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Middle School Students’ Perceptions, Experiences, And Behaviors Towards Using a Virtual Reality Application to Build Molecules

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MIDDLE SCHOOL STUDENTS' PERCEPTIONS, EXPERIENCES, AND BEHAVIORS TOWARDS USING A VIRTUAL REALITY APPLICATION TO BUILD MOLECULES

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ABSTRACT

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To deliver successful integration of virtual reality (VR) technology into chemistry education, it is essential that students have clear and positive perceptions about the purpose and the value of such integration. An important part of establishing a plan for integrating virtual reality technology into chemistry education is to explore the current perceptions, experiences, and behaviors of students towards the use of VR technology to establish an initial baseline of skills and areas in need of development. The purpose of this exploratory mixed methods study was to explore the perceptions, experiences, and behaviors of 62 middle school students in the state of Colorado towards the use of virtual reality technology in chemistry education. Quantitative and qualitative methods were used to collect data from participants using a demographic survey, observations, interviews, and a student perception survey. Participants went through a chemistry exercise delivered through a VR application called Molecule Builder. The first research question asked: "What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?". For this research question, the quantitative portion of the data were collected using 24-Likert-scale items in the student perception survey completed fully by 60 student participants and partially by two participants. Quantitative results of the student perception survey yielded an overall mean of 4.58, indicating that student participants, overall, had very positive perceptions of VR as a learning tool. In addition, the qualitative findings showed the emergence of three themes through the analysis of student responses to the five open-ended questions in Section B: Reflections in the student perceptions survey: (a) advantages of VR as a tool to learn chemistry, (b) disadvantages of using VR as a tool to learn chemistry, and (c) suggestions about using virtual reality applications for teaching chemistry. The second research question asked: “Are there any differences between female and male middle school students’ perceptions toward using VR technology as a learning tool in the chemistry exercise?”. This research question was answered using the findings from the 24 Likert-scale items in Section A: Perceptions in the student perception survey, the demographic data from the demographic survey, and participants’ responses to open-ended questions in Section B: Reflections in the student perception survey. Quantitative results of the student perception survey yielded a non-statistically significant difference between female and male students’ perceptions towards utilizing VR for learning chemistry. The results revealed that female and male students have similar perceptions towards using VR as a tool to learn chemistry. In addition, the qualitative findings showed that both females and males had similar perceptions on most of the three themes and nine sub-themes in general. The third research question asked: “How do middle school students describe their experience during the chemistry exercise using the VR tool?”. This research question was answered using structured interviews with all 62 participants. The majority of participants expressed an overall sense of a positive experience of the chemistry exercise using the VR tool. Two main themes were identified during the interviews: (a) positive experiences and (b) mixed experiences. The fourth research question asked: “How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?”. This research question was answered using observation notes and participants’ responses to three open-ended questions in section C: Behaviors in the student perception survey, which were completed by all 62 participants. The emergent themes from participant behaviors before using the VR tool to conduct the chemistry exercise were: (a) exited, (b) anxious, (c) ambivalent, and (d) joyful. The emergent themes from participant behaviors during the use of the VR tool to conduct the chemistry exercise were: (a) joyful, (b) engaged, (c) virtually present, and (d) ambivalent. The emergent themes from participant behaviors after using the VR tool to conduct the chemistry exercise were: (a) motivated, (b) joyful, (c) accomplished, (d) surprised, and (e) dissociated. In conclusion, results and findings indicated that the use of VR as a tool to learn chemistry was perceived positively by middle school students without gender differences. Additionally, the majority of students had positive experiences using the VR application to build molecules. Finally, students' behaviors were mostly positive towards the use of VR as a learning tool. The findings and recommendations made in the study could be addressed and utilized by the stakeholders including policymakers, administrators, and educators in the integration of virtual reality technology in the classroom and education in general.

Keywords: virtual reality, chemistry, molecules, middle school students, perceptions, experiences, behaviors, technology integration.

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CHAPTER I

INTRODUCTION

Digital technologies have been widely used in education to facilitate learning and have evolved from being used as means to transmit knowledge to being transformational to learning (Collins & Halverson, 2010). The 21st century has witnessed an enormous transformation in how education is delivered (Majid & Shamsudin, 2019). Digital technologies created a shift in learning environments to provide real-world settings that support multiple representations and collaboration (Harasim, 2017; Resnick & Robinson, 2017). The synergy between education and technology has proven to yield excellent results worldwide (Beas, 2016).

Virtual reality (VR) is an immersive three-dimensional (3-D) technology that enables the creation of interactive, simulated environments that look realistic in a multidimensional form (Freina & Ott, 2015). While VR technology has been commonly used for entertainment purposes, such as gaming and 3-D theatres, it is gaining attention as an educational and training tool to provide learners with a safe environment, where they can learn and develop skills using virtual elements (Ikhsan et al., 2020; Kavanagh et al., 2017).

Virtual reality is relevant to the current generation of students who spend most of their time online and in virtual worlds (Majid & Shamsudin, 2019). Globalization and the ongoing changes in society, economy, and technology have led to changes in the types of skills students need to learn to succeed in the 21st century, compared to what they needed 20 years ago (Kay & Greenhill, 2011). Over the next couple of decades, it is estimated that around 47% of total employment in the United States will face the potential threat of losing their jobs to robotics and artificial intelligence technologies (Frey & Osborne, 2017). Accordingly, it is going to be essential for students to have skills unique to the human brain, known as 21st-century skills or higher-order skills, to thrive in the job market (Soulé & Warrick, 2015). Creativity, empathy, critical thinking, and technological literacy are examples of some common higher-order skills (Qian & Clark, 2016). Integrating higher-order skills into educational systems became a necessity to equip students with the essential skills to survive in the future market, society, and world overall (Hu-Au & Lee, 2017; Kay & Greenhill, 2011). Virtual reality technology is a good candidate to provide opportunities to develop students' higher-order skills (Hu-Au & Lee, 2017; Ikhsan et al., 2020).

Constructivism is a theory of learning where learners construct their own knowledge instead of it being transmitted to them by their instructors. Interaction is essential to the development of individual thoughts where knowledge is constructed through experience and reflection. The student-teacher relationship is different from the common view where the teacher is in total charge of the learning process; instead, students are responsible for their own learning (Huang et al., 2010; Resnick & Robinson, 2017). Constructive pedagogies shifted the focus from the instructor to the learner and were characterized by active learning, learning by doing, scaffolded learning, and collaboration (Harasim, 2017). Immersion, interaction, and imagination are the three main features of virtual reality. These features provide opportunities for constructive learning (Hu-Au & Lee, 2017; Huang & Liaw, 2018; Huang et al., 2010).

This study focused primarily on exploring the initial perceptions, experiences, and behaviors of middle school students about virtual reality technology as a learning tool in chemistry education. Students went through a chemistry exercise delivered through a virtual reality application called Molecule Builder. Students did not have prior training on using the VR device or the application and accessed the application to carry out the exercise once and for a short amount of time. A constructivist pedagogy fit the chemistry exercise used in this study since it was student-centered, where students construct their own knowledge while conducting the exercise. However, neither the construction of knowledge nor the learning outcomes were evaluated in this study. Accordingly, the constructivist theory was not among the theoretical foundations for this study.

Educational applications of VR can be found in medicine, nursing, biology, and chemistry education (Hansen, 2008; Kavanagh et al., 2017). In chemistry education, VR technology could facilitate the learning process by overcoming the major restrictions of traditional educational methods (Georgiou et al., 2007). The use of VR technology in education suggests it is an effective tool in teaching topics that are proven difficult to carry out in traditional instructional settings and serves as a means of motivating and stimulating students' understanding of certain concepts (Limniou et al., 2008; Merchant et al., 2013; Shim et al., 2003). In distance learning, VR technology could provide students with interactive experiences regardless of their location at any time. This is a relevant enhancement over common online experiences that are limited to reading text and watching videos or simulations.

In chemistry education, teachers use different models to describe microscopic elements and their interactions to help learners visualize what they cannot see with their unaided eyes (Brown et al., 2019; Jones et al., 2005). Three-dimensional visualizations are essential for understanding spatial relations between atoms (Bowen et al., 2016). Virtual reality technology provides virtual forms of representation of microscopic elements that are interactive and multidimensional with the ability to view and manipulate these forms (Brown et al., 2019; Freina & Ott, 2015; Won et al., 2019).

Virtual chemistry labs have been developed using VR technology where students can access the lab and perform experiments multiple times in a safe environment. Virtual reality labs could be a cost-effective alternative to traditional labs that are constrained by cost, substance availability, the number of trials, and work hours (Georgiou et al., 2007; Ikhsan et al., 2020; Limniou et al., 2008; Nais et al., 2019; Xennial Digital, 2021). An example of such labs was the Virtual Laboratory developed in Greece where users were provided with educational and training materials to become familiar with the theory, equipment and procedures, and execution of experiments (Georgiou et al., 2007). Another example is two virtual reality experiences called Chemistry Lab and Molecule Builder developed by Xennial Digital (2021), an XR (eXtended Reality) company based in the United States that focuses on immersive learning for educational purposes. The Chemistry Lab experience provides students with a virtual lab where they can practice chemical reactions. In contrast, the Molecule Builder experience enables students to build and check the correctness of 3-D molecules (Xennial Digital, 2021).

Learners and educators are the key players in any learning environment, and it is essential to seek their feedback when adopting new educational technology (Edwards et al., 2019). This study attempted to evaluate the perceptions, experiences, and behaviors of middle school students toward the use of virtual reality technology in chemistry education. Students were selected because they serve as the largest population in the educational process. While other stakeholders such as educators, administrators, and other educational staff members are important in adopting virtual reality technology in education, they were beyond the scope of this study. The findings of this study could enlighten policymakers, administrators, and educators about the integration of virtual reality technology in the classroom and in education generally.

To deliver successful integration of virtual reality technology into chemistry education, it is essential that students have clear and positive perceptions about the purpose and the value of such integration. An important part of establishing a plan for integrating virtual reality technology into chemistry education is to explore the current perceptions, experiences, and behaviors of students towards the use of virtual reality technology to establish an initial baseline of skills and areas in need of development. Because the majority of research has focused on higher education students (Luo et al., 2021), this research focused on K-12 students, mainly middle school students. This study gathered and explored students' perceptions and experiences about the use of virtual reality technology in chemistry education. The results indicated how middle school students perceived using virtual reality in education. In addition, students' behaviors associated with the use of VR technology were addressed and discussed.

Statement of the Problem

Adaptation of technology in education has been moving fast, and it is important to base this adaptation on the foundations of theory and research (Alfalah, 2018; Huang & Liaw, 2018; Sprenger & Schwaninger, 2021). Virtual reality technology has gained lots of attention in the education field recently. While the capabilities of virtual reality are promising in aiding students and educators, it was important to investigate the different factors that mattered in the adaptation of new technologies in education, such as user acceptance and effectiveness of technology (Sprenger & Schwaninger, 2021).

Empirical evidence to support the adaptation of VR technology has been presented in many studies that compared the effectiveness of virtual reality as a learning tool in education to other forms of learning, such as physical models and simulations (Abdinejad et al., 2021; Brown et al., 2021; Gabunilas et al., 2018; Ikhsan et al., 2020; Madathil et al., 2017; Madden et al., 2020; Sun et al., 2019). Other areas that have been recently explored in terms of virtual reality adoption in education are the theoretical foundation for accepting virtual reality as a new technology, mainly the constructivist theory, the technology acceptance model (TAM), or a hybrid between both (Huang & Liaw, 2018; Majid & Shamsudin, 2019; Sprenger & Schwaninger, 2021). Both the constructivist theory and TAM agreed that learners' perceptions, attitudes, and intentions played a major role in technology adoption (Huang & Liaw, 2018).

Because the adoption of virtual reality in education is recent compared to the adoption of other technologies, it was important to understand the perceptions of students about using virtual reality as a learning tool in education. Existing research that addressed students' perceptions was limited and focused on higher education students (Baxter & Hainey, 2019; Huang & Liaw, 2018; Sprenger & Schwaninger, 2021; Won et al., 2019). The existence of virtual reality experiences that target K-12 students as their primary audience requires studies to evaluate the effectiveness of the experiences and the perceptions of K-12 students about the experiences.

Chemistry has a good portion of virtual reality experiences that aim at aiding students in their learning. Fundamental chemistry concepts are introduced to students during middle school. To make informed decisions about the appropriate ways to integrate virtual reality in chemistry education, it is vital to conduct research that explores the views of students based on their own experiences in using virtual reality in chemistry education. Therefore, this study was designed to evaluate the initial perceptions, experiences, and behaviors of middle school students based on their experience in conducting a chemistry exercise built with virtual reality technology.

Purpose of the Study

The primary purpose of this mixed methods research study was to explore the integration of virtual reality technology into education from the students' perspectives and based on their own actual experiences and interactions while using virtual reality technology for learning chemistry. First, the researcher gathered students' perceptions of virtual reality technology in six factors of perceptions: (a) ease of use, (b) interaction, (c) imagination, (d) immersion, (e) motivation, and (f) intention to use. The justification for selecting these six areas was they are the most common and essential factors of using virtual reality technology in education based on previous research (Huang et al., 2010; Majid & Shamsudin, 2019). A detailed discussion of how each factor was selected to be included in the study is provided in the data sources under the student perception survey section.

The secondary purpose of this mixed methods research study was to examine the behaviors associated with using virtual reality technology as a tool for chemistry education by observing the participants as they conducted the exercise and further seeking their input on how they described their behavior. All participants were middle school students in the state of Colorado. This particular study predominately focused on the initial perceptions, experiences, and behaviors of middle school students toward the use of virtual reality in education instead of evaluating the effectiveness of virtual reality technology in practice.

Research Questions

This study sought to answer the following research questions:

Q1 What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Q2 Are there any differences between female and male middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Q3 How do middle school students describe their experience during the chemistry exercise using the VR tool?

Q4 How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?

The researcher considered investigating any behavioral differences between females and males but decided to postpone that for future work because the basis for quantifying students' behavior towards virtual reality in educational contexts has not been well established in the literature as yet. The findings of this study could guide the exploration of how students behave when virtual reality is used as a learning tool. The emergent themes concerning students' behaviors identified in this study could be used as a reference to guide the design of quantitative exploration of student behaviors in future research.

Significance of the Study

This study was needed to explore students' perceptions, experiences, and behaviors toward using VR technology as a learning tool in chemistry education. In the existing literature, there was a lack of such studies since the idea of utilizing VR in education is relatively new. While there was a good number of published studies that pushed toward using VR in education (Georgiou et al., 2007; Nersesian et al., 2019; Wu & Shah, 2004), these studies did not explore the perceptions of students about using virtual reality technology as a learning tool.

Technology adaptation in education has been increasing along with an increasing trend in student-centered learning. Technology enhances learning through engagement, collaboration, feedback, and interaction, and bridging the context to authentic experiences. Virtual reality technology is a candidate to provide students with opportunities to learn by themselves inside and outside the classroom (Brown et al., 2021). To ensure effective integration of virtual reality in education, relevant factors that influence the acceptance or resistance of the technology integration must be examined including perceptions of students and educators, institutional support, barriers to integration, etc. (Alfalah, 2018).

Chemistry is a conceptual subject where students need to imagine different invisible concepts to construct an understanding of microscopic elements and their interactions (Brown et al., 2021). Imagining invisible concepts poses two challenges to students. First, students find it more difficult to formulate clear mental images as the complexity of elements increases (Won et al., 2019). Secondly, students' spatial and visual skills vary, which could result in misunderstandings and misinterpretations of concepts (Brown et al., 2021; Gabunilas et al., 2018; Jones et al., 2005). Virtual reality has great potential in aiding in chemistry education because of its capabilities to provide visualization, interaction, and manipulation of invisible constructs (Brown et al., 2021; Jones et al., 2005).

While virtual reality technology has been widely accepted by researchers and educators as being a useful tool in education, it is essential to evaluate learners' motivation and intention to use VR in education (Huang & Liaw, 2018). Existing literature addressed the efficacy of virtual reality applications but missed addressing students' preferences for using virtual reality technology as a learning tool (Lin et al., 2011). This study explored the initial perceptions, experiences, and behaviors of middle school students about using virtual reality technology as a learning tool.

The majority of studies that attempted to explore students' perceptions about the use of virtual reality in education targeted higher-education students (Brown et al., 2019; Cooper et al., 2019; Huang & Liaw, 2018; Huang et al., 2010; Majid & Shamsudin, 2019; Won et al., 2019). Therefore, this study sought to contribute to the literature by bridging the existing gap and giving a voice to middle school students to share their perceptions and experiences about using virtual reality as a learning tool in chemistry education. Also, since the existing literature lacked studies that investigated students' behaviors associated with using virtual reality technology in chemistry education, this study sought to contribute to the literature by bridging this gap as well.

The confirmation of the attitudes toward using VR in education could guide teachers on how and when to integrate VR into their instruction. Research that considered the perceptions of middle school students specifically in this context was scarce. Therefore, this study attempted to reduce the aforementioned gap in the literature and take a small step forward in presenting middle school students' perceptions, experiences, and behaviors based on their own actual experience in using virtual reality as a learning tool instead of relying on assumptions not based on actual experience.

