (determining false positives), and if that was the case, the article would be downloaded.

Given that other phrases that are interchangeably used with virtual realities were considered as outlined above, the researcher was convinced that there were no other similar phrases or synonyms to virtual reality that could have been used in the search to expand the pool of the results. The researcher further narrowed the criteria and used advanced search tools for filtering relevant data specific to the research objectives by using search tools such as Boolean statements; "virtual reality" AND (physics OR chemistry OR astronomy OR science OR teaching OR learning). Where some databases would not allow for the use of filters such as Boolean operators, the search keywords would be modified accordingly (Tawfik et al., 2019). This advanced search method enabled the researcher to limit search results to only those results relevant to the research goals. This initial process of searching for potentially relevant articles was carried out until a point of saturation was reached.

The second round of screening after downloading all the potentially relevant articles entailed first reading the titles and abstracts of the articles to assess relevance and establish whether necessary statistical information was provided in the abstracts. If this information was evident in the abstracts, the article would be selected for inclusion in the study. It was only in cases where it was not specified or clear what research design and methodology were used or which statistical information was provided in the abstracts, that the researcher would consult the full text to find this information. In addition, the researcher manually gathered other potentially relevant papers as they read through the articles extracted from the initial search. These would be articles that fell within the set inclusion/exclusion criteria but which the researcher had not come across during the initial search (Card, 2015). The process is known as "backward searching" (Card, 2015, p. 50).

### 3.5.2 Inclusion and Exclusion criteria

The purpose of conducting a literature search in a research synthesis study is to collect as much data as possible in order to have a sufficient pool of subjects from which to evaluate, thereby enabling the researcher to answer their research question(s). Here, again, the researcher must be transparent about the criteria used to include and exclude subjects. The root criterion for inclusion of articles in this study was that such articles must have been based on using virtual reality (immersive/desktop) technology specifically for the teaching and learning of physical science. The study was limited to peer-reviewed, quantitative (or mixed methods with quantitative results) empirical studies published between 1990 and 2020. Further, these studies must have "reported [the] necessary statistical information for effect size calculation" (Luo et al., 2021, p. 9). Only peer-reviewed articles were considered in this study as a "quality criterion" measure (Savelsbergh et al., 2016, p. 163). Additionally, the study design should have been experimental or quasi-experimental. The debates and criticisms regarding quality criterion issues in research synthesis as deliberated in Glass (1976, 1977) and Kulik et al. (1979) were noted. However, these discussions were deemed out of scope for the purposes of this study.

The rationale for searching for articles published between 1990 and 2020 was that, over this period, there have been notable advances in VR technology design, development and accessibility, which would likely have attracted the interest of researchers seeking to establish the pedagogical potentialities of the technology. Moreover, this is something that Clark (1983) also raises in *Reconsidering research on learning from media* that with each new medium comes "a set of advocates who make claims for improved learning and stimulate research questions which are similar to those asked about the previous popular medium" (p. 447). This is particularly the case with virtual reality technology as Dalgarno & Lee (2010) suggest that much of the existing evidence from studies on VR technology emanates from "personal impressions that cannot be usefully generalised beyond the local context" (p. 23). Thus, the researcher foresaw an upward trend in published articles around VR technology over this period.

All other papers that did not meet the eligibility criteria, such as conference papers, dissertations, systematic reviews, articles falling outside the publication date of interest, articles published in languages other than English, and many others were excluded from this study.

### 3.5.3 Literature search results

Upon completion of the literature search on the specified databases, a total of 517 publications were identified as potential articles for further screening to establish whether they met the eligibility criteria. Figure 6 provides an overview of the literature search and screening processes in this study. A total of 11 articles were found to be repeats and duplicates were removed. Upon thoroughly reading the abstract and methodology sections of the articles to determine the relevant research design and reported statistical information, a substantial amount of the studies was found to meet the study's exclusion criteria. Screening yielded 481 studies for exclusion.

At this point, a total of 25 publications remained for potential inclusion in the study. A further exhaustive reading of the full text of the 25 potentially relevant articles led to 17 more articles being excluded. A total of 8 articles were therefore included for further analysis. In the process of extracting the necessary statistical information from the studies in order to compute an effect size, 2 more articles cited in the remaining 8 articles were identified as meeting the study's inclusion criteria. Ultimately, a total of 10 articles was accepted for the intended meta-analysis.

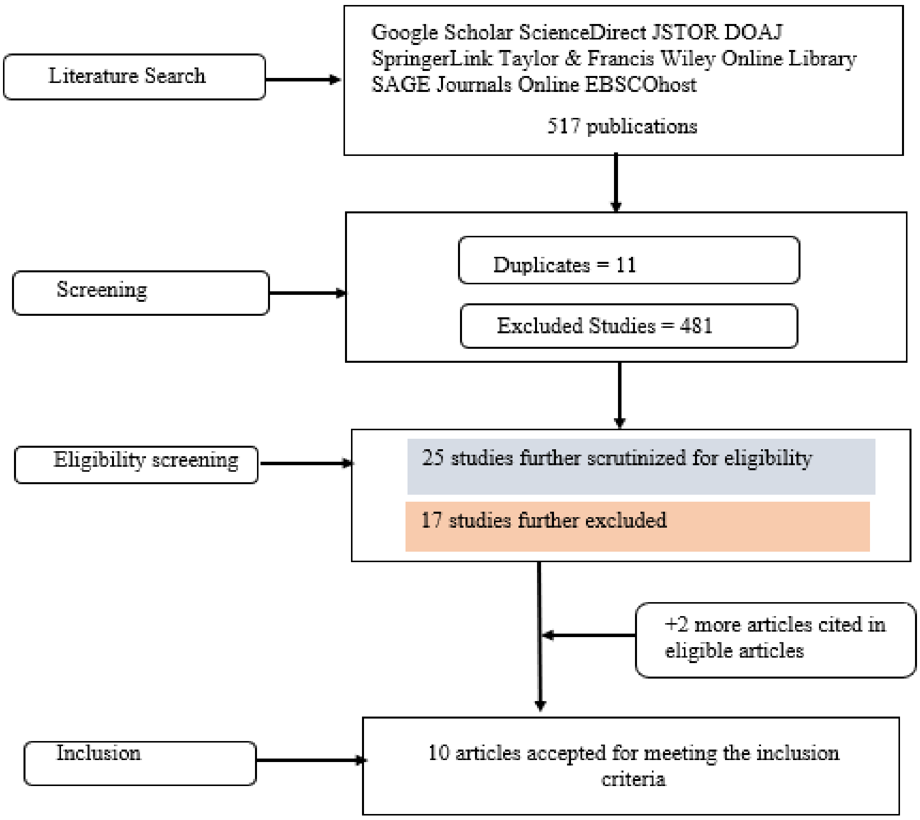


**Figure 6: Flowchart of the literature search and screening processes**

Adapted from Emily Jones (n.d.)

Exclusion of the 17 articles from the 25 identified for potential inclusion in the study was because some studies were based on topics that fall in other subject areas other than physical science, or the reported statistical information would not have made it possible to compute an effect size, among other reasons. For instance, although studies by Merchant et al. (2012) and Chen and Tsai (2020) are quite relevant for this study and it would have been significant to include them in this study, the studies used structural equation modelling techniques in their data analysis. The techniques for applying meta-analysis to structural equation modelling are reportedly complex (Cheung, 2019; Wilson, Polanin & Lipsey, 2016) and due to time constraints, the researcher did not undertake to discuss them here, particularly as most of the included studies reported the means, standard deviations and their sample sizes.

## 3.6 Validity and Reliability

One of the key questions that researchers are confronted with in conducting their research is why anyone should believe their findings and conclusions, and whether the same research instruments could yield consistent findings when repeated at different intervals. Moreover, it is key to check whether the results gathered from a sample can be generalized to a population (Bracht & Glass, 1968). Research findings must be valid and reliable so that they are believed and trusted. The relationship between validity and reliability implies that if findings are unreliable, then they are invalid (Karras, 1997; Cohen et al., 2017), and the research becomes invalid. Although research suggests that it is impossible to completely eliminate validity and reliability concerns, paying attention to these issues enables their mitigation (Oluwatayo, 2012; Cohen et al., 2017).

Challenges related to validity and reliability are many and they vary according the type of research (Kumar, 2018). According to Oluwatayo (2012), some of these challenges are conceptual bias, design bias, sampling bias, and process bias, discussion of which is deemed unnecessary here. Hammersley (1987) states that these terms are defined differently by different authors since much attention has been given to the measurement techniques rather than conceptual issues around these terms. As a result, their definitions are not standardized.

### 3.6.1 Validity

When it comes to research that aims to derive findings from analysis of data comprising responses from research participants, it is important that the design of research, collection, and analysis of such data is free from biases and errors. This will allow for accurate and trustworthy inferences to be drawn. In simple terms, validity can be defined as the trustworthiness, accuracy and appropriateness of the findings in relation to the evidence from which the findings are derived. Hammersley (1987) and Oluwatayo (2012) provide several different variations of these terms and indicate that earlier definitions were more concerned with the extent to which an instrument measures what it purports to measure, with Cohen et al. (2017) echoing the same sentiments.

In this study the researcher was fully transparent with the criteria followed in searching for studies by providing all the databases that were selected, identifying the keywords and strategies used, and providing, with reasons, the eligibility criteria that was used for inclusion and exclusion of articles for analysis. Due to time and resources constraints, the researcher was able to ask only one colleague to use the same literature search strategies on the same databases from the same University library databases to establish how closely the search results could be replicated.

### 3.6.2 Reliability

Reliability relates to how consistently the same questions are answered similarly on different occasions. It measures “variability in answers over repeated conceptual trials” (Groves et al., 2011, p. 281). In research, it is problematic if questions could be answered “one way one day and another the next” (De Vaus & de Vaus, 2013, p. 62). Notwithstanding, as Kumar (2018) suggests, it is impossible to achieve perfect accuracy in social sciences research due to factors that are beyond a researcher’s control that affect reliability. These, as Kumar (2018) indicates, may include ambiguity in the wording of questions leading to respondents understanding or interpreting questions differently, a change in either a respondent’s or an interviewer’s mood while answering a questionnaire or interviewing respondents, respectively, or many other factors. Moreover, De Vaus and de Vaus (2013) posit that unreliability problems can exist even in well-developed questions.