The findings of this study could establish an understanding of students' perceptions, experiences, and behaviors towards using VR as a learning tool. Researchers could refer to this study as a starting point to further explore students' perceptions of VR in education and further investigate the effectiveness of VR technology as a learning tool. Educators as well could benefit from this study in designing their curriculum and instruction. Administrators and policymakers could use the findings of this study in making decisions and policies related to the integration of technology in education.

Students shared their perceptions and described their experiences in using VR for learning. They also talked about the advantages and disadvantages of VR as a learning tool based on their own experiences. Additionally, students provided suggestions about using VR to teach chemistry. The students' feedback has valuable information for educators and administrators who are making decisions about integrating virtual reality technology as a learning tool into education. In chemistry education, VR technology could facilitate the learning process by overcoming the major restrictions of traditional educational methods. The information from this study can be utilized in designing a curriculum that integrates VR as a learning tool. Based on the students' feedback, it is advised that school administrators provide training for students and teachers on using VR equipment and applications before requiring them to use VR in their classes. Additionally, VR software providers could benefit from the suggested improvements to the VR application, such as a more realistic-looking virtual environment, embedded guidance, and sufficient feedback, when they design and deliver educational VR applications to schools.

Key Terms

Intention to Use: Intention to use is defined as the "degree to which a learner intent to adopt the learning system" (Huang & Liaw, 2018, p. 101).

Mixed Methods Research Design: Mixed methods research design is defined as "a special question posed in a mixed methods study that directly addresses the mixing of the quantitative and qualitative strands of the research. This is the question that will be answered in the study based on the mixing (Creswell & Creswell, 2017, p. 267).

Perceived Imagination: Perceived imagination in this study is defined as the "degree to which a learner can perceive nonexistent objects" (Burdea & Coiffet, 2003, p. 3). Perceived imagination is also referred to by imagination in literature and throughout this study.

Perceived Immersion: Perceived immersion in this study is defined as the degree to which a learner has a "real sensation of being inside the virtual world through devices, such as digital helmet or digital cave" (Majid & Shamsudin, 2019, p. 53). Perceived immersion is also referred to by immersion in literature and throughout this study.

Perceived Interaction: Perceived interaction in this study is defined as the "degree to which a learner is able to interact with other learners or with the learning system" (Huang &

Liaw, 2018, p. 101). Perceived interaction is also referred to by interaction in literature and throughout this study.

Perceived Motivation: Perceived motivation in this study is defined as the "degree to which a learner stimulates and sustains the desired learning behaviors" (Huang & Liaw, 2018, p. 101). Perceived motivation is also referred to by motivation in literature and throughout this study.

Virtual Reality: Virtual reality is defined in the context of this study as "immersive, realistic, three-dimensional environments that involve visual feedback from body movement" (Hu-Au & Lee, 2017, p. 216).

Summary

Understanding students' perspectives, experiences, and behaviors about the use of virtual reality is important in order to make informed decisions about the integration of virtual reality in education. Research that considered the perceptions, experiences, and behaviors of middle school students specifically in this context was scarce. Therefore, this study attempted to reduce the aforementioned gap in the literature and take a small step forward in presenting middle school students' perceptions, experiences, and behaviors based on students' own experiences using virtual reality as a learning tool.

Chapter II provides a review of the definition and evolution of virtual reality technology, followed by a detailed review of virtual reality in education and then in chemistry education. A brief discussion of the Technology Acceptance Model was presented in the last section of Chapter II. Chapter III describes the methodology related to the study design, the participants, types of methods and instruments that were used, research procedures, and the data analysis plan followed by strategies to ensure trustworthiness and validity.

CHAPTER II

LITERATURE REVIEW

The past decade has witnessed a rapid and vast integration of technology into education (Alfalah, 2018; Huang & Liaw, 2018; Sprenger & Schwaninger, 2021). Such integration requires evaluation studies that help guide educators and policymakers to choose appropriate technologies that can help deliver content effectively (Rosell-Aguilar, 2017). While virtual reality technology has been around since the 1960s for simulation and gaming, its integration in education was introduced much later (Kavanagh et al., 2017).

This chapter discusses literature related to the problem this study poses, exploring the perceptions, experiences, and behaviors of middle school students about using virtual reality in chemistry education as a learning tool. The first section provides an overview of virtual reality technology in literature in terms of its definitions and evolution over time. The second section discusses the use of virtual reality technology in education in terms of effectiveness evaluation, perceptions of educators, and perceptions of students. The third section discusses the use of virtual reality technology in chemistry education in terms of effectiveness evaluation, perceptions of educators, and perceptions of students. The chapter is concluded with a brief discussion of the Technology Acceptance Model in the fourth section.

Virtual Reality Technology

Definition

The term "virtual reality" has been used for several decades with an evolution of what it refers to as time progresses. The definition of virtual reality in the literature varies based on the perspective used to define virtual reality, which can be problematic when the definition is based on the applications, the techniques of its use, or even the devices used to deliver virtual reality (Baxter & Hainey, 2019; Fuchs et al., 2011). Steuer (1992) defined virtual reality as “a real or simulated environment in which a perceiver experiences telepresence” (p. 76). This early definition captures the essence of virtual reality in terms of the environment and the presence it provides. Luo et al. (2021) broadly defined virtual reality as “a type of simulated reality that provides users with mediated experience” (p. 887). This definition is too broad because it can fit the description of other technologies, such as augmented reality. A comprehensive, technical definition of virtual reality that focuses on the technical factors of VR was provided by Fuchs et al. (2011) and states that:

> Virtual reality is a scientific and technical domain that uses computer science and behavioural interfaces to simulate in a virtual world the behaviour of 3D entities, which interact in real time with each other and with one or more users in pseudo-natural immersion via sensorimotor channels. (p. 8)

Hu-Au and Lee (2017) defined virtual reality as “immersive, realistic, three-dimensional environments that involve visual feedback from body movement” (p. 216). The definition focuses on the main characteristics of virtual reality, which include immersion, reality, three-dimensional representations, and body movements, and fits the context of this study. This study uses a virtual reality experience that is fully immersive in a totally virtual environment. Immersion refers to the degree to which a learner has a real sensation of being inside the virtual world (Majid & Shamsudin, 2019), while a totally virtual environment refers to providing a virtual environment to conduct activities without the need to interact with the real world.

Virtual reality falls under a larger umbrella of technologies currently referred to as eXtended Reality (XR), which encompasses augmented reality, virtual reality, and mixed reality. Augmented reality is defined as “a technique to show extra information over the real world” (Muñoz-Saavedra et al., 2020). Virtual reality operates over a totally virtual environment, while augmented reality operates over the real world. As its name implies, mixed reality refers to technologies in between augmented reality and virtual reality that operates within the borders of the real world and a totally virtual environment (Muñoz-Saavedra et al., 2020). It is important to distinguish between the different types of extended reality when referring to the literature because some authors use virtual reality and augmented reality interchangeably, which is incorrect.

Evolution

The roots of the term “virtual reality” date back to the 19th century, referring to the first 360-degree art through panoramic murals (Freina & Ott, 2015). The concept of virtual reality was introduced by Morton Heilig, who invented a mechanical device in 1962, called the Sensorama that simulated a motorcycle ride using three-dimensional film with colors, sounds, smells, and wind sensations created using a fan. However, the device was not interactive (Freina & Ott, 2015; Mandal, 2013).

In 1965, Ivan Sutherland proposed the concept of the “Ultimate Display” that could simulate reality, which included a virtual world, interactive graphics, force-feedback, sound, smell, and taste (Mandal, 2013). Soon after that, in 1968, Ivan Sutherland created the first prototype virtual reality system that consisted of a head-mounted display device and a mechanical head tracking system (Mandal, 2013). The system was heavy and attached to the ceiling, and the computer graphics were very primitive. Further developments continued in head-mounted display-based systems (HMDs) to improve the quality of images and to make the system more convenient for users.

Until the early 1990s, the use of virtual reality was limited to certain purposes, such as military training, flight simulation, and 3-D visualizations (Hu-Au & Lee, 2017; Wohlgenannt et al., 2020). The early versions of virtual reality technology were expensive, uncomfortable, not realistic, and consumed so much computing power (Hu-Au & Lee, 2017). The use of HMDs for consumers was introduced in the 1990s by the Sega VR and Nintendo's Virtual Boy, but both did not succeed due to the limitations of their capabilities and for causing motion sickness (Wohlgenannt et al., 2020). Motion sickness in simulated environments is known as simulated sickness. It is caused by the mismatch in sensory inputs that occurs when switching from the real world to the three-dimensional world (Dayarathna et al., 2020). A new approach to virtual reality called CAVE Automatic Virtual Environment (CAVE) was introduced in 1992, where stereoscopic images are projected on the walls of a room and LCD shutter glasses are used instead of a head-mounted display. The approach had a better quality of images and a wider field of view than systems that use head-mounted displays (Mandal, 2013). The use of CAVE was limited to professional purposes because of the associated cost and space requirements (Wohlgenannt et al., 2020).

In the early 2010s, the gaming industry revolutionized the use of HMDs through the release of several modern HMDs for consumer use, such as Oculus Rift, HTC Vive, and PlayStation VR (Martín-Gutiérrez et al., 2017; Wohlgenannt et al., 2020). Currently, several big companies are leading the development and the investment in the market of virtual reality, such as Apple, Facebook, Google, Magic Leap, and Samsung (Martín-Gutiérrez et al., 2017). The recent technical developments had successfully resolved many of the problems that existed in the previous VR products (Hu-Au & Lee, 2017). Accordingly, several virtual reality products became mainstream consumer products, such as the Google Cardboard, Daydream View, Oculus Rift, HTC Vive, Samsung Gear VR, Playstation VR, and Microsoft HoloLens (Hu-Au & Lee, 2017; Martín-Gutiérrez et al., 2017). The HMD system used in this study is called the Oculus Quest 2 and it was introduced in 2020 by Facebook. Oculus Quest 2 is characterized by portability, high-quality graphics, and powerful processing capabilities. It is considered portable due to its lightweight and not being tethered to a computer (Kerstein, 2021).

Virtual Reality Technology in Education

Virtual reality technology has been introduced as an educational technology for many years (Baxter & Hainey, 2019). The primary motivation to use virtual reality in education is the opportunity VR creates to virtually access situations that cannot be accessed physically. Such situations are inaccessible due to restrictions like time, distance, safety, and ethics (Freina & Ott, 2015). Existing literature that focused on addressing virtual reality technology in education revolves around several axes including (a) evaluating the effectiveness of virtual reality technology compared to other methods as a tool for learning (Dayarathna et al., 2020; Madathil et al., 2017), (b) evaluating the perceptions of educators (pre-service and in-service) about using virtual reality as an educational technology tool (Alfalah, 2018; Cooper et al., 2019; Majid & Shamsudin, 2019), and (c) evaluating the perceptions of students about using virtual reality as a learning tool (Allcoat & von Mühlenen, 2018; Baxter & Hainey, 2019; Han, 2021; Huang & Liaw, 2018; Lin et al., 2011; Sprenger & Schwaninger, 2021). Pre-service teachers are considered educators in this literature review because their participation in the reported studies was based on their role as educators, not as students.

Evaluation of Virtual Reality Effectiveness

Whenever a new technology is introduced to be used in education, evaluation studies that attempt to investigate the effectiveness of that technology in educational contexts arise. Madathil et al. (2017) conducted an experiment to investigate the effectiveness of virtual reality in enhancing learning outcomes and engagement compared to other methods in an online asynchronous learning environment. Participants were 165 two-year college students across five sites in the United States and were assigned to one of three groups: control group, case studies group, or VR group. The control group had the online module only.

In contrast, the case studies group had the online module plus photo-based case studies, and the VR group had the online module plus virtual reality simulations. Participants in all three groups completed an experimental task that included a pre-test and a pre-survey, then completed the online module that was followed by a post-test and a post-survey. Participants in the case studies group completed photo-based case studies additionally, while participants in the VR group completed the VR simulations. Both the pre- and post-surveys utilized these four constructs: perceived learning outcomes, engagement, usability, and satisfaction and perception.

Results showed that there were no significant differences between the three groups in terms of learning gains based on comparing the pre- and post-test scores. Perceived learning outcomes were evaluated using ease of comprehension, ease of memorization, ability to apply what was learned, and ability to better analyze problems. Results showed no significant differences among the three groups based on ease of comprehension and ease of memorization. The perceived ability to apply what was learned and the perceived ability to better analyze problems were significantly higher for the control and the virtual reality groups when compared to the case-study group. However, there were no statistically significant differences between the control group and the virtual reality group. The perceived engagement levels and usability were significantly higher for the control and the virtual reality groups when compared to the case-study group, with no statistically significant differences between the control group and the virtual reality group (Madathil et al., 2017). In terms of satisfaction and perceptions, results showed that the control and virtual reality groups reported enhanced students' experience and perception of learning more than the case-study group. Madathil et al. (2017) suggested that virtual reality provides authentic and active learning activities similar to the real context.

To investigate the gender differences between males and females in terms of the efficacy and effectiveness of VR in teaching manufacturing concepts, Dayarathna et al. (2020) designed and developed a virtual reality module to teach the queuing theory. Efficacy was measured using simulation sickness, system usability, and user experience. Effectiveness was measured using knowledge gain, NASA Task Load Index (NASA TLX), and level of post-motivation. The queuing theory is a widely-used mathematical concept in engineering that deals with waiting lines (queues) when managing operations. The VR queuing theory teaching module was built using the Unity game engine and delivered through Oculus Rift. Simulation sickness was measured using a questionnaire with 16 possible symptoms associated with discomfort caused by the virtual environment. The symptoms were grouped under three groups: nausea, oculomotor discomfort, and disorientation. System usability was measured using a questionnaire with 10 items related to usability components. User experience was measured using a questionnaire with 22 questions grouped under five categories: involvement, immersion, visual fidelity, interface quality, and sound.

Knowledge gain is concerned with assessing students' conceptual and analytical skills in the content presented to them. A quiz that consisted of 14 conceptual questions and six analytical questions was used to measure knowledge gain. NASA Task Load Index (NASA TLX) is a tool developed by NASA to measure the perceived workload of a task based on physical demand, temporal demand, mental demand, frustration, effort, and performance. A survey with 14 Likert-scale questions was used to measure the level of post-motivation after going through the virtual reality module (Dayarathna et al., 2020).

Participants were 56 students, including 21 females, 32 males, and 3 unspecified. Each participant was presented with a short tutorial about the VR device and the module, then proceeded to spend a few minutes playing with the system to get familiar with it. The participant was presented with the first simulation sickness survey, and then the VR module was presented to the participant. Upon completion of the module, the participant was presented with the second simulation sickness survey followed by the knowledge gain quiz. Then, the participant was presented with the third simulation sickness survey, followed by two other surveys to measure system usability and user experience. Participation was concluded with the NASA TLX survey (Dayarathna et al., 2020).

To explore the gender differences, Dayarathna et al. (2020) analyzed the data and reported their findings. Results showed that participants reported simulation sickness at the beginning of the study, during the study, and at the end of the study. However, male participants reported a steady increment in sickness while female participants reported fewer symptoms at the beginning of the study with increasing severity as the study progressed. Females reported fewer symptoms at the beginning of the study, and higher symptoms during the study and at the end of the study. However, there was no significant difference between females and males in simulation sickness at the beginning of the study, during the study, and at the end of the study (Dayarathna et al., 2020). Dayarathna et al. (2020) reported no significant differences between females and males in all system usability items, and in the total system usability score for both groups. In terms of user experience, results showed no significant difference between females and males in all user experience items. However, the t-test showed that females were significantly different from males in the items' overall score with a better user experience (Dayarathna et al., 2020).

Effectiveness was measured using knowledge gain quiz scores, NASA Task Load Index (NASA TLX) performance assessment, and level of post-motivation survey. Both females and males performed better on the conceptual part than they did in the analytical part. Females scored higher than males in both parts and the overall scores of knowledge gain. The difference in the scores between females and males was not significant in both parts and the overall score of knowledge gain. Females had a higher overall NASA TLX index score (M=61.54) than males (M=49.15), but males scored higher in temporal demand, mental demand, and effort.

The difference between females and males in the NASA TLX index score was not significant. Males had higher scores in 9 out of the 14 questions in the post-motivation survey, and the total score was higher for males than that for females. However, the difference between the females and males was not significant in the level of post-motivation (Dayarathna et al., 2020). In summary, there was no significant difference between females and males in either the efficacy or the effectiveness of the VR teaching module. The study is important because it addresses gender differences in using virtual reality technology in education, and the findings of the study contribute to abolishing negative stereotypes about females in STEM fields.

Perceptions of Educators

The perceptions of educators and students towards the acceptance of or resistance to the adoption of virtual reality technology in education should be investigated to ensure that the integration of virtual reality in education is effective (Alfalah, 2018). To examine the perceptions of educators towards VR integration in education, a study was conducted by Alfalah (2018) at a university in the Middle East region. Participants were 11 faculty members in the information technology department who are proficient in using technology. A quantitative method that utilized a questionnaire was used. The questionnaire had five categories: demographics, the general attitude toward technology and VR, knowledge of VR, barriers to technology integration, and available resources. Results showed that participants had positive attitudes toward technology and VR and believed that technology has a positive impact on students' learning and that VR is suitable for students' engagement through immersion.

In terms of knowledge of VR, results showed that participants were aware of virtual reality technology and its benefits and applications as an educational tool. Participants reported several issues as barriers to VR technology integration in education, including high cost, the need for training, not knowing the effectiveness of VR in specific disciplines, low self-efficacy in VR use, and lack of administrative support and available resources. In terms of available resources, participants reported that workshops and seminars provided by their institution as well as their informal network of friends and colleagues are two essential sources of information regarding technology integration (Alfalah, 2018). I found two issues with this study. First, all participants were faculty in the information technology department who are proficient in technology, hence expected to support technology integration in general. Secondly, there was no information on whether the participants had any experience using virtual reality previously, thus their opinions might not be based on actual experiences.

To examine the perceptions of pre-service teachers about using virtual reality as a teaching tool in the classroom, Cooper et al. (2019) conducted a mixed methods case study. Participants were 41 pre-service teachers pursuing a bachelor's degree in education at an urban university in Australia. A case study that employs quantitative and qualitative methods through a survey instrument was used. The survey had two categories in addition to demographics.

The first category focused on self-efficacy and usage of digital technologies/VR, while the second category focused on the perceptions of VR as a learning and teaching tool inclusive of its potential positives, efficacy, and concerns or barriers. Results showed that participants' self-efficacy to teach using VR is significantly lower than using other digital technologies in their pedagogy. About two-thirds of the participants reported that they never used VR. In terms of the perceptions of VR as a learning and teaching tool, the majority of the participants showed high interest in using VR, and about half of the participants thought that VR has a positive effect on student learning (Cooper et al., 2019). I think it would have been beneficial to distinguish between participants who had experience with VR and participants who never used it to see how that affects their perceptions.

Another study referred to the TAM model in investigating educators' perceptions and attitudes towards integrating virtual reality in the classroom. Majid and Shamsudin (2019) conducted a quantitative study to identify the factors affecting teachers' acceptance of VR in the classroom. Participants were 98 in-service teachers pursuing a master's degree in education at a public university in Malaysia. A questionnaire that solicited participants' feedback on ease of use, usefulness, attitude, and intention was used. Results showed that the ease of use does not significantly influence attitude, but both usefulness and attitude affect intention with a stronger influence by attitude. This means that teachers intend to use VR based on their perceived usefulness and attitude towards the technology (Majid & Shamsudin, 2019).

Perceptions of Students

To evaluate students' attitudes toward using an e-commerce virtual reality learning system, Huang and Liaw (2018) conducted a study that was designed based on constructivist and technology acceptance approaches. The constructivist approach was achieved by allowing students to actively construct their own knowledge by using a virtual reality system to create authentic learning experiences. The technology acceptance approach was achieved by using the Technology Acceptance Model (TAM) as the basis to evaluate students' intentions towards the use of virtual reality in a 3D shopping mall experience. Participants, who were 308 undergraduate students majoring in information management at a Taiwanese university, were asked to provide feedback on six TAM-based constructs after using the virtual reality system.

The constructs were perceived self-efficacy, perceived interaction, perceived ease of use, perceived usefulness, learning motivation, and intention to use. Correlation analysis revealed that perceived self-efficacy and perceived interaction were two strong predictors of perceived ease of use. Perceived self-efficacy, perceived interaction, and learning motivation were strong predicators of perceived usefulness. Perceived self-efficacy and perceived interaction were two strong predictors of learning motivation. Finally, perceived ease of use, perceived usefulness, and learning motivation were found to be strong predictors of learners' intention for system use (Huang & Liaw, 2018). One issue I found with this study is that the constructs that were used to evaluate participants' intentions were not specific to virtual reality technology that has its own features and capabilities compared to other technologies. In this study, I took the specific features and capabilities of virtual reality into consideration when designing the student perception survey.

A mixed methods study was conducted at the University of the West of Scotland to explore the views of students about VR use in education using a questionnaire (Baxter & Hainey, 2019). Participants were 100 undergraduate students in the creative computing program. Findings showed that students had positive perceptions towards using virtual reality in an educational context based on pedagogical benefits. Participants pointed out that the cost of VR equipment and potential health issues, such as motion sickness, can limit the adoption of VR technology in higher education (Baxter & Hainey, 2019). One issue I found with this study is that students were not presented with a virtual reality experience, but provided their views based either on past experiences with VR or hypothetical assumptions about VR. Also, the generality of the study findings was limited by the discipline of the participants.

To gain an insight into college students' perceptions about using VR technology in psychology education, Sprenger and Schwaninger (2021) compared four digital learning technologies (e-lectures, classroom response system, classroom chat, and mobile virtual reality) in terms of their technology acceptance after three months usage. E-lectures refer to recordings of classroom lectures to allow students to access the content individually at their own pace. A classroom response system allows students to respond to multiple-choice questions posed before, during, and after the lecture using their own electronic devices. A classroom chat refers to an application that allows students to submit questions anonymously to their instructor, who in turn can respond with answers. A mobile virtual reality is a specific type of virtual reality. The processor of a smartphone and its screen are used together with a cardboard headset to create the immersion experience (Sprenger & Schwaninger, 2021).

Participants were 94 students in an introductory course to Psychology at a university in Switzerland. Technology Acceptance Model (TAM) was used to gather perceptions by measuring perceived usefulness and perceived ease of use to predict behavioral intention. Findings showed that the classroom response system was rated the best, closely followed by e-lectures, then the classroom chat, and then mobile virtual reality at last. All learning technologies were favored after usage by participants, except for mobile virtual reality (Sprenger & Schwaninger, 2021).

I found two issues with this study. First, it compared technologies that were used for different purposes. The classroom response system and the classroom chat were used to get students engaged with the class, while the e-lectures and the mobile virtual reality were used to access the content individually. Secondly, the content delivered through each technology can vary drastically for each participant based on what they choose to access and learn, which affects their experiences and perceptions and makes the comparison questionable.

To investigate the effect of virtual reality on students' performance, emotion, and engagement, Allcoat and von Mühlenen (2018) conducted an evaluation study. Performance was measured using a pre- and a post-test that assessed biology knowledge. Emotion was rated before and after participation using nine categories: interest, amusement, sadness, anger, fear, anxiety, contempt, surprise, and elatedness. The engagement was measured using a Likert-scale questionnaire with three categories: learning, design, and engagement. Participants were 99 first-year Psychology students at a university in the United Kingdom and were assigned randomly to one of three learning conditions: traditional (textbook style), virtual reality, and video. All three conditions used the same text and 3D model of a plant cell. An application called Lifeliqe Museum was used to deliver the immersive VR content using a head-mounted display and controllers. The video condition used a recording of the virtual reality device to create similar content but in two dimensions instead of three dimensions. Results showed that the VR and the traditional groups showed better learning than the video group. The VR groups performed best at remembering, while the traditional group performed best at understanding. In terms of emotion, the VR group reported an increase in positive emotions and a decrease in negative emotions. The other two groups reported a decrease in positive emotions. Finally, in terms of engagement, the VR group scored the highest on all three categories of learning, design, and engagement, followed by the traditional group, then the video group (Allcoat & von Mühlenen, 2018). I found this study to be one of the very few studies that addressed students' emotions associated with the use of VR.

While field trips play an important educational role, they can be situated in remote areas, have unfavorable or dangerous conditions, or place students under heavy cognitive loads (Lin et al., 2011). Virtual field trips have been used for educational purposes in many areas, such as geology, history, science, and engineering. A virtual field trip is used in an educational context to overcome temporal, spatial, and cost limitations imposed by traditional physical field trips (Lin et al., 2011; Lukes, 2014). A virtual field trip is "a journey taken without actually making a trip to the site" (Lin et al., 2011). An enhancement of virtual field trips is the addition of immersion to achieve presence and improve engagement and interaction with the virtual world.

A recent study examined the perceptions of 28 elementary students in South Korea about using immersive virtual field trips in the classroom (Han, 2021). Using the Google Expeditions application, students went through virtual field trips to Paris and New York, then to San Diego Zoo and Reef Sharks. Students were asked to write reflection papers about their experiences, and teachers were interviewed by the researcher. Findings showed that students perceived field trips to be efficient in terms of time and cost and offer opportunities to enhance learning. Students preferred traditional field trips over virtual field trips because traditional field trips support physical interaction with real places. Further, students stated that immersive virtual field trips were engaging, real, and provided an increased perception of virtual presence. However, students also expressed concerns about health and safety, psychological side effects, technical difficulties, and low social interaction (Han, 2021).

Field trips in earth science can be limited by remote sites and bad weather conditions. Lin et al. (2011) investigated the relationship between the use of a three-dimensional Virtual Reality Learning Environment for Field Trip ($3DVLE_{(ft)}$) system and the achievement levels of senior high school students. The 3DVLE(ft) system emulates the Hsiaoyukeng Walking Area at Yangmingshan National Park in Taiwan. Participants were 82 tenth-grade senior high school students, including 44 females and 38 males. Participants attended two earth science classes at a high school in Taiwan and were assigned to one of two groups: a teacher-demonstrated based group or student co-navigated based group.

The teacher-demonstrated based group was led by a teacher, while the student co-navigated based group was self-guided by students. Four assessment tools were used in the study: a 3DVLE(ft) learning achievement test, a series of tasks in the virtual world, a 3DVLE(ft) questionnaire, and the Classroom Learning Environment Instrument (CLEI). The $3DVLE_{(ft)}$ learning achievement test was used to evaluate students' understanding of the content before and after using the virtual field trip system. The series of tasks in the virtual world contained two tasks completed by students during the virtual field trip. The 3DVLE(ft) questionnaire had 11 items to gather students' feedback about their experience of using the virtual field trip system. The CLEI was adapted from the literature to capture the variation in students' learning outcomes. The CLEI had two categories: the Actual Learning Environment Instrument (ALEI) and

Preferred Learning Environment Instrument (PLEI). Gender comparison was used in the data analysis (Lin et al., 2011).

Results showed that students of both genders preferred the student co-navigated based treatment over the teacher-demonstrated based treatment regardless of their assigned group. Interestingly, the results showed that students in the teacher-demonstrated based group significantly outperformed their peers on the post-test, on average (Lin et al., 2011). In terms of learning outcomes and when controlling for all other factors, females with high levels of prior virtual environment exposure outscored females with little or no prior virtual environment exposure, but the level of prior virtual environment exposure had no effect on learning outcomes for males. Students' perception of helpfulness had a significant effect on post-test scores when controlling for other factors. The findings of the study are tied to the Taiwanese educational system that implements a didactic manner and cannot be generalized to other countries where a different educational system is implemented (Lin et al., 2011).

In conclusion, the general themes that emerged from the reviewed studies that pertain to virtual reality in education reveal that virtual reality is perceived positively among educators and students in general. Also, there is empirical evidence that supports the effectiveness of virtual reality in educational contexts when compared to other educational technologies. In terms of gender differences, there was no significant difference between females and males when the efficacy and the effectiveness of a virtual reality teaching module were evaluated.

Virtual Reality Technology in Chemistry Education

Virtual reality technology has been used in education to aid in various subject areas such as science and social studies. Chemistry is a subject that has gained a lot of attention from virtual reality applications and experiences. The reason behind that is because chemistry is a conceptual subject where students need to imagine different invisible concepts to construct an understanding of microscopic elements and their interactions (Brown et al., 2021). Virtual reality has a great potential in aiding in chemistry education because of its capabilities to provide visualization, interaction, and manipulation of invisible constructs (Allcoat & von Mühlenen, 2018; Brown et al., 2021; Jones et al., 2005).

Existing literature that focused on addressing virtual reality technology in chemistry education revolves around three main axes: (a) evaluating the effectiveness of virtual reality technology compared to other methods as a tool for learning chemistry (Brown et al., 2021; Gabunilas et al., 2018; Ikhsan et al., 2020; Merchant et al., 2013), (b) evaluating the perceptions of (pre-service and in-service) educators about using virtual reality as an educational technology tool in chemistry (Brown et al., 2019; Ikhsan et al., 2020; Saritas, 2015), and (c) evaluating the perceptions of students about using virtual reality as a learning tool in chemistry education (Edwards et al., 2019; Won et al., 2019).

However, the amount of research that focuses on the perceptions of students is small compared to the other aforementioned axes and targets college students mostly. Studies that target K-12 students, specifically middle school students, are very scarce. Additionally, the existing literature lacks studies that are dedicated to investigating students' behaviors associated with the use of virtual reality technology in education. Again, pre-service teachers are considered educators in the following literature review because their participation in the reported studies was based on their role as educators, not as students.

Evaluation of Virtual Reality Effectiveness

It is common when a new technology emerges as an educational tool to have studies conducted to evaluate its effectiveness in the educational context. Merchant et al. (2013)

conducted a quasi-experimental study that investigated using a three-dimensional virtual world to enhance undergraduate students' learning of certain chemistry concepts. Participants were 384 undergraduate students enrolled in two sections of the Chemistry 101 course at a large south-western university. Participants from one section of a chemistry course were assigned to the experimental group that used 3-D virtual environment instruction. In contrast, participants from a second section of the chemistry course were assigned to the control group that used 2D image-based instruction. Chemistry achievement and spatial ability were used to compare the control group and the experimental group. Merchant et al. (2013) concluded no significant difference between the two groups, neither in chemistry achievement nor in spatial ability. However, students with poor spatial ability had an improved understanding of the 3-D nature of molecules if they did relevant activities in a VR environment compared to those students who used only 2-D images (Merchant et al., 2013).

Another study was conducted to compare the effectiveness of three methods used to teach molecular geometry to undergraduate chemistry students (Brown et al., 2021). A group of 15 participants was assigned to each of the three methods: virtual reality, computer simulation, and traditional modeling. Participants came from a general chemistry laboratory course at a mid-size, western U.S. public institution. A pre- and post-test quasi-experiment was used to collect data about students' performance in a given chemistry exercise. The study evaluated and compared the effectiveness of the three methods in assisting students in understanding the concepts, performing a relevant exercise correctly, and addressing students' attitudes towards the use of virtual reality in chemistry education (Brown et al., 2021). Results showed no significant difference among the three methods. However, participants expressed positive attitudes toward the use of virtual reality in molecular geometry education.

To compare the effectiveness of VR-assisted instruction to traditional instruction based on a PowerPoint presentation, Gabunilas et al. (2018) conducted an evaluation study. Participants were 50 students in 11th grade and were divided into two groups of equal size. The content used in the study was related to the structure of the atom and was delivered using a mobile application called MEL Chemistry VR Lessons to the virtual reality group. A pre- and a post-test were administered to both groups to evaluate students' understanding of the content. Findings show that students in the virtual reality instruction group outperformed the traditional instruction group. Informal face-to-face interviews with the students in the virtual reality group were conducted to gain an insight into their views on the use of VR-assisted instruction. The responses of the students were positive in general and recommended using virtual reality in other science subjects (Gabunilas et al., 2018).

Some researchers choose to develop their own virtual reality applications based on needs analysis. Ikhsan et al. (2020) developed a virtual chemistry laboratory that is operated using an Android with 3-D glasses and a controller. They conducted a quasi-experiment to compare the performance across three groups of 10th graders enrolled in a senior high school in Indonesia. Each group consisted of 32 participants. The first group used the virtual chemistry laboratory, the second group used a real laboratory with hybrid learning mediated by virtual reality, and the third group used a real laboratory only. A post-test about chemical bonding was used to evaluate students' performance in their critical thinking skills. Results showed that the difference in the post-test values of critical thinking skills among the three groups was significant. The first group scored the highest average on critical thinking skills, followed by the second group, and then the third group (Ikhsan et al., 2020).

Perceptions of Educators

The perceptions of educators are critical and should be investigated when it comes to the adoption of new technology in an educational context (Alfalah, 2018). In literature, the perceptions of pre-service teachers about using virtual reality in education were solicited based on their role as educators, not as students. A study to evaluate the attitudes of pre-service teachers towards using virtual reality in chemistry education through a focus group was conducted by Brown et al. (2019). Participants were education students enrolled in teacher preparation technology and STEM courses. After being exposed to different active learning activities related to molecular structures delivered using virtual reality, participants were asked to provide feedback about their experiences. The findings of the study showed that participants had positive perceptions about the potential of VR in learning and its capabilities of visualizing the invisible but expressed concerns about anxieties and training associated with its use (Brown et al., 2019). One issue I found with this study is that the number of participants was not specified.

A group of researchers who conducted a study to evaluate the effectiveness of VR also investigated the perceptions of educators towards using virtual reality as a learning tool in the same study. Ikhsan et al. (2020) developed a virtual chemistry laboratory for students to learn at their own pace in a safe environment and then investigated its effectiveness relative to other technologies, as discussed under the “Effectiveness of VR” section. Additionally, Ikhsan et al. (2020) investigated the quality of VR based on feedback from eight senior high school teachers. The quality of VR was captured using three aspects, namely content, learning, and technical quality. Results showed that teachers perceived VR to have very good quality overall (Ikhsan et al., 2020).