Extensive literature (see, for example, Vogt, Gardner & Haeffele, 2012; Cohen et al., 2017; Kumar, 2018) suggests that there are well developed statistical methods to establish reliability in quantitative data while it is trickier with qualitative data. That said, since the current study is a conceptual study that sought to integrate results of other primary studies, the reliability issues here primarily relate to the transparency and replicability of the coding process (Card, 2015; Vevea, Zelinsky & Orwin, 2019). However, the researcher coded all the included studies alone. This information would have mainly been statistical information such as the means and standard deviations that are reported in the included studies for the purposes of computing effect sizes. Consequently, reliability assessments were not computed.

## 3.7 Limitations of the Study

Building on the limitations described in section 1.9, the other limitation of this study was that, due to time constraints, the researcher could not recruit an independent coder which would have enabled provision of the measure of reliability of the coding process. The process of coding involved the researcher making judgements alone on what measures reported in the included studies would be crucial for the purposes of this study. Although section 4.2 describes the coding process, the researcher was unable to indicate to what extent the same decisions would be reached by an independent coder. Another limitation was that there were relevant studies that had to be excluded because they had used structural equation modelling in their data analysis. The techniques for applying meta-analysis to structural equation modelling exist, but they are inordinately complex (Cheung, 2019; Wilson et al., 2016).

A further limitation of the current study was that the kinds of virtual realities used in all the studies differed. Even though most of the studies had used virtual laboratories (labs), the virtual labs were also unique to each study and were also not developed by one entity. The limitation here is that the affordances of virtual reality technology are a function of the features of the technology itself. For instance, not all virtual realities exhibit the same degree of immersion. The implication foreseeable from this limitation is that this may lead to high heterogeneity in the meta-analysis results.

## 3.8 Conclusion

This chapter began by deliberating on three key research paradigms and justifying the philosophical assumption that underpins the current study. It has been indicated that pragmatism is the philosophical assumption underlying this study chiefly because the researcher was of the view that the inquiry needed not be circumscribed by some pre-determined ethos. The research design and methodological approach for this study were also elucidated, indicating that the current study is meta-analytic conceptual research that synthesizes and does further analysis on peer-reviewed empirical studies that investigated the pedagogical uses of virtual reality technology in physical science. The Chapter that follows presents the statistical analysis of the studies that met the inclusion criteria in this research.

# CHAPTER 4: ANALYSIS AND RESEARCH FINDINGS

## 4.1 Introduction

This chapter presents an analysis of the studies that were identified as meeting the research inclusion criteria. Meta-analysis was the selected data analysis method and the researcher used Viechtbauer's (2010) metafor package, Balduzzi et al.'s (2019) meta package and Harrer et al.'s (2019) dmetar package, all of which are freely available in R 4.1.1, to run the meta-analyses. First, the summary data necessary for computing effect sizes were extracted from the studies and prepared for analysis. The data analysis outcomes are presented below, followed by a discussion of the results.

## 4.2 Statistical Data Extraction and Preparation

As outlined in the previous chapter, the means, standard deviations, and sample sizes were summary data measures of importance that the included studies had to report in order to meet this study's inclusion criteria. This data was needed for the computation of effect sizes and performance of a meta-analysis (Harrer, Cuijpers, Furukawa & Ebert, 2021). In addition, the studies were required to have investigated the pedagogical use of virtual reality technology in promoting teaching and learning. Figure 7 below presents an overview of the data that was extracted from the 10 included studies.

| A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| author | year | dependent_variable | sample_size | E_sample_size | E_means | E_SD | C_sample_size | C_means | C_SD | measurement_reliabiity | p_value |
| 1. Al Amri et al | 2020 | motivation | 65 | 32 | 152.13 | 12.51 | 32 | 98.91 | 17.76 | 0.72 | 0.001 |
| 2. Al Amri et al | 2020 | achievement | 65 | 32 | 23.88 | 3.8 | 33 | 17.45 | 4.45 | 0.72 | 0.001 |
| Chen et al | 2007 | achievement | 21 | 21 | 9.86 | 3.99 | 21 | 6.95 | 3.96 | | 0.001 |
| 1. Makransky et al | 2020 | declarative knowledge | 131 | 64 | 14.31 | 2.93 | 67 | 14.35 | 2.59 | | 0.925 |
| 2. Makransky et al | 2020 | presence | 131 | 64 | 3.64 | 0.48 | 67 | 2.92 | 0.66 | | 0.001 |
| 3. Makransky et al | 2020 | enjoyment | 131 | 64 | 4.22 | 0.56 | 67 | 3.67 | 0.84 | | |
| 1. Merchant et al | 2013 | molecule angles | 384 | 204 | 0.92 | 1.2 | 178 | 0.78 | 1.08 | 0.77 | |
| 2. Merchant et al | 2013 | molecular geometry | 384 | 204 | 3.53 | 1.27 | 178 | 3.59 | 1.23 | 0.54 | |
| 3. Merchant et al | 2013 | species identification | 384 | 204 | 0.33 | 3.01 | 178 | 0.06 | 3.06 | 0.44 | |
| 4. Merchant et al | 2013 | PVRT | 384 | 204 | 11.56 | 4.12 | 178 | 11.71 | 4 | 0.61 | |
| 5. Merchant et al | 2013 | CRT | 384 | 204 | 124.84 | 24.024 | 178 | 127.28 | 29.18 | 0.77 | |
| Sun et al | 2010 | achivement | 128 | 63 | 84.76 | 12.26 | 65 | 80.38 | 13.15 | 0.778 | 0.02 |
| Tarng et al | 2018 | achivement | 109 | 50 | 71.2 | 11.05 | 59 | 60.08 | 13.85 | 0.98 | |
| Tatli & Ayas | 2013 | achivement | 90 | 30 | 59.33 | 11.121 | 60 | 53.083 | 11.92 | | 0.014 |
| Wu et al | 2019 | prolem-solving ability | 54 | 29 | 104.72 | 9.094 | 25 | 98.76 | 12.238 | 0.91 | |
| Tüysüz | 2010 | achivement | 341 | 174 | 10.67 | 2.73 | 167 | 5.4 | 2.02 | 0.86 | 0.001 |
| Faour & Ayoubi | 2018 | achievement | 50 | 25 | 7.28 | 4.067 | 25 | 4.56 | 3.874 | 0.702 | 0.031 |

**Figure 7: Data extracted from the included studies for computing effect sizes**

The reported outcome measures differed across the studies, however, most of the studies provided reports on students' academic achievement. Other measures that were reported included motivation, presence, declarative knowledge, and problem-solving ability. Merchant et al. (2013) reported on achievement and spatial ability in the form of Valence Shell Electron Pair Repulsion (VSEPR) theory test, Purdue Visualizations of Rotations Test (PVRT), and Card Rotation Test (CRT). In their analysis of the data, the authors broke down VSEPR into three parts: molecule angles, molecular geometry, and species identification. For the purposes of meta-analysis in the present study, the researcher collapsed all the different variable names into just one variable: learning. Thus, the current meta-analysis investigates the pedagogical effectiveness of VR technology on the learning of physical science. The data coded in Figure 7 above were reported in all the included studies, together with the measurement reliability scores and the p-values, except in the control group data in the study by Tatli and Ayas (2013).

The study by Tatli and Ayas (2013) had participants in one experimental group and two control groups. The researcher estimated the mean and standard deviation of these two control groups by pooling the summary data measures of the two control groups (Turner & Bernard, 2006; Savelsbergh et al., 2016; Harrer et al., 2021) since both groups were taught using "conventional methods," with the real laboratory used only "when it was possible" to do so (Tatli & Ayas, 2013, p. 163). Three studies by Al Amri et al. (2020), Makransky et al. (2020) and Merchant et al. (2013) provided reports on more than one outcome measure of interest for this study. The study by Chen et al. (2007) used a pre-test-post-test design wherein participants completed a pre-test before the study, and then had exposure to learning with a desktop VR, after which a post-test was run to establish differences in the scores. Ultimately, 17 effect sizes were computed from the 10 included studies.

## 4.3 Data Analysis and Discussion of Results

When conducting a meta-analysis, the goal is to compute a pooled effect size from the effect sizes of all the studies included in one's meta-analysis. An effect size is an index used in meta-analysis to determine and quantify the magnitude of an intervention or an association between variables. There are at least three commonly used indices for representing effect sizes: the Pearson correlation coefficient ($r$), standardized mean difference (Hedges' $g$, Glass's $\Delta$ or Cohen's $d$) and the odds ratio ($o$) (Ellis, 2010; Card, 2015).

The meta-analysis in the current study used a standardized mean difference approach that compared the differences in means between one group that pedagogically used virtual reality technology and a control group that did not use any variant of virtual reality in a similar learning activity. Selection of this effect size computation procedure over other options was informed by what was reported in the included studies; all included studies reported the means, standard deviations, and sample sizes. Cohen's *d* is widely known to be biased in small sample sizes (Borenstein & Hedges, 2019; Card, 2015; Harrer et al., 2021), so, Hedges' *g* was formulated to correct for this bias in Cohen's *d*. Thus, the current study used the recommended corrected Hedges' *g*.

A random-effects model approach was applied instead of the fixed-effect model. The difference between the two is that the fixed-effect model assumes sampling variance only, whereas the random-effects model assumes sampling variance and between-study variance (Card, 2015; Borenstein, Hedges, Higgins & Rothstein, 2010; Harrer et al., 2021). As indicated above, several variants of virtual reality technology were explored in the included studies, it was therefore assumed that not only did the data possess sampling variance, but it also possessed between-study variance, a condition that favours the existence of heterogeneity. With these assumptions, a meta-analysis was conducted.

```
Review:     The pedagogical effectiveness of VR technology in physical science

                        SMD            95%-CI %W(random)
1. Al Amri et al    3.4225 [ 2.6385; 4.2066]        5.1
2. Al Amri et al    1.5335 [ 0.9763; 2.0907]        5.6
Chen et al          0.7183 [ 0.0922; 1.3443]        5.5
1. Makransky et al -0.0144 [-0.3570; 0.3282]        6.0
2. Makransky et al  1.2360 [ 0.8612; 1.6108]        5.9
3. Makransky et al  0.7626 [ 0.4074; 1.1177]        6.0
1. Merchant et al   0.1220 [-0.0793; 0.3232]        6.2
2. Merchant et al  -0.0478 [-0.2489; 0.1532]        6.2
3. Merchant et al   0.0888 [-0.1123; 0.2900]        6.2
4. Merchant et al  -0.0368 [-0.2379; 0.1642]        6.2
5. Merchant et al  -0.0917 [-0.2929; 0.1094]        6.2
Sun et al           0.3423 [-0.0068; 0.6914]        6.0
Tarng et al         0.8732 [ 0.4784; 1.2680]        5.9
Tatli & Ayas        0.5311 [ 0.0857; 0.9764]        5.8
Wu et al            0.5509 [ 0.0053; 1.0966]        5.6
Tüysüz              2.1831 [ 1.9144; 2.4519]        6.1
Faour & Ayoubi      0.6741 [ 0.1029; 1.2453]        5.6

Number of studies combined: k = 17
Number of observations: o = 3246

                        SMD            95%-CI    t p-value
Random effects model 0.7260 [0.2633; 1.1887] 3.33  0.0043

Quantifying heterogeneity:
 tau^2 = 0.7256 [0.3892; 1.8912]; tau = 0.8518 [0.6239; 1.3752]
 I^2 = 95.5% [94.0%; 96.6%]; H = 4.71 [4.08; 5.44]

Test of heterogeneity:
      Q d.f.  p-value
 355.19   16 < 0.0001
```

**Figure 8: The pooled effect size estimate on the pedagogical use of VR technology in physical science**

The results in Figure 8 above show a pooled effect size estimate of *g = 0.7260* in the range of *[95% CI: 0.2633, 1.1887]* and a p-value of $p = 0.0043$. Qualitative interpretation of these quantitative results is that, with *0.7260 standard deviation units*, the sample estimate of the effect of the pedagogical use of virtual reality technology in physical science is significant and effective. Moreover, since the effect of the pedagogical use of virtual reality technology in physical science in the population is in the range of *[95% CI: 0.2633, 1.1887]*, which excludes zero, it could not be by chance that the estimated effect size is *0.7260 standard deviation units*. The meta-analysis' pooled effect size estimate is statistically significant at $\alpha = 0.05$. Only four effect size estimates appeared to not be significant in the results above.

However, the results show substantial heterogeneity of $Q(df = 16) = 355.19, p < 0.0001$ and $I^2 = 95\%$. This was foreseen, as stated elsewhere. It was therefore crucial to investigate which studies were causing this high variability in the results. A forest plot provides a comprehensive summary of the meta-analysis results, including the individual study effect sizes, the pooled effect size and the confidence intervals (Harrer et al., 2021). Since a forest plot provides a graphical display of the results, it enables easier and quicker identification of studies with effect size estimates that deviate from the rest (Viechtbauer & Cheung, 2010). A "somewhat brute force approach" according to Harrer et al. (2021, p. 153).

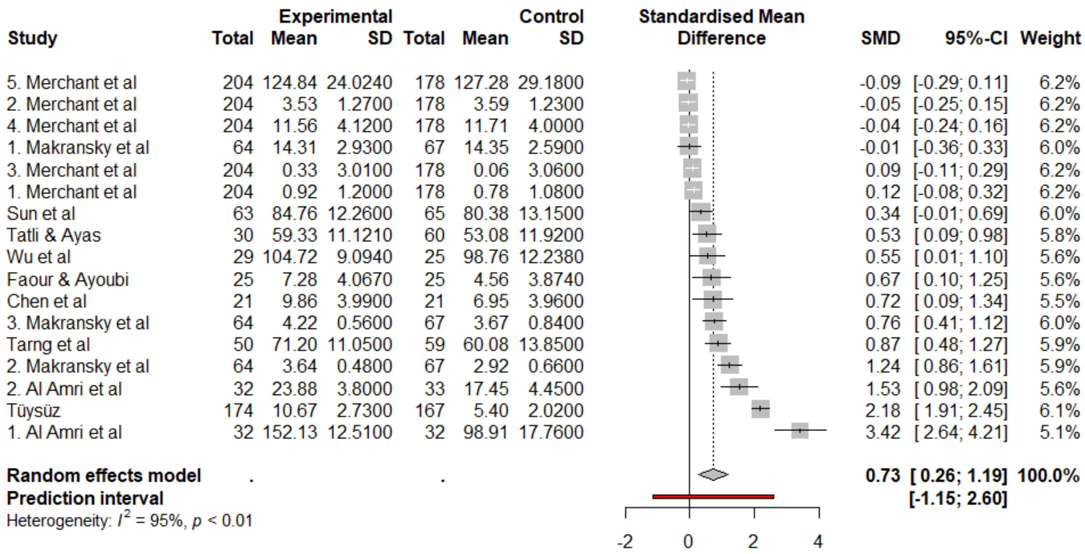


**Figure 9: A forest plot of the pooled estimate of the effect size sorted by effect size**

However, studies whose 95% confidence intervals does not overlap with the 95% confidence interval of the pooled effect size estimate are also viewed as outliers (Harrer et al., 2021). In

Figure 9, above, it can be easily seen that the bottom two studies, Tüysüz and 1. Al Amri et al., appear to deviate from the observed pattern. It is also clear that their respective effect size estimates are relatively larger than the rest. The sample size of the study by Merchant et al (2020) was relatively larger than the sample sizes of the other studies. This is reflected by the relatively narrower confidence intervals of the five effect size estimates as seen in Figure 9. This is because large sample sizes lead to higher precision in effect size estimates, thereby shrinking the confidence intervals of such studies (Borenstein & Hedges, 2019; Card, 2015). Conversely, wider confidence intervals translate to low precision effect size estimates. As can be seen in Figure 9, for instance, the study by Tüysüz (2010) has the widest confidence interval, signifying a high standard error.

The 95% confidence intervals of the top three studies do not overlap with the 95% confidence interval of the pooled effect size estimate. According to Harrer et al. (2021), the difficult part when investigating heterogeneity in study results is establishing the amount of variation that is due to sampling error and that which is a result of differences in true effect sizes. Moreover, it is possible that an outlier "may not be of much consequence if it exerts little influence on the results" (Viechtbauer & Cheung, 2010, p. 116). For this reason, other possible diagnostics for the high heterogeneity are considered.

Figure 10, below, shows that the study by Tüysüz (2010) had a substantially large impact on both the overall heterogeneity and the pooled effect size estimate. The study by Al Amri et al. (2020) also had a relatively large contribution to the overall heterogeneity.

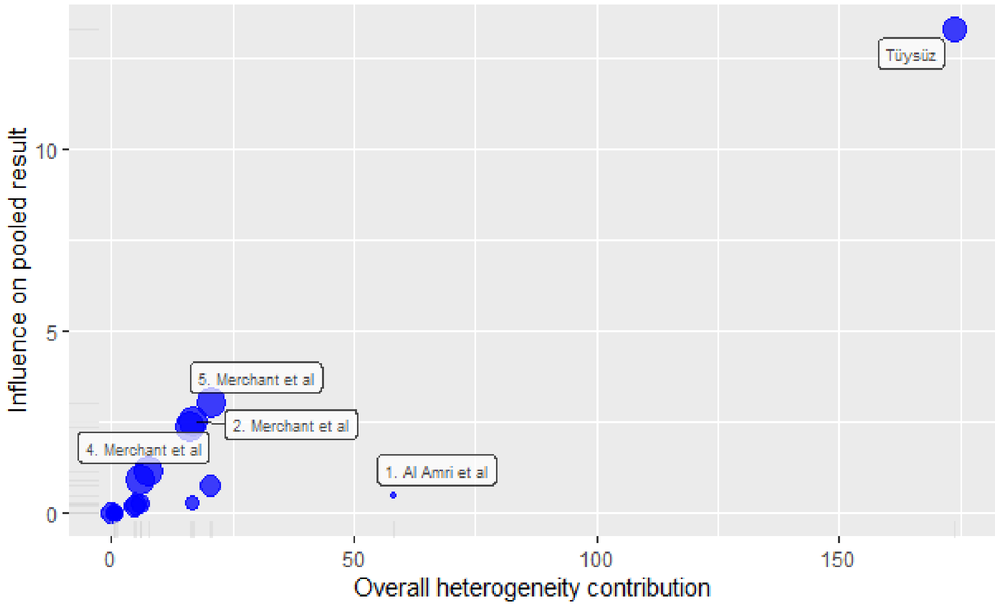


**Figure 10: An influence diagnostic of studies having an impact on the current study's high heterogeneity**

Outliers and influential studies are likely to distort the pooled effect size estimate in a meta-analysis (Viechtbauer & Cheung, 2010; Harrer et al., 2020). For this reason, the five studies that were found to be outliers were later removed from the meta-analysis. The results remained significant, with a pooled effect size estimate of $g = 0.5879$ *standard deviation units* in the range of *[95% CI: 0.2938, 0.8820]* and a p-value of $p = 0.0011$. However, some heterogeneity of $Q(df = 11) = 69.27$ with a highly significant p-value, $p < 0.0001$ and $I^2 = 84.1\%$ persisted. This suggests that about 84% of the variation in the results was possibly a result of between-study variation (Card, 2015; Harrer et al., 2020), something which was foreseen, or due to some unknown factors (Turner & Bernard, 2006).