To evaluate pre-service teachers' perceptions about using VR for molecular geometry, Saritas (2015) developed a desktop VR tool and conducted an evaluation study. The VR tool allows users to build and revise their molecular models within molecular geometry. Participants were 29 undergraduate chemistry teacher candidates from a public university in Turkey. The study used a 5-point Likert-scale questionnaire that consists of seven constructs: facilitation, motivation/ impact, rapidity/intuition, creativity, logical-analytical thinking, global view, and negative effects.

Interviews with participants were also conducted to gain further insight into participants' perceptions. Survey results showed that participants rated the VR tool highly on all constructs, with the highest score for facilitation (M=3.98) and the lowest score for negative effects (M=2.82). The interview results showed that participants had a very good impression of VR and were willing to use it as an educational tool in chemistry (Saritas, 2015). I believe it would be more beneficial if educators were able to utilize the VR tool as part of their instruction or lesson plans instead of conducting an exercise or just trying the virtual reality tool.

Perceptions of Students

A limited number of studies that investigate students' perceptions about the use of virtual reality in educational contexts exist in literature. Won et al. (2019) adopted a design-research approach to developing activities that visualize complex molecules using virtual reality technology, then evaluated students' collaborative interactions and perceptions about these activities (Won et al., 2019). Participants were 22 first-year college chemistry students at an Australian university. Pre-interviews were used to assess students' background knowledge about molecular structure and interactions before their VR experience. Post-interviews were used to gather students' views about their VR experience. Results showed that students enjoyed the features of interactivity and collaboration of the activities in virtual reality and its ability to transform the abstract into the concrete. Participants with limited negotiation skills benefited the least from the immersive virtual reality collaboration (Won et al., 2019).

Organic chemistry is a subject in chemistry that is challenging to teach and learn because it requires spatial skills or abilities. Spatial ability refers to a student's "capacity to understand, reason, and remember the spatial relations among objects or space" (Brown et al., 2021, p. 69). Virtual reality technology has been utilized to help in providing virtual environments that aid in teaching and learning organic chemistry.

Edwards et al. (2019) developed an immersive VR learning environment with haptic feedback, called VR Multisensory Classroom (VRMC), to aid in organic chemistry learning. In addition to the head-mounted display, the VRMC has haptic gloves that have a sensor to monitor hand movement and vibration motors to provide feedback to the users. Edwards et al. (2019) conducted a mixed methods study to investigate the perceptions of users on using the VRMC as an instructional tool for organic chemistry. Participants who were 13 individuals from a diverse age group ranging from 12-36, accessed the VRMC as learners. Quantitative data were collected using a short survey, while qualitative data were collected using open-ended questions and participant observations. The survey evaluated participants' views on the VRMC as a learning tool based on six factors: support for multisensory learning, haptics, motivation, engagement, adequacy, and support for chemistry learning (Edwards et al., 2019).

Results showed that participants had positive perceptions of the VRMC and rated it high to very high on all six factors. Results from the open-ended questions also showed positive feedback in general, and all participants reported that the system was impressive, interesting, and educative. Participant observations showed engagement and motivation. In terms of limitations, participants reported the need for built-in audio for instructions and feedback, and improved sensitivity and precision of the haptic system (Edwards et al., 2019). One issue I found with this study is that it was limited to 13 participants only without identifying their backgrounds or experiences.

In conclusion, the general themes emerging from the previous studies reviewed under virtual reality in chemistry education topic reveal that virtual reality is effective in chemistry education in general when compared to other technologies used to assist in learning and teaching. A second theme reveals that educators have positive perceptions about the use of virtual reality for educational purposes, but have concerns associated with its use, such as self-efficacy and the high cost of VR. A third theme reveals students have positive perceptions about the use of virtual reality for educational purposes.

Technology Acceptance Model

The reviewed literature related to virtual reality in chemistry education in this study has referred to the Technology Acceptance Model in multiple studies that investigated the effectiveness of virtual reality in chemistry education as well as studies that investigated students' perceptions towards using virtual reality in chemistry education. TAM was developed in 1989 to explain and predict the acceptance of specific types of technologies by users (Majid & Shamsudin, 2019; Sprenger & Schwaninger, 2021). According to TAM, the acceptance of a new technology can be predicted by the users' intention to use it, which is dependent on perceived ease of use and perceived usefulness (Sprenger & Schwaninger, 2021). Many extensions and modifications to TAM have been proposed in the literature to increase its predictive power (Sagnier et al., 2020; Sprenger & Schwaninger, 2021).

TAM has been the leading model among all acceptance models by the information systems community and has been widely used to predict the acceptance of new technologies successfully (Chuttur, 2009). However, several researchers expressed skepticism about the application and theoretical accuracy of the TAM (Chuttur, 2009). In the context of virtual reality technology, TAM is limited because it does not address the specific aspects of virtual reality technology, user experience, or the variables related to user characteristics (Sagnier et al., 2020). Also, in the context of this research, the acceptance of VR technology in this study is primarily dependent on the students' spontaneous and immediate reactions and views. Therefore, TAM is not used as part of the theoretical foundation for this study.

Summary

This chapter presented a review of literature related to the problem under investigation - perceptions, experiences, and behaviors of middle school students towards the use of virtual reality technology in chemistry education. The first section presented a discussion about virtual reality in literature in terms of its definition and evolution. The second section discussed the use of VR technology in education in terms of the evaluation of its effectiveness and the perceptions of educators and students about the use of VR in education. The third section reviewed the literature related to virtual reality use in chemistry education in terms of the evaluation of its effectiveness and the perceptions of educators and students about the use of VR in education. The fourth and last section presented a brief discussion of the Technology Acceptance Model. The following chapter provides the methodology related to research design, the participants, methods, and instruments used, research procedures, and the data analysis procedures.

CHAPTER III

RESEARCH METHODOLOGY

This chapter discusses the research design for this mixed methods study. It describes the theoretical perspective, the researcher's stance, the methods used to collect and analyze the data, and the process that was utilized to ensure trustworthiness and validity. As outlined in previous chapters, the purpose of this mixed methods study was to explore the initial perceptions, and experiences of middle school students towards the use of virtual reality technology as a tool in chemistry education. In addition, this study attempted to gather information on how middle school students behave while using the virtual reality tool in the chemistry exercise.

Based on the purposes of the study, the research was guided by the following research questions:

Q1 What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Q2 Are there any differences between female and male middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Q3 How do middle school students describe their experience during the chemistry exercise using the VR tool?

Q4 How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?

Theoretical Foundation

Crotty (1998) defines four key elements of the research framework: epistemology, theoretical perspectives, methodology, and methods (Crotty, 1998). In the following sections, I described each element in the context of this study.

Epistemology

Epistemology is the assumptions and beliefs about what constitutes knowledge, what knowledge is, and what its characteristics (Merriam & Tisdell, 2016). Epistemology influences how researchers frame their research in their attempt to discover knowledge (Moon & Blackman, 2014). In scientific inquiry, there are two different views about knowledge. In the first view, knowledge is apart from the observer as the observer seeks to find this knowledge objectively. According to this view, knowledge is finite, measurable, and obtained through empirical methodologies. In the second view, knowledge can never be separated from the knower; therefore, humans perceive and interpret their experiences influenced by social and cultural factors that cannot be isolated from the perceiver (Merriam & Tisdell, 2016).

This study utilized the second view of knowledge. The research was guided by the assumption that knowledge cannot be separated from the knower, having the researcher as the knower in this case. While the researcher carefully interpreted the data as objectively as possible, she was aware that the interpretations could not be fully separated from her own personal experiences and cultural and social backgrounds.

For this study, I have adopted the subjectivist epistemology because it is aligned with how I perceive knowledge. The subjectivist epistemology considers that what constitutes knowledge depends on how people perceive and understand reality (Moon & Blackman, 2014). Objectivism is the opposite epistemology of subjectivism. Crotty (1998) defines objectivism as the belief that truth and meaning reside within an object and are independent of human subjectivity. Subjectivism considers the meaning to be imposed through the lens of the subject (Crotty, 1998). Also, the reality is viewed as pluralistic in the sense that it can be expressed using a range of symbols and language systems, and plastic in the sense that it can be shaped to fit individual needs (Moon & Blackman, 2014). Subjectivism aligns well with mixed methods research as it employs qualitative methods in addition to quantitative methods.

Theoretical Perspective

I utilized pragmatism as the theoretical perspective for this study. Because mixed methods include both quantitative and qualitative methods, there were concerns about the conflicting paradigmatic issues earlier (Hesse-Biber, 2015). Creswell and Creswell (2017) recommended using a pragmatic perspective in mixed methods research as "pragmatism opens the door to multiple methods, different worldviews, and different assumptions, as well as different forms of data collection and analysis" (Creswell & Creswell, 2017, p. 29).

The theoretical basis for pragmatism rests on the debate over how meaning and knowledge are perceived, and how meaning and knowledge can be passed from one individual to another. Based on the pragmatic worldview, the best methods are the ones that answer the research question, independent of the researcher's assumptions and values about the nature of the social world (Hesse-Biber, 2015). Pragmatism aligns well with mixed methods research because it offers a flexible view of what constitutes truth and provides the researcher with the freedom of choice (Creswell & Creswell, 2017). My pragmatic view is in alignment with the subjectivist epistemology for this study.

Methodology

Based upon my epistemological stance and theoretical framework, the chosen methodology to conduct this research was mixed methods. Since this study sought to explore the perceptions, experiences, and behaviors of middle school students towards using virtual reality technology as a learning tool in chemistry, a mixed methods design was the best methodology to investigate this phenomenon.

This study used a mixed methods research design, specifically a convergent (or parallel or concurrent) mixed methods design, in which both quantitative and qualitative data are simultaneously collected, data are merged, and results are used to understand the research problem and answer the research questions (Creswell, 2012). Mixed methods research design enables triangulation where the weaknesses of one data collection form are offset by the strengths of the other form (Creswell & Creswell, 2017). Although the procedures for mixed methods are considered time-consuming and require extensive data collection and analysis, the benefits of using a mixed method research design outweigh the drawbacks of time and resources in the context of this study. The combination of quantitative and qualitative methods provides a better understanding of the research problem and research questions than either method by itself (Creswell, 2012).

This study attempted to identify the initial perceptions and experiences of middle school students about using virtual reality as a learning tool in chemistry education, and further understand middle school students' behavior while conducting a chemistry exercise developed using virtual reality technology. Furthermore, the nature of this study was broadly exploratory, as the research related to using virtual reality technology as a tool in chemistry education is considered in its infancy.

Researcher Stance

As a researcher, it is necessary to identify and explain my own biases, dispositions, and assumptions regarding the research undertaken (Merriam, 2009). My education, previous research, and work experiences all contributed to shaping my perceptions and biases. I have earned a bachelor's degree and two master's degrees in computer science before pursuing my current doctorate degree in educational technology. I have worked in the information technology sector at different software development companies before becoming an instructor at various academic institutes in Jordan and the United States. I have taught courses that encourage pre-service teachers to integrate technology into their instruction and assessment. I have worked on projects that integrate technology into education and have used different technology tools in my instruction. I have practiced teaching in technology-integrated environments, and I have my own perceptions concerning the use of technology in education. I also own virtual reality equipment and applications that I have used frequently.

I am a technology enthusiast who supports the effective use of technology in education. I am curious about how students cope with the continuous, rapid changes in technology and the unprecedented availability of technology tools to them, and how they expect these changes to influence their learning in the future. To avoid influencing the objectivity of the study, I tried to distance myself from my own perceptions and experiences. I did not share my own views with the participants at any time while conducting the study. I provided opened-ended questions in the survey and avoided leading participants during the interviews. Additionally, I used personal reflections while collecting qualitative data through observations. Reflexivity means that "researchers reflect about their biases, values, and personal backgrounds, such as gender, history, culture, and socioeconomic status, and how this background shapes their interpretations formed during a study" (Creswell & Creswell, 2017, p. 270).

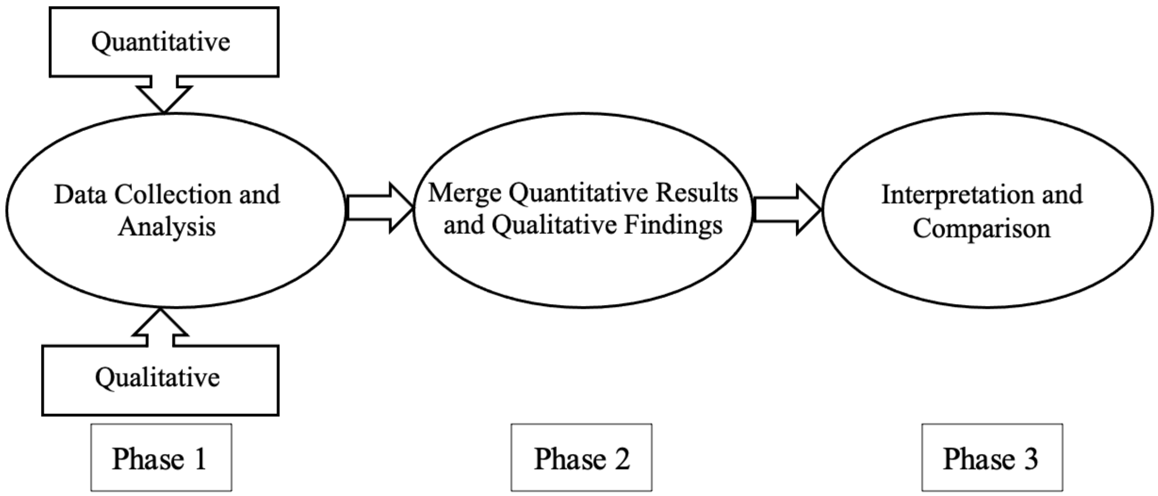
Mixed Methods Design

Methods are the specific techniques and procedures used in order to answer the research question (Crotty, 1998). To obtain an in-depth understanding of the perceptions and behaviors of middle school students in the context of this study, an exploratory mixed methods design that employed both quantitative and qualitative methods was used. In this study, quantitative methods were used to collect and analyze data pertaining to the research questions about students' perceptions, and differences in perceptions based on gender, while qualitative methods were used to collect and analyze data pertaining to research questions about students' perceptions, experiences, and behaviors. Data were integrated from both quantitative and qualitative methods to answer the research questions pertaining to students' perceptions.

The quantitative data for this study came from a Likert-scale student perception survey completed by student participants. In contrast, the qualitative data came from observations, interviews, and open-ended questions in the student perception survey. In this design, both quantitative and qualitative data were collected and analyzed separately and results were integrated during the discussion using a side-by-side approach (Creswell & Creswell, 2017; see Figure 1).

Figure 1

Convergent Mixed Methods Design



Participants and Setting

This study was conducted in the state of Colorado during the Fall semester of 2021. The participants of this study were chosen using convenient sampling and snowball sampling of middle school students in the state of Colorado, who completed either 7th or 8th grade during the school year of 2020-2021. A total of 62 students took part in this study, among them were 31 females and 31 males. There were 18 students in grade 7 and 44 students in grade 8 as middle school students are introduced to fundamental chemistry concepts in science classes in grade 7 and grade 8. The ages of student participants ranged from 12 to 15 years old, with 4 students aged 12, 23 students aged 13, 28 students aged 14, and 7 students aged 15.

Participation in the study was completely voluntary as participants were able to decide not to participate in this study or stop and withdraw at any time. Only students who provided a signed parental consent form and signed the minor assent form were considered for the study. Participants did not come from a vulnerable population.

The setting for this study was the state of Colorado. A space in a local public library was used as the place for participants to participate in the study. Transportation to and from the local library was provided to student participants who requested it. The researcher arranged with the local library to use a designated space that has a wireless internet connection in the library to conduct the study. The space was about 10 feet long and 6 feet wide and was cleared of any objects to create a safe environment for participants. The researcher had participants arrive at the public library at a scheduled time to participate in the study in order to have all participants participate in the study in the same environment. The researcher led the participants to the designated space, where all data collection took place. A parent or a guardian was allowed to be present with the participant but without communicating with the participant while participating in the study.

Sampling Method

The sampling approach that was followed in this study was non-probabilistic sampling (Kumar, 2011) because some students were not attending face-to-face classes due to the COVID-19 pandemic that started in early 2020. It caused difficulty in accessing students in their regular classroom settings. Specifically, the researcher decided to use convenience sampling since she had access to middle school students in her community.

The researcher contacted students known to her or known to other friends, to elicit students who fit the participation criteria defined above. The potential participants were invited to schedule a time to conduct the study. Sixty individuals were needed initially to participate in this study, divided into 30 males and 30 females. This number was met through snowball sampling as convenience sampling was not sufficient, and 62 participants, divided into 31 females and 31 males took part in this study. When additional participants were needed, a

Facebook post requesting participants who meet participation criteria was created and shared. It was my intention that participants encompassed different ethnicities and economic status levels that exist in the population of middle schools to constitute a representative sample of the whole middle school student population. Furthermore, to have a better representative sample of the population of middle school students, the study was comprised of 50% females and 50% males. The United States Census Bureau reported that in 2019, a total of 8,502,751 male students and a total of 8,092,035 female students were enrolled in schools in grades 5 through 8, which is about 50% in each group.

Materials

A chemistry exercise delivered using VR technology was provided to the participants. The chemistry exercise was part of a virtual reality educational application for chemistry called "Molecule Builder" developed and published by Xennial Digital and through the Oculus Quest App store (see Figure 2). Molecular Builder application provides a fully immersive virtual reality experience, where the user is immersed inside a computer-generated world that replaces the real world. The Molecule Builder application has three primary levels.

Figure 2

Molecule Builder Application

The first level focused on understanding atoms and molecules (see Figure 3). Users could create links between atoms to form 3-D molecules and check the correctness of their creations. The second level focused on the geometry of molecules. Users could predict a molecule's geometry by applying the Valence Shell Electron Pair Repulsion (VSEPR) model. The third level focused on the polarity of molecules. Users could determine the polarity of the intermolecular bonds and the overall polarity of the molecule and can calculate the force of the vector between each atom as well (Xennial Digital, 2021).

Figure 3

Molecule Selection

The chemistry exercise in this study belonged to the first level of the application, during which students built molecules and checked their correctness. Participants accessed the exercise using the Oculus Quest 2 head-mounted display and controllers that were provided by the researcher (see Figure 4). The head-mounted display and controllers were cleaned and sanitized before and after each use and were stored in a case to stay clean.

Figure 4

Oculus Quest 2 Head-Mounted Display and Controllers

Data Sources

This study employed multiple instruments to gather data from different angles and to be able to answer the research questions in the best way possible, namely a demographic survey, observations, interviews, and a student perception survey. A detailed description of each data source used in this study is provided in the following sections.

Demographic Survey

The demographic survey (see Appendix A) was used to collect demographic information about participants through four multiple-choice questions: age, grade, gender, and VR experience. Age had four categories: 12, 13, 14, and 15 because some students might be ahead or behind grade level compared to their age group. The grade had two categories: 7th and 8th. The sixth-grade category was not included because sixth-grade students may not study chemistry concepts yet. Gender had three categories: Female, Male, and Other. VR experience asked participants, “How much virtual reality experience do you have?” with five categories to choose from: never used it, fundamental (common knowledge only), novice (can use it with help), intermediate (can use it independently), and expert.

Observations

For the observations, the researcher watched each participant right before, during, and right after conducting the exercise to observe and take notes of their behavior, reactions, emotions, and body language. The observation protocol (see Appendix B) was designed by the researcher and was used to record the time of observation, date, place, participant’s name, followed by the researcher’s observations of each participant.

The observations of participants were organized into three categories: (a) emotion, (b) behavior, and (c) other across three periods of conducting the chemistry exercise: (a) before, (b) during, and (c) after. The protocol also contained a category to record comments by me as a researcher about my own biases and interpretations as a form of self-reflection. The observation protocol recorded each participant’s pseudonym for the purposes of identifying individual participants to group the data from interviews and student perception surveys. Pseudonym assignment took place when participants filled out the demographic survey.

Interviews

The interviews were conducted right after participants completed conducting the chemistry exercise to capture their immediate feedback about their experience of conducting the exercise. The researcher asked participants questions that addressed their views on their VR experience. The structured interview consisted of five open-ended questions written before the interview. The interview began with the first question that reads, “Describe your experience of using VR in the chemistry exercise”. The second question, “What models have you used before inside or outside the classroom to build molecules?", aimed at gaining information about participant's past experiences in building molecules to prepare for the next question that reads, "How is your experience of building molecules in 3-D using VR is different from previous experiences of building molecules?". The fourth question reads, "Based on your experience in conducting the exercise, how do you feel about using VR as a tool to learn chemistry?". The last question "Why do you feel that way?" looked for the reasoning behind the participant's answer to the previous question.

The wording of the open-ended questions was carefully designed to allow flexibility and avoid guiding the participants in certain directions. An audio recording was used to keep a record of the interview. The interview protocol (see Appendix C) was designed by the researcher. The interview protocol recorded each participant's pseudonym for the purposes of identifying individual participants to group the data from interviews and student perception surveys.

Student Perception Survey

The student perception survey (see Appendix D) was used to rate and gather participants' opinions about their encounter with the VR technology in the chemistry exercise, as well as their behaviors associated with conducting the exercise. The survey had two sets of questions, Likert-scale questions, and open-ended questions. The Likert-scale questions were adapted from four validated questionnaires conducted by Huang and Liaw (2018), Huang et al. (2010), and Huang et al. (2016). Two of the validated questionnaires belonged to one study with two case studies conducted within it (Huang et al., 2010).

Based on existing research, the most common factors that are of interest when investigating perceptions and behaviors of users towards virtual reality are the ease of use, interaction, imagination, immersion, motivation, intention to use, collaborative learning, and problem-solving capability (Huang & Liaw, 2018; Huang et al., 2010, 2016; Shin, 2017). Collaborative learning was not applicable in the context of this study because the Molecule Builder application used for the chemistry exercise was the single-user version, which meant that one user can use the application at a time. Also, the exercise was not intended nor designed to evaluate the problem-solving skills of the participants. Therefore, the problem-solving capability was not applicable in the context of this study as well. The remaining six factors that were considered in this study were (a) ease of use, (b) interaction, (c) imagination, (d) immersion, (e) motivation, and (f) intention to use. Questions under each factor were modified and added to address the perceptions and behaviors of students for the given chemistry exercise using the Molecule Builder application.

The student perception survey instrument had three main sections: (a) Perceptions, (b) Reflections, and (c) Behaviors. Section A: Perception contained Likert-scale questions and was designated to rate students' views on the ease of use (6 questions), interaction (3 questions), imagination (3 questions), immersion (3 questions), motivation (4 questions), and intention to use (5 questions) factors. This section contained 24 questions and used a 5-point Likert-scale ranging from 1 (strongly disagree) through 5 (strongly agree), with 5 being the highest score and 1 being the lowest score.

The questions in both sections B: Reflections and C: Behaviors were open-ended, to gain a deeper understanding of the students' reflections on their perceptions and behaviors towards the use of VR technology in chemistry education, thereby providing more information to the policymakers and the administrators from the conclusion of the study. The open-ended questions in sections B and C were designed by the researcher. Section B: Reflections had five open-ended questions that aimed at gaining an in-depth understanding of the students' perceptions by allowing students to expand on their views in their own words. The questions were “What did you like most about conducting the chemistry exercise through the virtual reality application?”, “What did you like least about conducting the chemistry exercise through the virtual reality application?”, “What was the most helpful thing about building molecules using the virtual reality application?”, “What was the least helpful thing about building molecules using the virtual reality application?”, and “If you were a teacher, what suggestions would you make about using virtual reality applications for teaching chemistry?”.

The student perception survey was concluded by Section C: Behaviors, which had three open-ended questions that aimed at gaining additional insight into how students behave before, during, and after the exercise, and complement the data from the observations. The questions were “Describe how you felt, emotionally and physically, right before your VR experience.”, “Describe how you felt, emotionally and physically, during your VR experience.”, and “Describe how you felt, emotionally and physically, right after your VR experience”.

Procedures

Permissions to Collect Data

Prior to collecting any data, approval for my research proposal was acquired from my research committee and the University of Northern Colorado’s Institutional Review Board (IRB). Following IRB approval (see Appendix H), I proceeded to recruit participants. A parental consent form was provided to potential participants either in digital format or printed on paper. Only participants who provided the consent of a parent or a guardian were included in the study. Also, participants were required to sign a minor assent form prior to participating in the study.

Data Collection

Since this was a convergent mixed methods study, the collection of quantitative and qualitative data occurred in one phase. The study began with the quantitative method of the demographic survey to collect demographic data, followed by the qualitative method of observations to collect observational data, then another qualitative method to collect experiences data based on first impressions through interviews, and was concluded by a student perception survey that employed both quantitative and qualitative methods to collect data pertaining to perceptions using Likert-scale questions and open-ended questions and behaviors using open-ended questions. Figure 5 shows the convergent mixed methods design used for this study. The procedure of data collection is described in the following in chronological order.

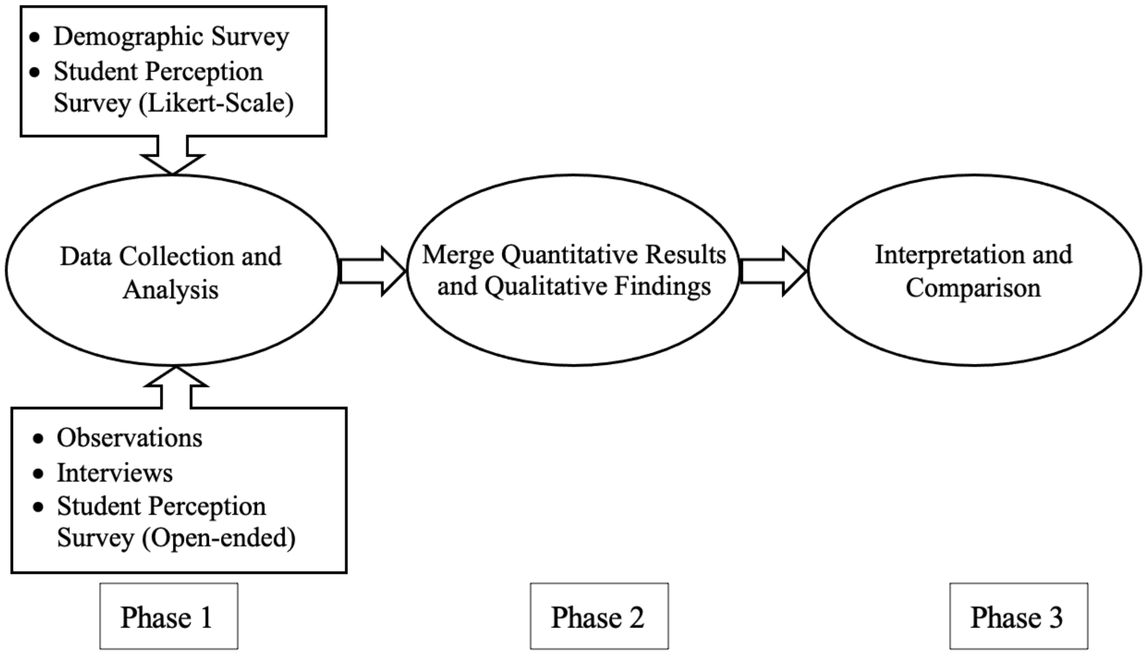
Recruited participants were invited to schedule a time to conduct the study, and transportation to the local public library was offered to participants who requested it. Once a participant arrived at the public library, she/he was led to the designated space and was asked to provide the signed parental consent form and sign a minor assent form. A briefing about the study was provided to the participant for about 5 minutes, after which the participant was asked to fill out a demographic form (see Appendix A) provided on a tablet. Each participant was assigned a pseudonym that was used for participant identification during data collection and in the written report. The researcher typed in the assigned pseudonym for the participant at the top of the demographic survey.

Once the participant completed the demographic survey, the researcher prepared the VR equipment and application for the participant to use. The head-mounted display and controllers were cleaned and sanitized. The researcher began observing the participant at this point by taking notes and writing comments following the observation protocol (see Appendix B). The researcher handed the head-mounted display and the controllers to the participant to put on and helped adjust the head-mounted display to the participant's head when needed. A self-paced tutorial that lasted for 5 minutes was presented to the participant as training on the virtual reality equipment and application. The tutorial walked users through the process of building a simple molecule and testing its correctness.

Once the participant completed the tutorial, she/he was asked to use the VR tool to conduct the chemistry exercise while standing, unless she/he requested to be seated. A revolving office chair was available for participants who request to be seated but wasn't used since all 62 participants conducted the exercise standing up. The researcher continued observing the participant by taking notes about the participant's behavior while using the VR to conduct the chemistry exercise that lasted about 10 minutes. Once the participant completed the exercise, she/he was asked to take off the head-mounted set and the controllers, and hand it to the researcher. At this point, the researcher completed her observation of the participant by taking notes about the participant's behavior after using the VR to conduct the chemistry exercise, then sat with the participant for the interview (see Appendix C). The interview lasted about 5 minutes and included five open-ended questions from the interview protocol. The interview was recorded using audio software already set up and working on the researcher's smartphone.

Figure 5

Convergent Mixed Methods Design for This Study



After completing the interview, the participant was presented with the student perception survey (see Appendix D) on a tablet. The survey contained 24 Likert-scale questions and a total of 8 open-ended questions and was completed in one 25-minute session. After completing the student perception survey, the participant's role was complete, and the researcher thanked the participant for their role in the study. The researcher exchanged contact information with the participant who was interested in receiving a copy of the study's findings.

To ensure confidentiality, all data obtained from conducting this study was confidential and was retained by the researcher. Participants were assigned generic, unique identifications for referencing and grouping of data. Observations, interviews, and surveys data were saved in files. All collected data were kept in locked files on the researcher's secure password-protected laptop.

The researcher stored the consent forms and the data. Consent forms and data will be stored for three years, after which time they will be destroyed.

Data Analysis

Since this study followed a mixed methods research design, both qualitative and quantitative data analyses were used. According to Creswell and Creswell (2017), data analysis in a convergent mixed methods design consists of three phases:

> First, analyze the qualitative database by coding the data and collapsing the codes into broad themes. Second, analyze the quantitative database in terms of statistical results. Third, comes the mixed methods data analysis. This is the analysis that consists of integrating the two databases. This integration consists of merging the results from both the qualitative and the qualitative findings. (p. 241)

This study had four types of data: demographic data, observational data, interview data, and survey data. In the following, the analysis of each type is discussed.

Quantitative Data Analysis

Quantitative data were collected using the demographic survey and the Likert-scale questions from Section A: Perceptions in the student perception survey. The researcher used descriptive indicators to present demographic information from the demographic survey. There were 24 Likert-scale questions in Section A: Perceptions in the student perception survey, divided into six categories (see Appendix D). After completing the surveys, the researcher analyzed the responses of the participants. The researcher conducted a precise survey data analysis, which enabled her to interpret the results accurately. The researcher ensured that all survey items were coded correctly using built-in codes in the Qualtrics survey. Next, the researcher completed the data validation step that confirmed that the survey questionnaires were completed and represented consistent data. To handle the missing data, missing listwise was used where SPSS first eliminated all observations that had one or more missing values across all variables that were specified for the analysis procedure.

To answer the first research question, quantitative and qualitative methods were utilized, and data were consolidated from the students' responses to the 24 Likert-scale items in Section A: Perceptions in the student perception survey with the data from the responses to the open-ended questions from Section B: Reflections in the student perception survey. Students' responses to the 24 Likert-scale items in the student perception survey were aggregated and averaged, and thematic analysis was performed on the data from the responses to the open-ended questions from Section B: Reflections in the student perception survey.

Students' responses to items 1-6 were aggregated and averaged to obtain a score for the Ease of Use factor. Students' responses to items 7-9 were aggregated and averaged to obtain a score for the Interaction factor. Students' responses to items 10-12 were aggregated and averaged to obtain a score for the Imagination factor. Students' responses to items 13-15 were aggregated and averaged to obtain a score for the Immersion factor. Students' responses to items 16-19 were aggregated and averaged to obtain a score for the Motivation factor. Finally, students' responses to items 20-24 were aggregated and averaged to obtain a score for the Intention to Use factor. SPSS software was used to analyze the data. Descriptive statistics, including means and standard deviations, were calculated.

To answer the second research question, quantitative and qualitative methods were utilized, and data were consolidated from the Likert-scale questions in Section A: Perceptions in the student perception survey, with responses to open-ended questions in Section B: Reflections in the student perception survey, and with the demographic data from the demographic survey.

Quantitively, a one-way MANOVA was used to compare the perceptions of females to the perceptions of males based on the six factors of perceptions in the student perception survey grouped by gender from demographic data. The perceptions on using virtual reality as a learning tool in chemistry education based on the total value of all factors and individual survey items for females were compared to those of males and results were summarized and shared.

Qualitative Data Analysis

Data analysis in qualitative research is the process of making meaning out of the data through consolidation, reduction, and interpretation of what the researcher has collected (Merriam & Tisdell, 2016). To further answer the first research question, thematic analysis was performed on the data from students' responses to open-ended questions in Section B: Reflections in the student perception survey. The first step was to explore the data by reading through it to obtain a general sense of the data. The next step was to code the data by segmenting and labeling text to create themes in the data. To answer the second research question based on the qualitative data collected through the students' responses to open-ended questions in Section B: Reflections in the student perception survey, themes identified through the thematic analysis were grouped based on gender.

To answer the third research question, thematic analysis was performed on the data from the interviews. After each interview, participants' responses were transcribed, and data were typed into a computer file to be analyzed by hand. The first step was to explore the data by reading through it to obtain a general sense of the data. The next step was to code the data by segmenting and labeling text to create themes in the data. Coding is the process of assigning shorthand designations to different aspects of the data to facilitate retrieval (Merriam & Tisdell, 2016). Designations are symbols, which can be single words, letters, numbers, colors, etc. From the generated codes, categories were constructed. Categories are more prominent conceptual themes that capture some recurring pattern (Merriam & Tisdell, 2016).