The sources of this high heterogeneity in the results would usually be probed through moderator analyses (Turner & Bernard, 2006; Merchant, 2012; Card, 2015), a process which the researcher did not set out to do. Figure 11, below, provides a detailed summary of the results as discussed in the preceding paragraph, with outliers removed. Studies with an asterisk (*) on the far right were excluded in the analysis and assigned a weighting of *0.0*.

```
Results with outliers removed
-----------------------------
Review:     The pedagogical effectiveness of VR technology in physical science

                          SMD             95%-CI %W(random) exclude
1. Al Amri et al    3.4225 [ 2.6385; 4.2066]        0.0       *
2. Al Amri et al    1.5335 [ 0.9763; 2.0907]        7.2
Chen et al          0.7183 [ 0.0922; 1.3443]        6.6
1. Makransky et al -0.0144 [-0.3570; 0.3282]        8.9
2. Makransky et al  1.2360 [ 0.8612; 1.6108]        8.7
3. Makransky et al  0.7626 [ 0.4074; 1.1177]        8.8
1. Merchant et al   0.1220 [-0.0793; 0.3232]        9.9
2. Merchant et al  -0.0478 [-0.2489; 0.1532]        0.0       *
3. Merchant et al   0.0888 [-0.1123; 0.2900]        9.9
4. Merchant et al  -0.0368 [-0.2379; 0.1642]        0.0       *
5. Merchant et al  -0.0917 [-0.2929; 0.1094]        0.0       *
Sun et al           0.3423 [-0.0068; 0.6914]        8.9
Tarng et al         0.8732 [ 0.4784; 1.2680]        8.5
Tatli & Ayas        0.5311 [ 0.0857; 0.9764]        8.1
Wu et al            0.5509 [ 0.0053; 1.0966]        7.3
Tüysüz              2.1831 [ 1.9144; 2.4519]        0.0       *
Faour & Ayoubi      0.6741 [ 0.1029; 1.2453]        7.1

Number of studies combined: k = 12
Number of observations: o = 3246

                          SMD           95%-CI    t p-value
Random effects model 0.5879 [0.2938; 0.8820] 4.40  0.0011

Quantifying heterogeneity:
 tau^2 = 0.1736 [0.0654; 0.5665]; tau = 0.4167 [0.2558; 0.7527]
 I^2 = 84.1% [73.8%; 90.4%]; H = 2.51 [1.95; 3.23]

Test of heterogeneity:
     Q d.f.  p-value
 69.29   11 < 0.0001
```

**Figure 11: Results of the pooled effect size estimate with outliers removed**

## 4.4 Discussion of Research Findings

This section discusses the implications of the results outlined above in relation to the study's research question. Despite the narrowing down of the focus of the discipline selected for the current meta-analysis to physical science, the analysis' findings appear to be consistent with those of Merchant (2012) and Wu, Yu and Gu's (2020) meta-analysis, even though these two meta-analyses were not restricted to a specific discipline. Merchant's (2012) meta-analysis found VR technology to be more effective in the teaching and learning of mathematics, whereas Wu et al.'s (2020) meta-analysis found it to be more effective in the discipline of science education.

The current meta-analysis exclusively focused on physical science education because, as already highlighted in section 2.2.4, conceptual learning issues are well documented in this domain. According to the present researcher, it is key that learning tasks that are effectively mediated through the interplay between virtual reality technology affordances and pedagogical affordances be identified in order to establish ways in which this interplay can contribute to teaching and learning. The present reseacrher posits that the misuse or abuse of any educational tool happens when such an educational tool is viewed and used as a one-size-fits-all.

Most concepts or learning tasks in physical science are abstract and not easy to assimilate into one's existing intuitive experiences or mental models, which conventional instruction often fails to change (Clement, 1982; Halloun & Hestenes, 1985). The use of 2-dimensional, static, images and symbols to represent what happens when chemical bonding, for instance, happens is insufficient to facilitate learning. What is needed is to provide interactive educational environments that represent the physical world in a dynamic, yet realistic, sense and enable learners to act upon this by applying configurations of what is represented in their mental models to the phenomena. This view is informed by Piaget's (1964) account of how his mathematician friend (possibly Papert) "discovered a property of the action of ordering" (p. 180). According to Piaget (1964), his friend was applying some counting configurations on pebbles when he discovered that "The pebbles had no order" (p. 180).

It often happens that students are competent enough to correctly manipulate the symbolic representations of concepts without actually understanding what that means in the physical sense. This is because conceptual understanding of these concepts is something that is lacking in the students (Uyulgan & Akkuzu, 2016). Sufficient understanding of a scientific concept is demonstrated by the correct application of the "concept to make complex inferences or to do any scientific work with it" (Reif, 1995, p. 263). To facilitate conceptual learning in physical science, learners should be afforded learning spaces that promote constructivist principles. One way to do this is through integrating virtual reality technology in education for generative uses.

The current study shows that the generative use of VR technology to augment the teaching and learning of abstract and spatially overwhelming concepts such as the motion of celestial objects or the Valence Shell Electron Pair Repulsion (VSEPR) theory for promoting qualitative conceptual understanding of the geometry of molecules requires attention. The teaching and learning of molecular structures, for instance, is spatially demanding and "a lack of spatial abilities" is cited by Oliver-Hoyo and Babilonia-Rosa (2017, p. 996) as a barrier to conceptual understanding. "The ability to visually depict and interact with spatial representations of abstract concepts" (Merchant et al., 2013, p. 580) is a distinguishing feature of virtual reality technology that should be pedagogically considered when it comes to facilitating conceptual understanding of abstract concepts.

The pedagogical integration of virtual reality technology presents potential pedagogical affordances that could facilitate learning tasks that are abstract and complex to assimilate. However, it is crucial to determine what learning tasks are effectively enhanced by the pedagogical integration of VR technology given the interplay between the technological affordances of VR technology and the perceived pedagogical affordances. Knowing what learning tasks would be mediated effectively through the pedagogical integration of VR technology and the conducive learning environment within which the teaching and learning happens should arguably be the guiding principle that determines the integration of virtual reality technology in education.

# CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Despite the excitement around advances in technology and the technological affordances of ICTs in relation to teaching and learning, the evidence suggests that the desired and expected pedagogical results have not been forthcoming. It emerged from the literature reviewed in this study that a "technocentric approach" has underpinned most research into the pedagogical integration of ICTs in education. Early inventions of educational tools such as chalkboards, pencils or pens were necessitated by the teaching and learning challenges encountered then. On the contrary, the adoption of ICTs in education in contemporary times appears to be driven by the appeal of advances in the technology and the successes achieved in sectors such as healthcare and telecommunications, among others.

The major concern with repurposing ICTs initially designed and developed for other uses is that they must first be pedagogically explored before advocating for their integration in education. Such exploration informs the designers and developers of said ICTs on the essential elements or components that are indispensable in the teaching and learning process, particularly essential learning theories that underpin how learners come to know that which they know. Through such a process, ICTs may be modified and enhanced with essential instructional features that specifically address educational imperatives.

This study advances the existing literature on the pedagogical integration of virtual reality technology in education. Specifically, this study highlights the significance of Piaget's (1964) conception of an *operation* which advocates that "To know is to modify, to transform the object, and to understand the process of this transformation, …" (p. 176). Virtual reality technology as a pedagogical tool affords learners an *operation space* that allows them to interact with virtual objects in the virtual environment as they would with natural objects as they construct their knowledge. Furthermore, virtual reality makes it possible to act upon phenomena that is inaccessible to one's everyday experiences (Mikropoulos & Natsis, 2011) thereby facilitating conceptual understanding of such phenomena. This study contributes to an understanding of situations in conceptual learning that may derive value from the pedagogical integration of VR technology in education. It further advances the existing literature on the integration of ICTs in education by reiterating that a move away from adopting a "technocentric approach" to research and pursuing research that is grounded in pedagogical affordances of ICTs holds more promise.

This study looked at the interplay between VR technology affordances and the technology's pedagogical affordances with respect to conceptual learning issues in physical science. Physical science is a subject that is known to entail abstract, microscopic and macroscopic concepts. Further, some concepts appear to not be in harmony with learners' everyday experiences. An illustrative example relates to the rotation of the earth relative to the sun. Despite knowing that the sun is static, our everyday language conveys a contradictory meaning. It also emerged, while reviewing the literature, that conceptual learning challenges such as misconceptions often persist even after learners successfully complete their courses. Thus, necessitating consideration of how best to address this pressing issue if we are to effectively promote learning. As a result, due to the unique features of VR technology, a number of empirical studies have been conducted to pedagogically explore how this technology may effectively facilitate learning. However, the findings of these empirical studies are inconclusive. By synthesizing the findings of these empirical studies, the current meta-analysis found their results to be significant and the pedagogical integration of VR technology in physical science to be effective.

The results of this meta-analysis were based on a sample of 10 peer-reviewed published studies. Book chapters, conference papers, dissertations, and many other data sources did not form part of the studies that were analysed. Studies that reported statistical summary data other than the means, standard deviations and sample sizes were also not considered in this meta-analysis. The processes involved in transforming other reported summary data measures to the desired effect sizes would have required a substantial amount of time, and due to time constraints, such studies were excluded. The implication is that the findings of this study are not representative of the true population. Consequently, making inferences to the entire population may not be advised.

Considering the limitations highlighted in the current study, the researcher's view is that there is a need for further research to empirically investigate the interplay between VR technological affordances and its pedagogical affordances. Most of the existing studies on the pedagogical integration of VR technology in education to date appear to be based on constructivism

(Mikropoulos & Natsis, 2011). Thus, one possible area for further research is to investigate the effectiveness of the pedagogical integration of virtual reality technology through the theoretical framework of embodied cognition which, “as (its) theoretical starting point” takes “not a mind working on abstract problems, but a body that requires a mind to make it function” (Wilson, 2002, p. 625). The value, if any, of bodily interactions in immersive virtual environments in relation to promoting effective learning is currently minimally understood.

Another possibly crucial area of research that may uncover interesting findings is to investigate the interaction effects amongst several independent variables that also have an influence on learning when virtual reality is used. In the current study, everything else was held constant while the influence of virtual reality technology on promoting learning was examined. For instance, the role played by the instructional method used in conjunction with VR technology needs to be investigated. The current study used a simplistic model for analysing the relationship between learning and the independent variable, virtual reality. That said, there is a possibility that some of the variables that were held constant in the process, may interact with virtual reality technology. Thus, in cases like this one, a more appropriate model would be a multivariate model; a model that considers the effects of all independent variables including their interaction effects.

One of the elements of constructivist learning environments in a model conceptualized by Jonassen (1999) is collaborative learning, which virtual reality technology can enable. Based on the literature reviewed in this study, research on collaborative learning that can be afforded by virtual reality technology is meagre. Thus, there is room for possible future research to investigate this, perhaps from the theoretical framework of social constructivism and Computer Supported Collaborative Learning (CSCL).

Virtual reality technologies are not designed and developed by one entity. As a result, these technologies vary on several features. Therefore, future research could empirically investigate the impact of the aforementioned gaps on promoting teaching and learning by conducting an evaluative research study that considers one virtual reality technology which exhibits the affordances discussed in this study and establish how it addresses learning.

# APPENDICES

## Appendix A: The Literature Data Collected

Data collected and used for computing effect sizes to be provided.

## Appendix B: R code for running meta-analysis

```
#A program computing effect sizes for meta-analysis
#author: Pheello Vincent Makhele

#meta_analysis2.r

#set current working directory
setwd("C:/Users/Molefi/OneDrive - University of Witwatersrand/MEd
Work/Research Report - By chapter/Data Analysis Stuff/")


#read data extracted from empirical studies to run a meta-analysis
mydata = read.csv("metadata.csv", header = TRUE)


#load the necessary packages for conducting meta-analyses
suppressPackageStartupMessages(library(metafor))
suppressPackageStartupMessages(library(meta))

#package for conducting influence diagnostics
suppressPackageStartupMessages(library(dmetar))

#package for data manipulation
suppressPackageStartupMessages(library(tidyverse))


#use meta package to run our meta-analysis
meta_analysis2 <- metacont(n.e = E_sample_size,
                   mean.e = E_means,
                   sd.e = E_SD,
                   n.c = C_sample_size,
                   mean.c = C_means,
                   sd.c = C_SD,
                   studlab = author,
                   data = mydata,
                   sm = "SMD",
                   method.smd = "Hedges",
                   comb.fixed = FALSE,
                   comb.random = TRUE,
                   method.tau = "REML",
                   hakn = TRUE,
```

```
                     title = "The pedagogical effectiveness of VR technology
in physical science")

#display meta-analysis results
meta_analysis2

#produce a forest plot to visualise the distribution of the individual
effect size estimates
forest.meta(meta_analysis2, sortvar = TE, xlim = c(-3,5),
            print.tau2 = FALSE,
            prediction = TRUE)

#check for influential studies
influential_studies <- InfluenceAnalysis(meta_analysis2,
                                         random = TRUE,
                                         subplot.heights = c(40,25),
                                         subplot.widths = c(40,40),
                                         return.separate.plots = FALSE,
                                         text.scale = 1.5)

#visualize studies that substantially contribute to heterogeniety
#and the pooled effect size
plot(influential_studies, "baujat")

#visualize sources of heterogeneity
plot(influential_studies, "influence")

#check for outliers, remove them and re-run the meta-analysis
outlies <-find.outliers(meta_analysis2)

#display the results
summary(outlies)

#forest plot of the meta-analysis with removed outliers
forest(outlies)
```

# Appendix C: Editor's certificate

## EDITOR'S NOTE

30 November 2021

**TO WHOM IT MAY CONCERN**

**RE: LANGUAGE EDITING OF MASTER OF EDUCATION RESEARCH REPORT FOR CANDIDATE PHEELLO VINCENT MAKHELE, STUDENT NUMBER: 765037, WITS UNIVERSITY**

I hereby attest that I have done and completed a thorough language edit of Mr Pheello Vincent Makhele's Master of Education Research Report, *Virtual Reality Technology as A Pedagogical Tool in Physical Science Education: A Conceptual Study*.

I hold a PhD in Communication Studies and have been editing theses, dissertations, scientific research/journal articles and other work of comparable academic standard, in various fields, for the past 10 years. I am a member of the Professional Editors' Guild (PEG) of South Africa (member number: CHA009).

My PEG membership and full contact details are in the signature below, should you wish to contact me for anything.

Yours Sincerely,

Professional EDITORS Guild

Tigere Chagutah
Associate Member

Membership number: CHA009
Membership year: March 2021 to February 2022

+27 (0)76 060 5643
editor@ccsdsouthernafrica.co.za

www.editors.org.za

## REFERENCE LIST


Abrami, P. C., Cohen, P. A., & d'Apollonia, S. (1988). Implementation problems in meta-analysis. *Review of Educational Research, 58*(2), 151-179.

Abulrub, A. H. G., Attridge, A. N., & Williams, M. A. (2011, April). Virtual reality in engineering education: The future of creative learning. In *2011 IEEE global engineering education conference (EDUCON)* (pp. 751-757). IEEE.

Ackermann, E. (2001). Piaget's constructivism, Papert's constructionism: What's the difference. *Future of learning group publication*, *5*(3), 438.

Ahn, E., & Kang, H. (2018). Introduction to systematic review and meta-analysis. *Korean journal of anesthesiology*, *71*(2), 103.

Al Amri, A. Y., Osman, M. E., & Al Musawi, A. S. (2020). The Effectiveness of a 3D-Virtual Reality Learning Environment (3D-VRLE) on the Omani Eighth Grade Students' Achievement and Motivation towards Physics Learning. *International Journal of Emerging Technologies in Learning (IJET), 15*(05), 4. https://doi.org/10.3991/ijet.v15i05.11890

Anderson, T. (Ed.). (2008). *The theory and practice of online learning*. Athabasca University Press.

Araiza-Alba, P., Keane, T., Chen, W. S., & Kaufman, J. (2021). Immersive virtual reality as a tool to learn problem-solving skills. *Computers & Education*, 104121.

Arya, A., Hartwick, P., Graham, S., & Nowlan, N. (2012). Collaborating through space and time in educational virtual environments: 3 case studies. *Journal of Interactive Technology and Pedagogy*, *2*.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human Memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *Psychology of Learning and Motivation* (Vol. 2, pp. 89–195). Academic Press.

https://doi.org/10.1016/S0079-7421(08)60422-3

Atkinson, R. C., & Shiffrin, R. M. (1971). *The control processes of short-term memory* (Report No. 173).

Ausubel, D. P., Novak, J. D., & Hanesian, H. (1968). *Educational psychology: A cognitive view*.

Badley, G. (2003). The Crisis in Educational Research: A Pragmatic Approach. *European Educational Research Journal*, *2*(2), 296–308.

https://doi.org/10.2304/eerj.2003.2.2.7

Balduzzi, S., Rücker, G., & Schwarzer, G. (2019). How to perform a meta-analysis with R: a practical tutorial. *Evidence - Based Mental Health*, *22*(4), 153. ProQuest Central. https://doi.org/10.1136/ebmental-2019-300117

Bangay, S., & Preston, L. (1998). An investigation into factors influencing immersion in interactive virtual reality environments. *Studies in Health Technology and Informatics*, *58*, 43–51.

Bangert-Drowns, R. L. (1992). Review of developments in meta-analytic method. In A. E. Kazdin (Ed.), *Methodological issues & strategies in clinical research* (pp. 439–467). American Psychological Association.

https://doi.org/10.1037/10109-034

Blascovich, J., Loomis, J., Beall, A. C., Swinth, K. R., Hoyt, C. L., & Bailenson, J. N. (2002). TARGET ARTICLE: Immersive Virtual Environment Technology as a Methodological Tool for Social Psychology. *Psychological Inquiry*, *13*(2), 103–124. https://doi.org/10.1207/S15327965PLI1302_01

Boden, W. E. (1992). Meta-analysis in clinical trials reporting: Has a tool become a weapon? *The American Journal of Cardiology*, *69*(6), 681–686.

https://doi.org/10.1016/0002-9149(92)90164-T

Bower, M., & Jong, M. S.-Y. (2020). Immersive virtual reality in education. *British Journal of Educational Technology*, *51*(6), 1981–1990.

https://doi.org/10.1111/bjet.13038

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2010). A basic introduction to fixed‐effect and random‐effects models for meta‐analysis. *Research Synthesis Methods*, *1*(2), 97–111.

Borenstein, M. & Hedges, L. V. (2019). Effect sizes for meta-analysis. In Cooper, H. M., Hedges, L. V., & Valentine, J. C. (Eds.). *Handbook of research synthesis and meta-analysis* (3rd Edition). Russell Sage Foundation.

Bracht, G. H., & Glass, G. V. (1968). The external validity of experiments. *American educational research journal*, *5*(4), 437-474.

Bricken, M. (1991). Virtual reality learning environments: potentials and challenges. *Acm Siggraph Computer Graphics*, *25*(3), 178-184.

Brown, S., Nunez, D., & Blake, E. (2005). *Using virtual reality to provide nutritional support to HIV+ women.*

Burdea, G. C. (2004). Teaching virtual reality: Why and how? *Presence: Teleoperators & Virtual Environments*, *13*(4), 463-483.

Burden, K., & Atkinson, S. (2008). Evaluating pedagogical affordances of media sharing Web 2.0 technologies: A case study. *Proceedings ascilite Melbourne*, 121-125.

Buteler, L. M., & Coleoni, E. A. (2014). Exploring the Relation Between Intuitive Physics Knowledge and Equations During Problem Solving. *The Electronic Journal for Research in Science & Mathematics Education*, *18*(2).

Buzbee, L. (2014). The simple genius of the blackboard: Why the board-centered classroom is still the best place to teach and learn. *Slate. Retrieved, June, 15, 2020.*

Card, N. A. (2015). *Applied meta-analysis for social science research*. Guilford Publications.

Carey, S. (1991). Knowledge acquisition: enrichment or conceptual change? In Carey, S. & Gelman, R. (Eds.), *The epigenesis of mind: essays in biology and cognition.* Hillsdale, NJ: Erlbaum.

Chen, C.J., Toh, S.C., & Fauzy, W.M. (2004). The theoretical framework for designing desktop virtual reality-based learning environments. *Journal of Interactive Learning Research,* 15(2), 147-167.

Chen, C.H., Yang, J.C., Shen, S., & Jeng, M. (2007). A desktop virtual reality earth motion in astronomy education. *Journal of Educational Technology & Society,* 10(3), 289-304.

Chen, Y. L. (2016). The effects of virtual reality learning environment on student cognitive and linguistic development. *The Asia-Pacific Education Researcher*, *25*(4), 637-646.

Cheng, K., & Tsai, C. (2020). Students' motivational beliefs and strategies, perceived immersion and attitudes towards science learning with immersive virtual reality: A partial least squares analysis. *British Journal of Educational Technology*, *51*(6), 2140–2159.

https://doi.org/10.1111/bjet.12956

Cheung, M. W. L. (2019). Some reflections on combining meta-analysis and structural equation modeling. *Research Synthesis Methods*, *10*(1), 15–22. https://doi.org/10.1002/jrsm.1321

Chow, S. L. (1987). Meta-analysis of pragmatic and theoretical research: A critique. *The Journal of Psychology*, *121*(3), 259-271.