In this study, behavior was concerned with participants' emotions, body language, and any apparent reactions as they conducted the chemistry exercise. Emotions associated with the use of virtual reality technology can be positive such as interest, amusement, elatedness, and surprise, or can be negative such as sadness, anger, fear, anxiety, and contempt (Allcoat & von Mühlenen, 2018). Balance, posture, and confidence are examples of the body language of interest. To answer the fourth research question, notes from the observations were consolidated with the responses to the open-ended questions from section C: Behaviors in the student perception survey. The consolidated data were analyzed by hand in a similar manner to the analysis of data from the interviews described above. Additionally, data were grouped and compared based on the time period specified during collection as (a) before, (b) during, and (c) after conducting the exercise.

Data Sources and Analysis by Research Question

Table 1 shows how the data sources and data analysis were aligned to answer each of the research questions. Research questions one and two were answered using quantitative and qualitative methods. Research questions three and four were answered using qualitative methods only.

Table 1

Data Sources and Analysis by Research Question

Research Question		Data Source	Analysis
Q1	What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?	Likert-scale questions (Student perception survey – Section A: Perceptions)	Descriptive statistics
		Open-ended questions (Student perception survey – Section B: Reflections)	Thematic analysis
Q2	Are there any differences between female and male middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?	Likert-scale questions (Student perception survey – Section A: Perceptions)	One-Way MANOVA
		Open-ended questions (Student perception survey – Section B: Reflections)	Thematic analysis
		Demographic survey	Descriptive indicators
Q3	How do middle school students describe their experience during the chemistry exercise using the VR tool?	Interviews	Thematic analysis
Q4	How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?	Observations	Thematic analysis
		Open-ended questions (Student perception survey - Section C: Behaviors)	Thematic analysis

Trustworthiness and Validity

Research studies are expected to produce valid and reliable knowledge and trustworthy findings in an ethical manner (Merriam & Tisdell, 2016). The validity of a mixed methods study is dependent on the validity of its quantitative and qualitative components, as well as the integration of both components (Creswell & Creswell, 2017). To establish validity for the qualitative components, trustworthiness was discussed. To establish validity for the quantitative components, quantitative validity was discussed. Potential threats to validity associated with using a convergent mixed methods approach include unequal sample sizes and the use of different concepts, which can lead to divergent results (Creswell & Creswell, 2017). In this study, both quantitative and qualitative components used an equal sample size and similar concepts.

Qualitative Components

To define and assess trustworthiness, the concepts of credibility, transferability, dependability, and confirmability are used in qualitative research (Merriam & Tisdell, 2016). Different strategies can be used to enhance the trustworthiness of a study, including but not limited to triangulation, member checks, peer reviews, adequate engagement in data collection, reflexivity, audit trail, rich descriptions, and maximum variation (Merriam & Tisdell, 2016).

Different strategies were used in this study to establish the various facets of trustworthiness. Credibility stands for the internal validity of the study, and it is concerned with the extent to which the research findings are congruent with reality (Cope, 2014; Merriam & Tisdell, 2016). To establish credibility, I used member checks and peer reviews. Member checks, also known as respondent validation, involved going back to participants and asking them to verify the findings. Peer reviews involved having discussions and getting feedback from colleagues, who have experience in conducting qualitative research, about the process of the study and the congruence of the findings (Merriam & Tisdell, 2016). I got feedback from my committee members and one colleague who has been conducting mixed methods research for several years.

Transferability, also known as external validity, is concerned with the extent to which the findings of the study can be generalized (Cope, 2014; Merriam & Tisdell, 2016). To establish transferability, I used rich or thick descriptions, and full descriptions of context when I generated the themes during the analysis of observation notes and the transcriptions of the interviews. Thick descriptions refer to providing a detailed description of the study so that others can understand the study's context to determine if the findings are transferable (Merriam & Tisdell, 2016).

Dependability, also known as reliability, is concerned with the extent to which the findings of the study can be replicated if the study is to be repeated (Cope, 2014; Merriam & Tisdell, 2016). This is a challenging concept in qualitative methods because human behavior is subject to change. To establish dependability, I used triangulation by collecting data from surveys, interviews, and observations. Triangulation refers to using multiple sources of data or data collection methods to confirm the findings (Merriam & Tisdell, 2016).

Confirmability is concerned with the extent to which the data are shaped by the participants' responses and not the researcher's views or biases (Cope, 2014). To establish confirmability, I used reflexivity, where I recorded notes and thoughts about the process of conducting this study. Reflexivity refers to the researcher's awareness of how the research process can be affected by the researcher's own values, background, and past experiences (Cope, 2014).

Quantitative Components

In order to establish the validity of the student perception survey, the Likert-scale questions were adapted from four validated questionnaires in studies conducted by Huang and Liaw (2018), Huang et al. (2016), and Huang et al. (2010). Validity and reliability measurement has been performed for each one of the referenced questionnaires. To ensure the validity of the first questionnaire used in the study by Huang et al. (2010), a content validity study that involved soliciting feedback from three experts and evaluating the content validity index was conducted.

A similar content validity study was conducted for the second questionnaire used by Huang et al. (2010), but in addition to the experts' feedback, a pre-test that solicited feedback from students about the constructs in the questionnaire and resulted in revising the questionnaire was conducted (Huang et al., 2010). The questionnaire used in the study conducted by Huang et al. (2016) was reviewed by three subject matter experts and a pre-test was conducted to ensure its validity.

The internal consistency reliability was assessed by computing Cronbach's alpha for each item in the questionnaire, as well as the overall alpha of the questionnaire with a value of 0.96, indicating a high degree of reliability (Huang et al., 2016). The questionnaire in the study conducted by Huang and Liaw (2018) was validated using feedback from three experts and a pre-test that solicited feedback from students about the constructs in the questionnaire (Huang & Liaw, 2018). The researcher made changes to the initial student perception survey adapted from previous research. These changes were validated based on peer-review recommendations, including feedback from the research advisor and a colleague.

Summary

In this chapter, I presented the research methodology for my study in detail. I described my subjectivist epistemological view and my pragmatic theoretical framework. My researcher stance was discussed, as well as the mixed methods research design for the study. My procedures for data collection and analysis were presented, followed by a discussion of the different strategies that were used to establish the trustworthiness and validity of this study. The next chapter presents the results and findings from this study.

CHAPTER IV

RESULTS AND FINDINGS

This study represented an exploratory mixed methods design utilized to explore the perceptions, experiences, and behaviors of middle school students in the state of Colorado towards the use of virtual reality technology in chemistry education. This study was shaped using an epistemology of subjectivism as described by Crotty (1998) and based on a theoretical framework of pragmatism as described by Creswell and Creswell (2017). The study incorporates data from four sources: (a) a demographic survey, (b) observations, (c) interviews, and (d) a student perception survey.

The quantitative portion of the study utilized a demographic survey that was developed by the researcher and a 24-item 5-point Likert-scale student perception survey that was developed based on four previously validated questionnaires conducted by Huang and Liaw (2018), Huang et al. (2010), and Huang et al. (2016). The six factors of interest when investigating perceptions and behaviors of users towards using virtual reality that are considered in this study are (a) ease of use, (b) interaction, (c) imagination, (d) immersion, (e) motivation, and (f) intention to use. Over the course of four months of data collection, the demographic survey was completed by 62 student participants, and the student perception survey was completed fully by 60 participants, and partially by two participants. I conducted observations and interviews of all 62 participants within the period of the data collection.

The data for the quantitative portion of this study were analyzed using descriptive statistics to determine central tendencies, frequency distributions, and standard deviations.

Additionally, a one-way multivariate analysis of variance (MANOVA) was used to compare the perceptions of females to the perceptions of males based on the six categories of perceptions in the student perception survey grouped by gender from demographic data. The assumptions for the MANOVA were tested and results were reported. A Cronbach's alpha was also calculated to ensure the reliability of the student perception survey.

The qualitative portion of the study utilized observations of participants, interviews, and open-ended questions in sections B and C in the student perception survey. The open-ended questions in sections B and C were designed by the researcher. Section B: Reflections has five open-ended questions that aim at gaining an in-depth understanding of the students' perceptions by allowing students to expand on their views in their own words. Section C: Behaviors has three open-ended questions that aim at gaining additional insight into how students behave before, during, and after the VR exercise, and complement the data from the observations.

The qualitative portion of the study was analyzed using thematic analysis within a pragmatic framework as described by Nowell et al. (2017). After preparing and organizing the data, the researcher made herself familiar with the data by reading through it repeatedly and making notes about meaning and patterns. Then, data were coded, categorized, and grouped into themes (Lester et al., 2020).

In the following sections, I present the results of the quantitative data that emerged through the statistical analysis of survey responses and the findings of the qualitative data yielded from the thematic analysis of my observations of participants, interviews, and participant responses to the open-ended questions in the student perception survey. The results and findings are presented in an organized manner as they pertain to each of the research questions. The quantitative results are supported by a set of tables, and the qualitative findings are supported through rich descriptions, participant quotes, and tables that help clarify the substantial quantity of data yielded from the study as recommended by Creswell and Creswell (2017).

Research Question One

The first research question asked:

Q1 What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Two data sources were used to answer this research question. The first data source was obtained from the statistical analysis of participants' responses to the questions in section A in the student perception survey, which was completed fully by 60 participants and partially by two participants. Section A: Perception contains Likert-scale questions and is designated to rate students' views on the ease of use (six questions), interaction (three questions), imagination (three questions), immersion (three questions), motivation (four questions), and intention to use (five questions). This section contains 24 questions and uses a 5-point Likert-scale ranging from 1 (*strongly disagree*) through 5 (*strongly agree*), with 5 being the highest score and 1 being the lowest score.

The second data source was obtained from the analysis of the responses to Section B in the student perception survey, which was completed by all 62 participants. Section B: Reflections has five open-ended questions that aim at gaining an in-depth understanding of the students' perceptions by allowing students to expand on their views in their own words. In the following section, I present the results compiled from the analysis of both data sources described above.

Quantitative Data

Participants completed the student perception survey right after using the VR tool to conduct the molecule-building exercise. The average time to complete the student perception survey was about 24 minutes. To allow for statistical analysis, a numeric coding system was embedded in the survey design for the Likert-scale items with 1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, and 5=strongly agree.

The student perception survey was completed by 60 participants who responded to all 24 items. One additional participant missed responding to three items that corresponded to the factor of interaction, while another additional participant missed responding to three items that corresponded to the factor of motivation. The records for the two participants who had missing data values were not discarded completely since the amount of missing data were less than 5% of the collected data from all participants (Dong & Peng, 2013; Little et al., 2014).

To handle the missing data, missing listwise was used where SPSS first eliminated all observations that had one or more missing values across all variables that were specified for the analysis procedure. In other words, cases were dropped from the analysis because they had a missing value in at least one of the specified variables. The analysis ran only on cases that had a complete set of data.

Responses from the Likert-scale survey items were then assessed using descriptive statistics for each individual participant and for the collective group of participants as well. Higher numeric values for responses and means represented more positive perceptions toward using VR as a learning tool. Survey responses were analyzed based on the six factors of perceptions: (a) ease of use, (b) interaction, (c) imagination, (d) immersion, (e) motivation, and (f) intention to use. For each of the six factors, I determined a frequency distribution, central tendencies, and standard deviation.

The Cronbach's alpha for the student perception survey was .89, indicating good reliability. Individually, the reliability was acceptable for ease of use (six items, N=62, α = .77), interaction (three items, N=61, α = .73), motivation (four items, N=61, α = .79), and intention to use (five items, N=62, α = .69). For imagination, the reliability was higher, which is considered meritorious (three items, N=62, α = .82). Finally, the reliability for immersion was the lowest, but it is still in the satisfactory range (three items, N=62, α = .57; Taber, 2018). Because listwise was used to handle missing data, both interaction and motivation had a sample size of 61 instead of 62.

Results by Overall and Six Factors

The overall mean of student participant response to perceptions was 4.58, indicating that student participants, overall, had very positive perceptions of VR as a learning tool. The overall standard deviation for the survey is 0.64, which shows a small variation in the data collected (see Table 2). On average, all six factors received positive responses (M>=4.37), with means ranging from 4.37 to 4.71.

The two factors with the highest reported means were the intention to use (M=4.71, SD=0.58) and the motivation (M=4.69, SD=0.58) factors. Followed by the imagination (M=4.63, SD=0.66) and the immersion (M=4.61, SD=0.60) factors. The two factors with the lowest reported means were the interaction (M=4.37, SD=0.76) and the ease of use (M=4.47, SD=0.64) factors.

Table 2

Descriptive Statistics of the Six Factors of Perceptions

Factor	*M*	*SD*	Rank
1. Ease of use	4.47	0.64	5
2. Interaction	4.37	0.76	6
3. Imagination	4.63	0.66	3
4. Immersion	4.61	0.60	4
5. Motivation	4.69	0.58	2
6. Intention to use	4.71	0.58	1
Overall	4.58	0.64	

Findings by Individual Means

In the student perception survey, all 24 survey items scored positive means (*M*>=4.20) (see Appendix E). The five items with the highest mean scores were:" I paid more attention when using 3-D molecules" (survey item 14, *M*=4.87, *SD*=0.38), "Overall, I think that the Molecule Builder application is worth being a good learning tool" (survey item 24, *M*=4.77, *SD*=0.46), "I am willing to use virtual reality for learning in the future" (survey item 21, *M*=4.76, *SD*=0.62), "I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry" (survey item 22, *M*=4.76, *SD*=0.50), and "The Molecule Builder application can enhance my learning interest" (survey item 17, *M*=4.74, *SD*=0.58; see Table 2).

Of the five items with the highest mean, three items (survey items 21, 22, and 24) were from the intention to use factor, while one item (survey item 14) was from the immersion factor, and another item (survey item 17) was from the motivation factor.

In contrast, the five items with the lowest mean scores were “Using the Molecule Builder application, I was able to rotate 3-D molecules easily” (survey item 9, *M*=4.20, *SD*=0.89), “Learning how to use the Molecules Builder application was easy” (survey item 2, *M*=4.32, *SD*=0.70), “The Molecule Builder application created a realistic-looking learning environment” (survey item 13, *M*=4.32, *SD*=0.72), “Using the Molecule Builder application, I was able to move 3-D molecules easily” (survey item 8, *M*=4.39, *SD*=0.76), and “I was able to accomplish the exercise using the Molecules Builder application easily” (survey item 3, *M*=4.44, *SD*=0.67).

Although these items had the five lowest mean, they all had mean scores greater or equal to 4.20. Among the five items with the lowest mean, two items (survey items 2 and 3) were from the ease of use factor, two items (survey items 8 and 9) were from the interaction factor, and one item (survey item 13) was from the immersion factor. Table 3 shows the five highest and lowest item means of student perceptions.

Table 3

Five Highest and Lowest Item Means of Student Perceptions

	Survey Items	*M*	*SD*	Factor
Five Highest Means				
14.	I paid more attention when using 3-D molecules.	4.87	0.38	Immersion
24.	Overall, I think that the Molecule Builder application is worth being a good learning tool.	4.77	0.46	Intention to Use
21.	I am willing to use virtual reality for learning in the future.	4.76	0.62	Intention to Use
22.	I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry.	4.76	0.50	Intention to Use
17.	The Molecule Builder application can enhance my learning interest.	4.74	0.58	Motivation
Five Lowest Means				
9.	Using the Molecule Builder application, I was able to rotate 3-D molecules easily.	4.20	0.89	Interaction
2.	Learning how to use the Molecules Builder application was easy.	4.32	0.70	Ease of Use
13.	The Molecule Builder application created a realistic-looking learning environment.	4.32	0.72	Immersion
8.	Using the Molecule Builder application, I was able to move 3-D molecules easily.	4.39	0.76	Interaction
3.	I was able to accomplish the exercise using the Molecules Builder application easily.	4.44	0.67	Ease of Use

Qualitative Data

The qualitative data to answer research question one was derived from the student participant responses to the five open-ended questions in Section B: Reflections in the student perceptions survey. These five questions were worded to identify what the students thought were the advantages of using VR as a tool to learn chemistry ("What did you like most about conducting the chemistry exercise through the virtual reality application?" and "What was the most helpful thing about building molecules using the virtual reality application?"), the disadvantages of using VR as a tool to learn chemistry ("What did you like least about conducting the chemistry exercise through the virtual reality application?" and "What was the least helpful thing about building molecules using the virtual reality application?"), and suggestions they would make if they were a teacher ("If you were a teacher, what suggestions would you make about using virtual reality applications for teaching chemistry?"). After reading through the data multiple times, codes and sub-themes were created for each theme.

The discussion of the findings and the identified themes for the open-ended questions are presented by theme and include details of the findings supported by direct quotes from the participants. Peer reviews were utilized to validate the congruence of the thematic analysis process and outcome by discussing and getting feedback from a colleague who has experience in conducting qualitative research and getting feedback from my research advisor. Accordingly, I revised the process of thematic analysis and improved the identification of sub-themes and the reporting of findings.