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research*, *53*(4), 445–459. JSTOR.

https://doi.org/10.2307/1170217

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, *50*(1), 66–71.

https://doi.org/10.1119/1.12989

Cohen, L., Manion, L., & Morrison, K. (2017). *Research methods in education*. Routledge.

Cole, M., Cohen, C., Wilhelm, J., & Lindell, R. (2018). Spatial thinking in astronomy education research. *Physical Review Physics Education Research*, *14*(1), 010139.

Concannon, B. J., Esmail, S., & Roduta Roberts, M. (2019). Head-Mounted Display Virtual Reality in Post-secondary Education and Skill Training. *Frontiers in Education, 4*. https://www.frontiersin.org/article/10.3389/feduc.2019.00080

Conole, G., & Dyke, M. (2004). What are the affordances of information and communication technologies?

Cowan, N. (2014). Working memory underpins cognitive development, learning, and education. *Educational psychology review, 26*(2), 197-223.

Craig, A. B., Sherman, W. R., & Will, J. D. (2009). *Developing virtual reality applications: Foundations of effective design*. Morgan Kaufmann.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Dalgarno, B., & Lee, M. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, 41(1), 10-32.

De Vaus, D., & de Vaus, D. (2013). *Surveys in social research*. Routledge.

Dede, C., Salzman, M., Loftin, R. B., & Ash, K. (1997). Using virtual reality technology to convey abstract scientific concepts. *Learning the Sciences of the 21st Century: Research, Design, and Implementing Advanced Technology Learning Environments. Lawrence Erlbaum: Hillsdale, NJ*.

Dede, C., Salzman, M. C., Loftin, R. B., & Sprague, D. (1999). Multisensory Immersion as a Modeling Environment for Learning Complex Scientific Concepts. In W. Feurzeig & N. Roberts (Eds.), *Modeling and Simulation in Science and Mathematics Education* (pp. 282–319). Springer New York. https://doi.org/10.1007/978-1-4612-1414-4_12

Dede, C. J., Jacobson, J., & Richards, J. (2017). Introduction: Virtual, Augmented, and Mixed Realities in Education. In D. Liu, C. Dede, R. Huang, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education* (pp. 1–16). Springer Singapore. https://doi.org/10.1007/978-981-10-5490-7_1

Department of Education, (2003). *White Paper on e-Education: Transforming learning and teaching through Information and Communication Technologies*. Pretoria: Department of Education.

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. *British Journal of Educational Technology*, *51*(6), 2006-2033.

Duncan, I., Miller, A., & Jiang, S. (2012). A taxonomy of virtual worlds usage in education. *British Journal of Educational Technology*, *43*(6), 949-964.

Ellis, P. D. (2010). *The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results*. Cambridge university press.

Emily Jones, M. (n.d.). *LibGuides: Creating a PRISMA flow diagram: Creating a PRISMA flow diagram*. Retrieved September 12, 2021, from https://guides.lib.unc.edu/prisma/PRISMA2009

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. *Computers & Education*, *127*, 252-266.

Floden, R. E. (1981). Chapter 2: The Logic of Information-Processing Psychology in Education. *Review of research in education*, *9*(1), 75-109.

Fowler, C. (2015). Virtual reality and learning: Where is the pedagogy? *British Journal of Educational Technology*, 46(2), 412-422.

Fransson, G., Holmberg, J., & Westelius, C. (2020). The challenges of using head mounted virtual reality in K-12 schools from a teacher perspective. *Education and Information Technologies*, *25*(4), 3383-3404.

Glass, G. V. (1976). Primary, secondary, and meta-analysis of research. *Educational researcher*, *5*(10), 3-8.

Glass, G. V. (1977). Integrating findings: The Meta-Analysis of Research. *Review of research in education*, *5*(1), 351-379.

Gilson, L. L., & Goldberg, C. B. (2015). Editors' comment: So, what is a conceptual paper?.

Goodman, G. S. (2008). CHAPTER TWO: Coming to a Critical Constructivism: Roots and Branches. *Counterpoints*, *329*, 13-32.

Groves, R. M., Fowler Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2011). *Survey methodology* (Vol. 561). John Wiley & Sons.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. *Handbook of qualitative research*, *2*(163-194), 105.

Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics*, *53*(11), 1043–1055.

https://doi.org/10.1119/1.14030

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, *8*(1), 1–32. https://doi.org/10.1007/s40692-020-00169-2

Hammersley, M. (1987). Some notes on the terms 'validity' and 'reliability'. *British educational research journal*, *13*(1), 73-82.

Harrer, M., Cuijpers, P., Furukawa, T. & Ebert, D. D. (2019). dmetar: Companion R Package For The Guide 'Doing Meta-Analysis in R'. R package version 0.0.9000. URL http://dmetar.protectlab.org/.

Harrer, M., Cuijpers, P., Furukawa, T. A., & Ebert, D. D. (2021). *Doing Meta-Analysis with R: A Hands-On Guide*. Chapman and Hall/CRC.

https://doi.org/10.1201/9781003107347

Harrison, A. G., & Treagust, D. F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching chemistry. *Science education, 80*(5), 509-534.

Hawking, S. (1988). *A brief history of time: from big bang to black holes*. Bantam Press.

Hedberg, J., & Alexander, S. (1994). Virtual reality in education: Defining researchable issues. *Educational Media International, 31*(4), 214-220.

Hendrix, C., Brandt, J., & Barfield, W. (1995). The sense of presence and performance within virtual environments as a function of headtracking and stereopsis. *SAE transactions*, 765-769.

Heyer, I., Slater, S. J., & Slater, T. (2013). Establishing the empirical relationship between non-science majoring undergraduate learners'spatial thinking skills and their conceptual astronomy knowledge. *Revista Latino-Americana de Educação em Astronomia*, (16), 45-61.

Hokanson, B., & Hooper, S. (2000). Computers as cognitive media: examining the potential of computers in education. *Computers in human behavior*, *16*(5), 537-552.

Hokanson, B., & Hooper, S. (2004). Integrating Technology in Classrooms: We have met the enemy and he is us. *Association for Educational Communications and Technology*.

Huang, H. M., Rauch, U., & Liaw, S. S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, *55*(3), 1171-1182.

Hu-Au, E., & Okita, S. (2021). Exploring Differences in Student Learning and Behavior Between Real-life and Virtual Reality Chemistry Laboratories. *Journal of Science Education and Technology*, *30*(6), 862–876. https://doi.org/10.1007/s10956-021-09925-0

IJsselsteijn, W. A., Ridder, H. de, Freeman, J., & Avons, S. E. (2000). Presence: Concept, determinants, and measurement. *Human Vision and Electronic Imaging V*, *3959*, 520–529. https://doi.org/10.1117/12.387188

IQbusiness. (2018). *IQbusiness – Virtual Reality – Why South Africa and why now?* Retrieved from https://iqbusiness.net/iqbusiness-virtual-reality-why-south-africa-and-why-now/

Jarmon, L., Traphagan, T., Mayrath, M., & Trivedi, A. (2009). Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life. *Computers & Education*, *53*(1), 169-182.

Jonassen, D. H. (1995). Computers as cognitive tools: Learning with technology, not from technology. *Journal of Computing in Higher Education*, *6*(2), 40-73.

Jonassen, D. H., Carr, C., & Yueh, H.P. (1998). Computers as mindtools for engaging learners in critical thinking. *TechTrends*, *43*(2), 24-32.

Jonassen, D. (1999). Designing constructivist learning environments. In C. Reigeluth, (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (pp. 215-239). University Park: Pennsylvania State University.

Jonassen, D. H., Campbell, J. P., & Davidson, M. E. (1994). Learning with media: Restructuring the debate. *Educational technology research and development*, *42*(2), 31-39.

Johnston, E., Olivas, G., Steele, P., Smith, C., & Bailey, L. (2018). Exploring pedagogical foundations of existing virtual reality educational applications: A content analysis study. *Journal of Educational Technology Systems*, *46*(4), 414-439.

Karadağ, E. (Ed.). (2017). *The factors effecting student achievement: Meta-analysis of empirical studies*. Springer.

Kardong-Edgren, S. S., Farra, S. L., Alinier, G., & Young, H. M. (2019). A call to unify definitions of virtual reality. *Clinical Simulation in Nursing, 31*, 28-34.

Karras, D. J. (1997). Statistical methodology: II. Reliability and variability assessment in study design, Part A. *Academic emergency medicine: official journal of the Society for Academic Emergency Medicine*, *4*(1), 64-71.

Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of Virtual Reality in education. *Themes in Science and Technology Education*, *10*(2), 85-119.

Kim, J. H., Park, S. T., Lee, H., Yuk, K. C., & Lee, H. (2001). Virtual reality simulations in physics education. Retrieved from http://imej.wfu.edu/articles/2001/2/02/index.asp?referer=www.clickfind.com.au

Kim, B., & Reeves, T.C. (2007). Reframing research on learning with technology: In search of the meaning of cognitive tools. *Instructional Science*, *35*(3), 207-256.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational psychologist*, *41*(2), 75-86.

Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. *International Journal of higher education*, *6*(5), 26-41.

Kozma, R. B. (1991). Learning with media. *Review of educational research*, *61*(2), 179-211.

Krause, S. D. (2000). " Among the Greatest Benefactors of Mankind": What the Success of Chalkboards Tells Us about the Future of Computers in the Classroom. *The Journal of the Midwest Modern Language Association*, *33*(2), 6-16.

Kulik, J. A., Kulik, C. L. C., & Cohen, P. A. (1979). Research on audio-tutorial instruction: A meta-analysis of comparative studies. *Research in Higher Education*, *11*(4), 321-341.

Kumar, R. (2018). *Research methodology: A step-by-step guide for beginners*. Sage.

Lamb, R., Lin, J., & Firestone, J. B. (2020). Virtual Reality Laboratories: A Way Forward for Schools? *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(6), em1856.

Lapan, S. D., Quartaroli, M. T., & Riemer, F. J. (2012). *Qualitative research: An introduction to methods and designs*. Jossey-Bass.

Leavy, P. (2017). Research design: Quantitative, qualitative, mixed methods, arts-based, and community-based participatory research approaches.

Limniou, M., Roberts, D., & Papadopoulos, N. (2008). Full immersive virtual environment CAVETM in chemistry education. *Computers & Education*, *51*(2), 584-593.

Lincoln, Y. S. (2007). Naturalistic inquiry. *The Blackwell encyclopedia of sociology*.

Lincoln, Y. S., & Guba, E. G. (2007). Paradigms. *The Blackwell encyclopedia of sociology*.

Liu, D., Bhagat, K. K., Gao, Y., Chang, T. W., & Huang, R. (2017). The potentials and trends of virtual reality in education. In D. Liu, C. Dede, R. Huang, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education* (pp. 105-130). Springer, Singapore.

Lockwood, D. (2004). Evaluation of virtual reality in Africa: an educational perspective. Retrieved from http://www.unesco.org/new/en/communication-and-information/resources/publications-and-communication-materials/publications/full-list/evaluation-of-virtual-reality-in-africa-an-educational-perspective/

Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2010). *Methods in educational research: From theory to practice* (Vol. 28). John Wiley & Sons.

Loftin, R. B., Engleberg, M., & Benedetti, R. (1993). Applying virtual reality in education: A prototypical virtual physics laboratory. *Proceedings of 1993 IEEE Research Properties in Virtual Reality Symposium*, 67–74. https://doi.org/10.1109/VRAIS.1993.378261

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of computer-mediated communication*, *3*(2), JCMC321.

Lui, M., McEwen, R., & Mullally, M. (2020). Immersive virtual reality for supporting complex scientific knowledge: Augmenting our understanding with physiological monitoring. *British Journal of Educational Technology*, *51*(6), 2181-2199.

Luo, H., Li, G., Feng, Q., Yang, Y., & Zuo, M. (2021). Virtual reality in K-12 and higher education: A systematic review of the literature from 2000 to 2019. *Journal of Computer Assisted Learning*.

Mado, M., Fauville, G., Jun, H., Most, E., Strang, C., & Bailenson, J. N. (2022). Accessibility of Educational Virtual Reality for Children During the COVID-19 Pandemic. *Technology, Mind, and Behavior*. https://doi.org/10.1037/tmb0000066

Magadla, L. (1996). Constructivism: a practitioner's perspective. *South African Journal of Higher Education*, *10*(1), 83-88.

Makransky, G., Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Education Tech Research Dev* 66**,** 1141–1164.

https://doi.org/10.1007/s11423-018-9581-2

Makransky, G., & Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. *Computers & Education*, *134*, 15-30.

Makransky, G., Borre-Gude, S., & Mayer, R. E. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, *35*(6), 691-707.

Makransky, G., Andreasen, N. K., Baceviciute, S., & Mayer, R. E. (2020). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *Journal of Educational Psychology*, *113*(4), 719–735.

https://doi.org/10.1037/edu0000473

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational psychologist*, *38*(1), 43-52.

Mayes, J. T., & Fowler, C. J. (1999). Learning technology and usability: a framework for understanding courseware. *Interacting with computers*, *11*(5), 485-497.

McCloskey, M. (1983). Intuitive physics. *Scientific american, 248*(4), 122-131.

McKenzie, J. E., Beller, E. M., & Forbes, A. B. (2016). Introduction to systematic reviews and meta-analysis. *Respirology*, *21*(4), 626-637.

McLellan, H. (1994). Virtual reality and multiple intelligences: Potentials for higher education. *Journal of Computing in Higher Education*, 5(2), 33-66.

McLellan, H. (1996). Virtual realities. *Handbook of research for educational communications and technology*, 457-487.

Merchant, Z. H. (2012). *The impact of virtual reality-based learning environment design features on students' academic achievements* [Ph.D., Texas A&M University]. Retrieved October 8, 2021, from http://0.www.proquest.com/pqdtglobal/docview/1321217274/abstract/B0F0120F84FE4EF3PQ/1

Merchant, Z., Goetz, E.T., Keeney-Kennicutt, W., Kwok, O.M., Cifuentes, L., & Davis, T.J. (2012). The learner characteristics, features of desktop 3D virtual reality environments, and college chemistry instruction: A structural equation modelling analysis. *Computers & Education*, 59(2), 551-568.

Merchant, Z., Goetz, E. T., Keeney-Kennicutt, W., Cifuentes, L., Kwok, O., & Davis, T. J. (2013). Exploring 3-D virtual reality technology for spatial ability and chemistry achievement: Exploring 3-D virtual reality technology. *Journal of Computer Assisted Learning*, *29*(6), 579–590.

https://doi.org/10.1111/jcal.12018

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, *70*, 29-40.

Mikropoulos, T. A., & Strouboulis, V. (2004). Factors that influence presence in educational virtual environments. *CyberPsychology & Behavior*, *7*(5), 582-591.

Mikropoulos, T. A. (2006). Presence: a unique characteristic in educational virtual environments. *Virtual Reality*, *10*(3-4), 197-206.

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education*, *56*(3), 769–780. https://doi.org/10.1016/j.compedu.2010.10.020

Mills, S., & Madalena T de Araújo, M. (1999). Learning through virtual reality: a preliminary investigation. *Interacting with Computers*, *11*(4), 453-462.

Minty, R., & Moll, I. (2020). Gauteng paperless classrooms: fantasy, fiction, or reality? *Mousaion*, *38*(1), 1-16.

Mlambo, S., Rambe, P., & Schlebusch, L. (2020). Effects of Gauteng province's educators' ICT self-efficacy on their pedagogical use of ICTS in classrooms. *Heliyon*, *6*(4), e03730.

Moll, I. (1999). Reclaiming the natural line in Vygotsky's theory of cognitive development. *Lev Vygotsky: Critical assessments*, *1*, 38-50.

Moll, I., Bradbury, J. & Winkler, G. (2002). *Learners and learning: learning guide*. Cape Town: SAIDE & Oxford University Press.

Moll, I., Steinberg, C., Broekmann, I., Gewer, A., Bialobrzeska, M., & Allais, S. (2005). *Being a Vocational Educator: A guide for lecturers in FET colleges*. South African Institute for Distance Education (SAIDE).

Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of educational psychology*, *94*(3), 598.

Morgan, D. L. (2007). Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods. *Journal of mixed methods research*, *1*(1), 48-76.

Morgan, D. L. (2014). Pragmatism as a paradigm for social research. *Qualitative inquiry*, *20*(8), 1045-1053.

Mouton, S. (2018). Bridging the digital divide with photonoics. *Quest*, *14*(3), 11-11.

Mpehle, Z. (2011). Is Gauteng on-line or off-line? An empirical study of the Gauteng Department of Education. *Journal of Public administration*, *46*(1), 709-719.

Mullaney, T. (2020, December 23). *Lessons learned from loving and losing Google Expeditions*. Retrieved from https://tommullaney.com/2020/12/23/lessons-learned-from-loving-and-losing-google-expeditions/

Murray, C. D., & Sixsmith, J. (1999). The corporeal body in virtual reality. *Ethos*, *27*(3), 315-343.

Muttappallymyalil J., Mendis S., John L.J., Shanthakumari N., Sreedharan J., Shaikh R.B. (2016). Evolution of technology in teaching: Blackboard and beyond in Medical Education. *Nepal Journal of Epidemiology*, 6(3), 588-594.

Ndlovu, N. S., & Moll, I. (2016). Teachers, Technology and Types of Media: Teaching with ICTs in South Africa. *African Educational Research Journal*, *4*(3), 124-130.

Oliver-Hoyo, M., & Babilonia-Rosa, M. A. (2017). Promotion of Spatial Skills in Chemistry and Biochemistry Education at the College Level. *Journal of Chemical Education*, *94*(8), 996–1006.

https://doi.org/10.1021/acs.jchemed.7b00094

Oluwatayo, J. A. (2012). Validity and reliability issues in educational research. *Journal of educational and social research*, *2*(2), 391-391.

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional science*, *32*(1/2), 1-8.

Padayachee, K. (2017). A snapshot survey of ICT integration in South African schools. *South African Computer Journal*, *29*(2), 36-65.

Pan, Z., Cheok, A. D., Yang, H., Zhu, J., & Shi, J. (2006). Virtual reality and mixed reality for virtual learning environments. *Computers & graphics*, 30(1), 20-28.

Pan, X., & Hamilton, A. F. D. C. (2018). Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. *British Journal of Psychology*, *109*(3), 395-417.

Pandelidis, V.S. (1993). Virtual reality in the classroom. *Educational Technology*, *33*(4), 23-27.

Pandelidis, V.S. (2010). Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality. *Themes in Science and Technology Education*, 2(1-2), 59-70.

Papert, S. (1972). Teaching children thinking. *Programmed Learning and Educational Technology*, *9*(5), 245-255.

Papert, S. (1980). *Mindstorms: Children, Computers and Powerful Ideas*. New York: Basic Books.

Papert, S. (1987). Information technology and education: Computer criticism vs. technocentric thinking. *Educational researcher*, *16*(1), 22-30.

Phillips, D. C., Phillips, D. C., & Burbules, N. C. (2000). *Postpositivism and educational research*. Rowman & Littlefield.

Piaget, J. (1964). Cognitive development in children: Piaget. *Journal of research in science teaching*, *2*(3), 176-186.

Plummer, J. D. (2014). Spatial thinking as the dimension of progress in an astronomy learning progression. *Studies in Science Education*, *50*(1), 1-45.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science education*, *66*(2), 211-227.

Pratt, D. R., Zyda, M., & Kelleher, K. (1995). Virtual reality: in the mind of the beholder. *IEEE Annals of the History of Computing*, *28*(07), 17-19.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778.

Ray, A. B., & Deb, S. (2016, December). Smartphone based virtual reality systems in classroom teaching—a study on the effects of learning outcome. *2016 IEEE Eighth International Conference on Technology for Education (T4E)* (pp. 68-71). IEEE.

Recheis, W., Weber, G. W., Schäfer, K., Knapp, R., Seidler, H., & Zur Nedden, D. (1999). Virtual reality and anthropology. *European journal of radiology*, *31*(2), 88-96.