The three major themes identified during the thematic analysis of student participant responses to the open-ended questions were: (a) advantages of VR as a tool to learn chemistry, (b) disadvantages of using VR as a tool to learn chemistry, and (c) suggestions about using virtual reality applications for teaching chemistry. The findings from the open-ended questions in Section B: Reflections in the student perception survey are presented in the following sections by the three themes.

Theme 1: Advantages of Using Virtual Reality as a Tool to Learn Chemistry

Participants' responses to what they liked the most about conducting the chemistry exercise through the virtual reality application, and what was the most helpful thing about building molecules using the virtual reality application were used to discover the advantages of VR as a tool to learn chemistry. The three sub-themes that emerged from Theme1 were: (a) provides 3-D visualizations, (b) supports interactive and hands-on learning, and (c) enhances student focus and attention. The three emergent sub-themes from Theme 1 are presented in the following sections.

Sub-Theme 1: Provide Three-Dimensional Visualizations. Twenty participants (32%) were passionate about sharing their thoughts about how VR provides three-dimensional (3-D) visualizations of concepts and objects, and how that impacts their learning positively. For example, participant "PA09" first compared 3-D models of molecules in VR to those in none 3-D models on computers to emphasize the significance of VR's provision of 3-D visualizations, saying: "I really liked how interactive and realistic it was. Being able to move around parts of a molecule and look at it in 3-D was way more fun than just doing it on a computer, and it made me want to learn more about molecules" (PA09).

Then, PA09 proceeded to compare 3-D models of molecules in VR to drawings on paper, describing how VR made the molecules look realistic:

> It was quite helpful visualizing a molecule in 3-D and seeing how it would actually look in the real world. On a piece of paper, it feels like just an idea and not really something in real life, but when it's interactive and realistic. The whole learning experience is heightened and way more engaging.

To point out how 3-D visualizations made it easier to understand the structure of molecules, participant "PA50" wrote: "I enjoyed the interaction in using the 3-D method of learning. I felt that it was easier to understand the structure of molecules through this method of learning." Three-dimensional visualizations also led participant "PA06" to feel immersed in the virtual world: “I really enjoyed how I got to almost touch the molecules themselves and see them in 3D form. I loved how I really felt immersed in the VR, and how I got to choose which molecules I would work on and perfect.”

Likewise, participant “PA34” highlighted the benefit of 3-D models in helping students who struggle to pay attention or imagine invisible elements to understand chemistry concepts. He pointed out that 3-D visualizations accelerate learning. PA34 wrote in his response:

> The 3-D emergence of the construction was super helpful to learners who have trouble paying attention or learners who have trouble visualizing what the atoms look like on a full scale. It made it very easy to see and understand a molecule's composition without using an entire class period to visualize [it].

Sub-Theme 2: Support Interactive Learning. Seventeen participants (27%) recognized the value of interactive and hands-on learning and pointed out how VR supports such forms of learning. For example, participant “PA08” shared his admiration for the interactive experience he encountered. He connected interactivity to making him feel motivated to learn and increased his interest in the topic: “I admired the fact that it was really interactive, and that an action was required for everything. It made me willing to learn about the molecules and built my interest for learning the material.”

Another participant, “PA32”, appreciated VR’s support of interactive learning: “The most helpful thing was being able to interact with the objects and seeing how they work; it was also super cool to see the electrons and the molecules and how they interact and work together.” An insightful view was shared by participant “PA38”, who detailed how VR’s provision of interaction improves engagement and helps students focus, specifically when learning chemistry: “I like that I was able to interact with everything, staying engaged the entire time. Chemistry can sometimes get a little boring, but when you are actually working with everything and surrounded entirely, I wasn't distracted by anything else."

Participant "PA07" was one of two participants who tied interactive and hands-on learning to improved learning outcomes through retention of information: "Unlike other simulations on -say- a laptop, VR felt way more immersive and hands on, which lends itself well to actually retaining information and just having fun learning "The second participant was "PA46" who attributed a better recollection of what had been learned to his hands-on experience as he wrote: "I really liked that I could actually move the molecules and have a general hands-on experience. I could actually envision putting the molecules together, and that definitely makes it easier to remember."

Sub-Theme 3: Enhance Student Attention. Fifteen participants (24%) reported that VR enhanced their focus and helped them maintain their attention due to the features of VR. Participant "PA01" shared that what he liked the most about conducting the chemistry exercise through the virtual reality application was that he felt "like there was more objective rather than an assignment. Also, it was much more attention keeping." Briefly, participant "PA44" shared a description of his thoughts about the most helpful thing when building molecules using the virtual reality application: "It was really helpful to help me focus on what I need to do" (PA44). Some participants explained further how the increased focus could help them understand chemistry better. For example, participant "PA04" shared her view on how VR helped her focus and learn better:

> I liked how it made [me] focus more on what I was doing. Usually, in class, we used laptops and non-3D objects, which makes it harder for kids to learn. But in VR, I got the experience to see the molecules connect and to test them out. Even in this short

experience, I felt that using VR would help me better to understand chemistry and science.

Furthermore, participant "PA57" described a similar view to PA04 on the role of VR in attention and learning improvements by writing: "I personally believe that the sheer amount of concentration and detail that the VR simulation induces, is probably the best part of the program. I felt undistracted and learned new information about the molecule structures."

Theme 2: Disadvantages of Using Virtual Reality as a Tool to Learn Chemistry

Participants' responses to what they liked the least about conducting the chemistry exercise through the virtual reality application, and what they liked least about building molecules using the virtual reality application were used to discover the disadvantages of VR as a tool to learn chemistry. The four sub-themes that emerged from Theme 2 were (a) encounter technical issues, (b) receive insufficient feedback, (c) no disadvantages, and (d) require a learning curve. The four sub-themes are presented in the following sections.

Sub-Theme 1: Encounter Technical Issues. To build a molecule, participants had to grab atoms and place them in a certain zone, and then they had to grab the electrons to create the bonds between the atoms. Grabbing atoms and connecting them were two of the main functions in the VR exercise. Fifteen participants (24%) reported experiencing difficulties grabbing atoms and connecting them while conducting the exercise. Some participants briefly reported experiencing such difficulties such as participant "PA56" who wrote: "It was a little difficult to attach the electrons to the other atoms" and participant "PA61" who wrote: "I think just trying to connect the molecules together was the most difficult part." Participant PA06 thought the way to connect the atoms in the application could be improved: “I didn’t love how it was somewhat difficult to connect the atoms together; I feel there is improvement there.”

Some participants shared experiencing difficulty connecting the atoms but thought it might have been due to how they conducted the exercise. For example, participant PA09 wrote: “I didn't like how hard it was to select the electrons/atoms and grab them, although it might have been because I wasn't close enough to the molecule for the selection area to be very big/accurate.” Participant “PA41” also shared that she struggled to get the atoms to connect through the electrons. She thought that not being experienced in using VR might have contributed to her struggle:

> What I think I liked least about the conducting of chemistry throughout virtual reality was trying to connect the dots to bond the chemicals together and how delicate the items were. The dots weren't cooperating with me and were hard to drag, but it may have just been me since I am not experienced in it.

Few participants reported that molecules disappeared while they were building them. One of the four participants was “PA15”, who wrote: “Some of the molecules disappear if you put it in the wrong place.”. Another one was participant “PA53” who reported: “The only thing that I didn’t like was how the molecules disappeared, but it wasn’t a big problem!”. Likewise, PA44 reported that the molecule “floated away” while he was trying to build it.

Sub-Theme 2: Receive Insufficient Feedback. The VR app provided users with the ability to check if their built molecule is correct or not and get immediate feedback. While participants appreciated this ability, 12 participants (19%) shared that the feedback was insufficient and did not provide enough details on what was exactly wrong and how to fix it. For example, participant “PA24” shared that he loved everything about the VR application, except the insufficient feedback it provided when something went wrong: “The only thing I wish the program had done was to tell me what and why I did something wrong, but other than that, I loved it.”

Another example was participant “PA54”, who wrote: “If you can’t figure out how to build the molecules, it won’t show you.” Similarly, PA01 also shared a similar view: “Some of it doesn’t make sense and there is nowhere to [receive] help or give clues to what you did or are doing incorrectly.” Some participants gave examples of insufficient feedback that they had received while conducting the VR exercise, such as participant PA34, who wrote:

> One thing that was not very helpful about the application was that when you got the construction of a molecule wrong, it did not fully specify what went wrong. For example, when not creating enough bonds to tie the atoms to each other, instead of saying what bond is missing, it just said: "A bond is missing."

An insightful view was shared by some participants who explained what useful feedback they wished to receive in the VR application. For example, participant PA38 wished that he received hints when he did something wrong:

> I would have liked it if little hints popped up as I was working. I made the same mistake multiple times with the application, and it took me a while to figure out what I was doing. It would have been helpful if, after my second time making a mistake, a hint appeared describing what I should do.

Some molecules had special requirements in terms of the number and type of bonds they required. For example, CO_2 requires double bonds instead of single bonds. Participants who encountered such molecules expressed the need to have feedback that helped them build these specific molecules. For example, participant “PA36” who experienced building CO_2 molecule, wrote: “I thought the application was really awesome, however, I wish it had more specifics about individual molecules, like how you need two connections when making CO_2.”

Sub-Theme 3: No Disadvantages. Ten participants (16%) reported finding nothing they didn’t like or liked the least about using the VR tool to conduct the chemistry exercise. Participants’ responses indicated that they found no disadvantages to the VR tool based on their own experiences. For instance, participant “PA11” wrote: “I don’t think there was a problem with it.” PA11 in her response to what she did not like about the VR tool and replied: “Nothing really” to what she liked the least about using the VR in the exercise.

Another instance was participant “PA14” who wrote: “There was nothing that I did not like. Everything was helpful.” Similarly, participant “PA30” shared: “Nothing to be honest. It was amazing like I said. 10 out of 10. Must try again” and continued: “It was really helpful” in his response to the two open-ended questions. Some participants, such as “PA42” and PA46, just responded briefly with “Nothing” to both questions.

Sub-Theme 4: Require a Learning Curve. According to what participants had shared, the learning curve refers to the time required to learn how to use the VR set, the VR application, or both. Among the five participants (8%) who reported the learning curve, participant “PA21” shared his concern that some students would need time to learn how to use the VR headset, referring to the VR head-mounted set: “Some kids will have a hard time learning how to use the VR headset.” A similar view was shared by participant PA32, who wrote: “I really had no problem with the application, however, for some students, it might be a little tricky to get the hang of it.”

Both participants, “PA03” and PA09, pointed out the learning curve at the beginning of using VR. PA03 wrote: “There is a small learning curve towards the beginning of using virtual reality, but with a little guidance, you can understand how to use the technology in just a few minutes." PA09 wrote: "The learning curve took a little bit of time and trying to move the molecules around and making the bonds was quite challenging."

Theme 3: Suggestions about Using Virtual Reality Applications for Teaching Chemistry

Participants were asked to provide suggestions about using virtual reality applications for teaching chemistry if they were a teacher. Only three participants were not able to come up with any suggestions. Some participants' responses recommended using VR to teach chemistry, while other responses included suggestions about how to enhance the use of VR when teaching chemistry. The three sub-themes that emerged from Theme 3 were: (a) recommend using VR as a learning tool, (b) provide user training, and (c) improve the VR application. The three sub-themes are presented in the following sections.

Sub-Theme 1: Recommend Using Virtual Reality as a Learning Tool. Thirty-five participants (56%) recommended using VR as a learning tool to teach chemistry. Among these 35 participants, several of them shared a brief response of recommendation without elaborating on it. For example, participant "PA31" wrote: "I think if I were a teacher, I would want to use virtual reality in my class." Another example was participant PA14, who wrote: "They should bring these to every school they can. in reference to VR applications.

Other participants recommended using VR and shared how they came to that view, such as participant PA57, who based his recommendation on VR's provision of interactive learning: "I would suggest that virtual reality should be used to help students learn, because they would be more stimulated, interactive, and can visualize situations and how things interact and work more easily." Participant "PA40" who shared a similar view, wrote: "If I were a teacher, I would recommend using the virtual reality applications. I think it would help my students understand how atoms bond. Especially with this kind of building aspect in science."

Additionally, more participants pointed out the potential benefits of using VR for teaching chemistry in their recommendation, such as participant "PA58" who wrote: "I would advocate for using VR in chemistry; it is a very interactive and engaging service." One participant, "PA13", recommended using VR for all subjects in school:

> If I were a teacher, I would suggest using it for all classes, not only chemistry because, honestly, it was fun and visually easy to understand. I think using VR would help students understand better because of the vibe it sets in mind.

Sub-Theme 2: Provide User Training. Nine participants (15%) suggested providing training for students and teachers to learn how to use the VR device and the VR application. This is a common recommendation that is associated with the use of any new technology in a given context. Some participants focused on training students, while others focused on training teachers. Among the participants who suggested training students to learn using the VR device ahead of using VR for learning was PA09: "I would suggest teaching all the students the controls before going into the VR simulation, and to be careful with the VR headsets, since I know they cost like 150-400 dollars or something like that." Providing instruction guides to train students on using VR was also suggested by several participants, such as participant "PA60" who wrote: "Making an instruction guide so the kids know how to use it."

Providing training for teachers on using both the VR set and the VR application was suggested by some participants like "PA25", who wrote: "I would suggest that the teachers make sure that they know the full length of the virtual headset and the software." PA32 focused on providing training to teachers on the use of VR applications before using them in their instruction:

> I would suggest that first, you [the teachers] get a feel for how the application works, and experiment around a little bit with how the molecules and electrons work. Then start to teach the students chemistry and how molecules react together with heat and without it, and that sort of stuff.

Sub-Theme 3: Improve the Virtual Reality Application. Eight participants (13%) suggested improving certain features of the VR application to make it more usable and effective. Some participants suggested improving the feedback provided within the VR application. Receiving insufficient feedback was a sub-theme identified among the reported disadvantages of using VR to learn chemistry. Participant “PA16” suggested improving the feedback in the VR application by providing hints to help students: “Maybe give like little hints at the end of each experiment if you got it wrong and what you can improve on; that would really help the students.”

Adding instructions within the VR application to help guide students throughout the process was suggested by several participants. For instance, participant “PA39” wrote: “I think that I would suggest having instructions inside the project.” Another instance was participant “PA28”, who wrote: “I would suggest creating more instructions on the screen that is also easier to understand what to do.” Similarly, participant “PA55” shared: “If I were a teacher, I would suggest using more in-depth instructions.” Another suggestion was made by PA56 to improve the design of the application to make it more realistic: “I would make the design a little more realistic.”

Table 4 shows the themes and sub-themes of reflections data that represent the perceptions of participants towards using VR as a learning tool. A description of each sub-theme is provided with an example of a participant quote that represents the sub-theme. The percentages in the table show the number of participants who reported the sub-theme to the overall number of participants.

Table 4

Themes and Sub-Themes from Reflections

Theme	Sub-theme	Description of Category	Example Response
Advantages of using VR as a tool to learn chemistry	Provide 3-D visualizations (*N*=20, 32%)	Participants expressed preferring 3-D visualizations of objects and models.	"It was quite helpful visualizing a molecule in 3-D and seeing how it would actually look in the real world. On a piece of paper, it feels like just an idea and not really something in real life, but when it's interactive and realistic. The whole learning experience is heightened and way more engaging." (PA09)
	Support interactive learning (*N*=17, 27%)	Participants expressed having interactive and hands-on learning experiences using VR.	"I admired the fact that it was really interactive, and that an action was required for everything. It made me willing to learn about the molecules and built my interest for learning the material." (PA08)
	Enhance student attention (*N*=15, 24%)	Participants expressed increased focus and attention using VR.	"I felt like there was more objective rather than an assignment. Also, it was much more attention keeping." (PA01)
Disadvantages of using VR as a tool to learn chemistry	Encounter technical issues (*N*=15, 24%)	Participants expressed encountering difficulties while conducting the exercise due to the VR application design and features.	"I think just trying to connect the molecules together was the most difficult part." (PA61)
	Receive insufficient feedback (*N*=12, 14%)	Participants expressed receiving insufficient feedback that lacks details and guidance from the VR app.	"The only thing I wish the program had done was to tell me what and why I did something wrong, but other than that, I loved it." (PA24)
	No disadvantages (*N*=10, 16%)	Participants shared that they found nothing they did not like or liked the least about the VR tool.	"There was nothing that I did not like. Everything was helpful." (PA14)
	Require a learning curve (*N*=5, 8%)	Participants shared that a learning curve is associated with VR use.	"There is a small learning curve towards the beginning of using virtual reality, but with a little guidance, you can understand how to use the technology in just a few minutes." (PA03)
Suggestions about using VR applications for teaching chemistry	Recommend using VR as a learning tool (N=35, 56%)	Participants recommended using VR as a tool to learn chemistry	"If I were a teacher, I would recommend using the virtual reality applications. I think it would help my students understand how atoms bond. Especially, with this kind of building aspect in science." (PA40)
	Provide user training (*N*=9, 15%)	Participants suggested providing training for students and teachers to learn how to use VR.	"I would suggest teaching all the students the controls before going into the VR simulation." (PA09)
	Improve the VR Application (*N*=8, 13%)	Participants suggested improving certain features of the VR application.	"I would suggest creating more instructions on the screen that is also easier to understand what to do." (PA28)

Research Question Two

The second research question asked:

Q2 Are there any differences between female and male middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Three data sources were used to answer the second research question. The first data source was obtained from the quantitative analysis of the 24 Likert-scale questions in Section A: Perceptions in the student perception survey. The second data source was obtained from the quantitative analysis of the demographic data from the demographic survey. The third data source was obtained from the thematic analysis of participants' responses to open-ended questions in Section B: Reflections in the student perception survey.