Reece, C. (2008). *The digital divide in South Africa: identifying emerging inequalities in Internet access and online public spheres* (Master's thesis, University of Cape Town).

Reif, F. (1995). Understanding and teaching important scientific thought processes. *Journal of Science Education and Technology*, *4*(4), 261–282.

https://doi.org/10.1007/BF02211259

Roussos, M., Johnson, A., Moher, T., Leigh, J., Vasilakis, C., & Barnes, C. (1999). Learning and building together in an immersive virtual world. *Presence: Teleoperators & Virtual Environments*, *8*(3), 247-263.

Rowell, J. A. (1989). Piagetian epistemology: Equilibration and the teaching of science. *Synthese*, *80*(1), 141-162.

Rudmann, D. S. (2005). *Empirical accuracy and consistency in college students' knowledge of classical astronomy*. University of Illinois at Urbana-Champaign.

Salomon, G., Globerson, T., & Guterman, E. (1989). The computer as a zone of proximal development: Internalizing reading-related metacognitions from a Reading Partner. *Journal of educational psychology*, *81*(4), 620.

Salomon, G. (1976). A cognitive approach to media. *Educational technology*, *16*(5), 25-28.

Salomon, G. (1984). Computers in education: Setting a research agenda. *Educational Technology*, *24*(10), 7-11.

Salomon, G. (1998). Technology's promises and dangers in a psychological and educational context. *Theory into practice*, *37*(1), 4-10.

Salomon, G. (2002). Technology and pedagogy: Why don't we see the promised revolution? *Educational technology*, *42*(2), 71-75.

Salzman, M. C., Dede, C., Loftin, R. B., & Chen, J. (1999). A model for understanding how virtual reality aids complex conceptual learning. *Presence: Teleoperators & Virtual Environments*, *8*(3), 293-316.

Saracho, O. (Ed.). (2014). Handbook of Research Methods in Early Childhood Education Volume 2: Review of Research Methodologies.

Savelsbergh, E. R., Prins, G. T., Rietbergen, C., Fechner, S., Vaessen, B. E., Draijer, J. M., & Bakker, A. (2016). Effects of innovative science and mathematics teaching on student attitudes and achievement: A meta-analytic study. *Educational Research Review*, *19*, 158-172.

Schmidt, F. L., Le, H., & Oh, I. S. (2009). Correcting for the distorting effects of study artifacts in meta-analysis and second order meta-analysis. In Cooper, H., Hedges, L.V., & Valentine, J.C. (Eds.), *The handbook of research synthesis and meta-analysis* (pp. 317-332). Russell Sage Foundation.

Schubert, T., Friedmann, F., & Regenbrecht, H. (1999). Embodied Presence in Virtual Environments. In R. Paton & I. Neilson (Eds.), *Visual Representations and Interpretations* (pp. 269–278). Springer London.

https://doi.org/10.1007/978-1-4471-0563-3_30

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators & Virtual Environments*, *10*(3), 266-281.

Selepe, C., & Moll, I. (2016). Are teachers facilitators or are they mediators? Piaget, Vygotsky and the wisdom of the teacher. *The Independent Journal of Teaching and Learning*, *11*(1), 6-16.

Shalley, C. E. (2012). Writing good theory: Issues to consider. *Organizational Psychology Review*, *2*(3), 258-264.

Sherman, W. R., & Craig, A. B. (2018). *Understanding virtual reality: Interface, application, and design*. Morgan Kaufmann.

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1535), 3549-3557.

Slater, M. (2018). Immersion and the illusion of presence in virtual reality. *British Journal of Psychology*, *109*(3), 431-433.

Squelch, A. P. (2001). Virtual reality for mine safety training in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, *101*(4), 209-216.

Stemhagen, K. (2014). Kuhn, Thomas S. In D.C. Phillips (Ed), *Encyclopaedia of educational theory and philosophy*. Los Angeles: Sage.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of communication*, *42*(4), 73-93.

Sulaiman, N. (2020, November 20). Sisanda Tech makes learning science easy and fun: we find out how. *News24 Online*. Retrieved from https://www.news24.com/you/news/local/sisanda-tech-makes-learning-science-easy-and-fun-we-find-out-how-20201120

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational psychology review*, *10*(3), 251-296.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Cognitive load theory: Explorations in the learning sciences, instructional system and performance technologies.

Tatli, Z., & Ayas, A. (2013). Effect of a Virtual Chemistry Laboratory on Students' Achievement. *Journal of Educational Technology & Society*, *16*(1), 159–170.

Tawfik, G. M., Dila, K. A. S., Mohamed, M. Y. F., Tam, D. N. H., Kien, N. D., Ahmed, A. M., & Huy, N. T. (2019). A step by step guide for conducting a systematic review and meta-analysis with simulation data. *Tropical medicine and health*, *47*(1), 1-9.

Terashima, N. (2001). *Intelligent Communication Systems: Toward Constructing Human Friendly Communication Environment*. Elsevier.

Terrell, S. R. (2015). *Writing a proposal for your dissertation: Guidelines and examples*. Guilford Publications.

Tichon, J., & Burgess-Limerick, R. (2011). A review of virtual reality as a medium for safety related training in mining. *Journal of Health & Safety Research & Practice*, *3*(1), 33-40.

Truncellito, D. A. (2007). Epistemology. Internet encyclopedia of philosophy. Retrieved from https://iep.utm.edu/epistemo/.

Turner, H. M., III, & Bernard, R. M. (2006). Calculating and Synthesizing Effect Sizes. *Contemporary Issues in Communication Science and Disorders*, *33*(Spring), 42–55. https://doi.org/10.1044/cicsd_33_S_42

Tüysüz, C. (2010). The Effect of the Virtual Laboratory on Students' Achievement and Attitude in Chemistry. *International Online Journal of Educational Sciences*, 17.

U.S. Department of Education. (2010). *Transforming American education: Learning powered by technology*. *National Education Technology Plan 2010*.

Uyulgan, M. A., & Akkuzu, N. (2016). An Insight towards Conceptual Understanding: Looking into the Molecular Structures of Compounds. *Acta Didactica Napocensia*, *9*(4), 49–70.

Valsiner, J. (1996). Whose mind? *Human Development*, *39*(5), 295-300.

Vanderstoep, S. W., & Johnson, D. D. (2008). *Research methods for everyday life: Blending qualitative and quantitative approaches* (Vol. 32). John Wiley & Sons.

van Wyk, E. A., & Callaghan, R. (2007). E-learning as a solution for mine safety training in South Africa. *Proceedings of Online Educa Berlin*.

van Wyk, E., & de Villiers, R. (2008). Usability context analysis for virtual reality training in South African mines. In *Proceedings of the 2008 annual research conference of the South African Institute of Computer Scientists and Information Technologists on IT research in developing countries: riding the wave of technology* (pp. 276-285).

Vevea, J.L., Zelinsky, N.A., & Orwin, R.G. (2019). Evaluating coding decisions. In Cooper, H. M., Hedges, L. V., & Valentine, J. C. (Eds.). *Handbook of research synthesis and meta-analysis* (3rd Edition). Russell Sage Foundation.

Viechtbauer, W. (2010). Conducting Meta-Analyses in *R* with the **metafor** Package. *Journal of Statistical Software*, *36*(3).

https://doi.org/10.18637/jss.v036.i03

Viechtbauer, W., & Cheung, M. W.-L. (2010). Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods*, *1*(2), 112–125.

Vogt, W. P., Gardner, D. C., & Haeffele, L. M. (2012). *When to use what research design*. Guilford Press.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and instruction*, *4*(1), 45-69.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and instruction*, *11*(4-5), 381-419.

Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2004). Modes of knowing and ways of reasoning in elementary astronomy. *Cognitive Development*, *19*(2), 203-222.

Vygotsky, L. (1978). *Mind in society the development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International journal of environmental research and public health*, *15*(6), 1204.

Wellington*, J. (2005). Has ICT come of age? Recurring debates on the role of ICT in education, 1982–2004. *Research in Science & Technological Education*, *23*(1), 25-39.

Whetten, D. A. (1989). What constitutes a theoretical contribution? *Academy of management review*, *14*(4), 490-495.

Whitaker, R. J. (1983). Aristotle is not dead: Student understanding of trajectory motion. *American Journal of Physics, 51*(4), 352-357.

Wilhelm, J., Cole, M., Cohen, C., & Lindell, R. (2018). How middle level science teachers visualize and translate motion, scale, and geometric space of the Earth-Moon-Sun system with their students. *Physical Review Physics Education Research*, *14*(1), 010150.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625–636.

https://doi.org/10.3758/BF03196322

Wilson, S. J., Polanin, J. R., & Lipsey, M. W. (2016). Fitting meta-analytic structural equation models with complex datasets. *Research Synthesis Methods*, *7*(2), 121–139. https://doi.org/10.1002/jrsm.1199

Wilson-Strydom, M., Thomson, J., & Hodgkinson-Williams, C. (2005). Understanding ICT integration in South African classrooms: research: information and communication technologies. *Perspectives in education*, *23*(1), 71-85.

Winch, C. (2010). *Dimensions of expertise: A conceptual exploration of vocational knowledge*. Bloomsbury Publishing.

Winn, W. (1993). *A conceptual basis for educational applications of virtual reality*. Tech. rep., Human Interface Technology Laboratory, University of Washington. Report No. TR-93-9. Retrieved August 8, 2021 from http://www.hitl.washington.edu/projects/education/winn/winn-paper.html~

Winn, W. (1999). Learning in virtual environments: A theoretical framework and considerations for design. *Education Media International*, *36*(4), 271-279.

Winn, W., & Jackson, R. (1999). Fourteen propositions about educational uses of virtual reality. *Educational Technology,* 5-14.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence*, *7*(3), 225-240.

Wu, B., Yu, X., & Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis. *British Journal of Educational Technology*, *51*(6), 1991–2005.

https://doi.org/10.1111/bjet.13023

Xin, S. (2017). *The theory and practice of conceptual research in tourism* (Doctoral dissertation, University of Surrey).

Yvonne Feilzer, M. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of mixed methods research*, *4*(1), 6-16.