Quantitative Data

Data were consolidated from the first and second data sources to compare females' perceptions to males' perceptions based on the six factors of perceptions in the student perception survey, grouped by gender from demographic data. A one-way MANOVA using IBM SPSS Statistics 20 was executed to answer the second research question. According to Bray and Maxwell (1985), the Pillai's trace test produced from running MANOVA to determine a statistically significant difference between the groups is the most robust one when sample sizes are equal. That is the case for this study where the number of cases used for the analysis is equal (male=30, female=30). The sample size for the one-way MANOVA was 60, including 30 females and 30 males, since one male participant and one female participant were dropped from the analysis for having incomplete data. The male participant missed responding to three items in the student perception survey that corresponded to the factor of interaction, while the female participant missed responding to three items in the student perception survey that corresponded to the factor of motivation.

The output of this analysis included tests to ensure that the data met the necessary assumptions for multivariate analysis. It is not unusual to have one or more of the test assumptions violated when working with real-world data. However, even when data fail to meet certain assumptions, there is often a solution to overcome the issue (Field, 2013). Data were tested against the nine assumptions of the one-way MANOVA. The results showed that seven assumptions were met except assumption #6: normality and assumption #8: no multicollinearity (see Appendix F).

The data violated the test of normality as indicated by the Shapiro-Wilk Test of Normality, but since the sample sizes were equal (Male=30, Female=30), test statistics are robust to the violation (Aurah, 2017). The assumption of no multicollinearity was checked by running correlation analysis using IBM SPSS Statistics 20. The results of the correlation analysis showed that all six items were moderately correlated ($.30 < r < .90$), except for ease of use and immersion with a correlation coefficient equal to .299 (see Appendix G). It is especially useful when the dependent variables are correlated, but it is also important that the correlations not be too high (i.e., greater than .80) (Garson, 2012). Although the correlation between ease of use and immersion was low, it was right on the border of moderate values, and it was significant.

Results by Overall Means

Overall, females scored a slightly higher overall mean value for the six factors (M=4.64, SD=0.44) than males (M =4.57, SD=0.40). The one-way MANOVA output at a significance level α=.05, indicated a non-statistically significant difference between female and male students' perceptions towards utilizing VR for learning chemistry, $F(6, 53.00) = .779$, $p = .590$;

Pillai's T = .081. The results revealed that female and male students have similar perceptions towards using VR as a tool to learn chemistry. While the difference in perceptions between females and males was not significant, comparing the means of the six factors and the 24 items of perceptions individually for both groups provided an insight into the gender differences in perceptions.

Results by Six Factors

The three factors with the highest reported means for females were the motivation (*M* =4.78, *SD*=0.36), the immersion (*M* =4.71, *SD*=0.39), and the intention to use (*M* =4.71, *SD*=0.34) factors, followed by the imagination (*M*=4.69, *SD*=0.52) factor. The two factors with the lowest reported means for females were the interaction (*M* = 4.46, *SD* =0.58) and the ease of use (*M* =4.50, *SD*=0.46) factors.

The two factors with the highest reported means for males were the intention to use (*M* =4.75, *SD*=0.30) and the motivation (*M* =4.69, *SD*=0.36) factors, followed by the imagination (*M* =4.63, *SD*=0.46) and the immersion (*M* =4.58, *SD*=0.30) factors. The two factors with the lowest reported means for males were the interaction (*M* =4.33, *SD*=0.58) and the ease of use (*M* =4.45, *SD*=0.41) factors. Table 5 provides a comparison of means for females and males for the six factors of perceptions.

Table 5

Comparison of Means for Females and Males for the Six Factors of Perceptions

Factor	Female		Male	
	M	*SD*	*M*	*SD*
1. Ease of use	4.50	0.46	4.45	0.41
2. Interaction	4.46	0.58	4.33	0.58
3. Imagination	4.69	0.52	4.63	0.46
4. Immersion	4.71	0.39	4.58	0.30
5. Motivation	4.78	0.36	4.69	0.36
6. Intention to use	4.71	0.34	4.75	0.30
Overall	4.64	0.44	4.57	0.40

Note. *N*=60

Overall, females scored a higher mean value in five out of the six factors: ease of use, interaction, imagination, immersion, and motivation, while males scored a higher mean value in only one factor: intention to use (see Table 5). Females scored the highest mean value in motivation, while males scored the highest mean value in intention to use. Both females and males scored the lowest mean value in the interaction factor. The biggest difference between males and females was in interaction and immersion, where females scored 0.15 higher mean value than males in both. The smallest difference between males and females was in intention to use, where males scored 0.04 higher mean value than females.

Results by Individual Items

To gain a deeper insight into the differences between the perceptions of males and females, the means of the 24 survey items were also reported and compared based on gender (see Table 6). The five items with the highest mean scores for females were “I paid more attention when using 3-D molecules" (survey item 14, *M*=4.93, *SD*=0.25), "I felt that the 3-D simulated chemistry lab made me concentrate more while learning" (survey item 19, *M*=4.83, *SD*=0.38), "I feel that using virtual reality to build 3-D molecules is impressive" (survey item 16, *M*=4.80, *SD*=0.41), "The Molecule Builder application can enhance my learning interest" (survey item 17, *M* =4.80, *SD*=0.48), "I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry" (survey item 22, *M* =4.77, *SD*=0.50), and "Overall, I think that the Molecule Builder application is worth being a good learning tool" (survey item 24, *M* =4.77, *SD*=0.43).

The five items with the highest mean scores for males were "I am willing to use virtual reality for learning in the future" (survey item 21, *M* =4.87, *SD*=0.35), "I paid more attention when using 3-D molecules" (survey item 14, *M* =4.83, *SD*=0.46), "Overall, I think that the Molecule Builder application is worth being a good learning tool" (survey item 24, *M* =4.83, *SD*=0.40), "The VR application gave me more engagement to help me understand molecules" (survey item 10, *M* =4.80, *SD*=0.48), and "I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry" (survey item 22, *M* =4.80, *SD*=0.41).

The five items with the lowest mean scores for females were "Learning how to use the Molecules Builder application was easy" (survey item 2, *M* =4.37, *SD*=0.67), "Using the Molecule Builder application, I was able to rotate 3-D molecules easily" (survey item 9, *M* =4.37, *SD*=0.77), "Learning how to use the VR device was easy" (survey item 1, *M* =4.43, *SD*=0.57), "Using the Molecule Builder application, I was able to move 3-D molecules easily" (survey item 8, *M* =4.43, *SD*=0.73), and "I was able to accomplish the exercise using the Molecule Builder application easily" (survey item 3, *M* =4.50, *SD*=0.68).

The five items with the lowest mean scores for males were “Using the Molecule Builder application, I was able to rotate 3-D molecules easily” (survey item 9, *M* =4.13, *SD*=0.82), “The Molecule Builder application created a realistic-looking learning environment” (survey item 13, *M* =4.13, *SD*=0.51), “Learning how to use the Molecules Builder application was easy” (survey item 2, *M* =4.27, *SD*=0.74), “I was able to accomplish the exercise using the Molecules Builder application easily” (survey item 3, *M* =4.37, *SD*=0.67), and “Using the Molecule Builder application, I was able to move 3-D molecules easily” (survey item 8, *M* =4.40, *SD*=0.78).

Overall, individual survey item results revealed that female and male students had three survey items (14, 22, and 24) with the highest mean scores among the 24 survey items. The results also showed that female and male students had four survey items (2, 3, 8, and 9) with the lowest mean scores among the 24 survey items. In addition, the biggest mean value difference between males and females was in survey item 13 (The Molecule Builder application created a realistic-looking learning environment), where females scored 0.47 higher mean value than males. There is no mean value difference between males and females in survey item 11 (I feel the Molecule Builder application improved my understanding by the imagination of the molecule structure).

Table 6

Comparison of Means for Females and Males for the 24 items of Perceptions

Item		Female *M*	Female *SD*	Male *M*	Male *SD*
Ease of Use					
1.	Learning how to use the VR device was easy.	4.43	0.57	4.53	0.57
2.	Learning how to use the Molecules Builder application was easy.	4.37	0.67	4.27	0.74
3.	I was able to accomplish the exercise using the Molecules Builder application easily.	4.50	0.68	4.37	0.67
4.	The Molecules Builder application provided me with the features I needed to complete the exercise.	4.57	0.57	4.60	0.56
5.	Using the Molecule Builder application for creating molecules was convenient for me.	4.57	0.57	4.47	0.63
6.	Using the Molecule Builder application for testing molecule correctness was convenient for me.	4.60	0.62	4.47	0.68
Interaction					
7.	Using the Molecule Builder application, I was able to observe 3-D objects from various perspectives easily.	4.57	0.63	4.47	0.63
8.	Using the Molecule Builder application, I was able to move 3-D molecules easily.	4.43	0.73	4.40	0.78
9.	Using the Molecule Builder application, I was able to rotate 3-D molecules easily.	4.37	0.77	4.13	0.82
Imagination					
10.	The VR application gave me more engagement to help me understand molecules.	4.70	0.65	4.80	0.48
11.	I feel the Molecule Builder application improved my understanding by the imagination of the molecule structure.	4.70	0.60	4.70	0.54
12.	I feel the Molecule Builder application helped me better understand by the imagination of the relative positions of atoms.	4.67	0.61	4.40	0.68
Immersion					
13.	The Molecule Builder application created a realistic-looking learning environment.	4.60	0.56	4.13	0.51
14.	I paid more attention when using 3-D molecules.	4.93	0.25	4.83	0.46
15.	I felt immersed in the 3-D Molecules VR experience.	4.60	0.72	4.77	0.50

Table 6 Continued

Item		Female *M*	Male *SD*	Female *M*	Male *SD*
Motivation					
16.	I feel that using virtual reality to build 3-D molecules is impressive.	4.80	0.41	4.70	0.54
17.	The Molecule Builder application can enhance my learning interest.	4.80	0.48	4.73	0.58
18.	The Molecule Builder application can enhance my learning motivation.	4.67	0.66	4.70	0.47
19.	I felt that the 3-D simulated chemistry lab made me concentrate more while learning.	4.83	0.38	4.63	0.49
Intention to Use					
20.	I think this system can strengthen my intentions to learn	4.63	0.56	4.60	0.50
21.	I am willing to use virtual reality for learning in the future.	4.70	0.75	4.87	0.35
22.	I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry.	4.77	0.50	4.80	0.41
23.	I wish that teachers adopt virtual reality technology to facilitate my learning of other subjects.	4.70	0.60	4.67	0.66
24.	Overall, I think that the Molecule Builder application is worth being a good learning tool.	4.77	0.43	4.83	0.40

Note. *N*=60

Qualitative Data

The qualitative data to answer research question two were derived from comparing the themes and sub-themes identified using thematic analysis of the open-ended questions in Section B: Reflections in the student perception survey based on gender. Section B: Reflections has five open-ended questions that aim at gaining an in-depth understanding of students' perceptions by allowing students to expand on their views in their own words. The three main themes identified were (a) advantages of VR as a tool to learn chemistry, (b) disadvantages of using VR as a tool to learn chemistry, and (c) suggestions about using virtual reality applications for teaching chemistry. To understand the differences between males and females, frequencies for each theme and sub-theme were reported and compared (see Table 7).

Based on frequencies, females and males had similar perceptions on most three themes and nine sub-themes in general (see Table 7). Overall, 28 females contributed to the first theme (advantage of using VR as a tool to learn chemistry) compared to 24 males, 19 females contributed to the second theme (disadvantage of using VR as a tool to learn chemistry) compared to 23 males, and 25 females contributed to the third theme (suggestions about using VR application for teaching chemistry) compared to 27 males. However, the "Require a learning curve" sub-theme under the second theme was stated only once by females but four times by males. In addition, the "Provide user training" sub-theme under the third theme was stated three times by females but six times by males.

Table 7

Comparison of Themes and Sub-Themes of Perceptions for Females and Males

Theme	Sub-theme	Female		Male	
		N	%	*N*	%
1. Advantages of using VR as a tool to learn chemistry		28	45	24	39
	Provide 3-D visualizations	11	18	9	15
	Support interactive learning	9	15	8	13
	Enhance student attention	8	13	7	11
2. Disadvantages of using VR as a tool to learn chemistry		19	30	23	37
	Encounter technical issues	7	11	8	13
	Receive insufficient feedback	6	10	6	10
	No disadvantages	5	8	5	8
	Require a learning curve	1	2	4	7
3. Suggestions about using VR applications for teaching chemistry		25	40	27	44
	Recommend using VR as a learning tool	18	29	17	27
	Provide user training	3	5	6	10
	Improve the VR Application	4	7	4	7

Note. N=60

Research Question Three

The third research question asked:

Q3 How do middle school students describe their experience during the chemistry exercise using the VR tool?

One data source was used to answer the third research question, which was obtained from the thematic analysis of structured interviews with 62 participants. Individual interviews were conducted right after participants completed the chemistry exercise to capture their immediate feedback about their experience of conducting the exercise. The researcher asked participants questions that addressed their views on their VR experience. An audio recording was used to keep a record of each interview. At the beginning of each interview, the researcher mentioned the participant's assigned pseudonym to identify the participant in the recording and the written report. Pseudonym assignment took place when participants filled out the demographic survey.

The average time to complete the interview was about 3.5 minutes. After each interview, participant's responses were transcribed, and data were typed into a computer file. Once all interview data were typed in the file, the researcher conducted thematic analysis within a pragmatic framework of the interview data (Nowell et al., 2017). After preparing and organizing the data, the researcher made herself familiar with the data by reading through it repeatedly and making notes about meaning and patterns. Then, data were coded, categorized, and grouped into themes (Lester et al., 2020).

The findings and the emergent themes for the interviews are presented by theme and include details of the findings supported by direct quotes from participants. Peer reviews were utilized to validate the congruence of the thematic analysis process and outcome by discussing and getting feedback from a colleague who has experience in conducting qualitative research and getting feedback from my research advisor. Accordingly, I revised the process of thematic analysis and improved the identification of sub-themes and the reporting of findings.

When asked about what previous models they used inside or outside the classroom to build molecules, participants reported using a variety of models. The most common model was reported by 36 participants who used balls made from plastic, styrofoam, or candy to represent atoms, and sticks made from spaghetti, plastic, or toothpicks to represent bonds. The second most common model was reported by 22 participants who used drawings on paper worksheets to represent the molecules visually. The third most common model was reported by 22 participants who used computer simulations, such as PhET or Gizmos, to practice building molecules. Additionally, eleven participants reported never using any model to build molecules before.

The majority of participants expressed an overall sense of a positive experience of the chemistry exercise using the VR tool. The two main themes that were identified during the interviews were: (a) positive experiences and (b) mixed experiences. Theme 1 was given sub-themes to better represent specific aspects of this theme that were emphasized by the participants. The findings from the participant interviews are presented in the following sections by theme.

Theme 1: Positive Experiences

Out of 62 participants, 52 participants (84%) expressed having a fully positive experience without downsides. A positive experience refers to an experience that participants reported using positive words to describe how the experience made them feel, the process of the experience, or the outcome of the experience. Examples of words used to describe positive experiences include, but are not limited to, fun, good, cool, easy, educational, engaging, and interesting. Most participants began describing their experiences broadly as interesting, cool, easy, or fun, then proceeded to provide more specific descriptions of their experiences such as interactive, having a sense of virtual presence, engaging, and educational. Four sub-themes emerged from Theme 1: (a) interactive, (b) virtually present, (c) engaging, and (d) educational. The sub-themes that emerged from Theme 1 are discussed in the following sections.

Sub-Theme 1: Interactive

Twenty-three participants (37%) shared having an experience that was interactive, reflecting on the process of their experience. Participants used words such as interactive, more interactive, hands on, and more hands on to describe their interactive experiences. Some participants who described their experiences to be more interactive, connected them to increased motivation and improved learning. One example was participant PA08, who shared that he enjoyed his experience and felt more motivated to build molecules. He said: “It was just more interactive; it made it more fun. It made me more willing to want to do it.” Another example was participant PA38, who shared that her interactive experience helped her remember what she learned better: “It is more interactive, so you end up learning more. Sometimes, you don't remember things as well when you describe them, but when you did them, you remember them better.”

Some participants compared their VR experience to other learning experiences. For example, participant “PA17” described his experience as cool and interactive compared to taking notes in a chemistry class: “It was really cool because learning chemistry in school isn't that fun; you don't get to do anything but take notes. This this was really fun because you got to a game almost, and hands on.” Analogous to that, participant PA54 said: “I think it was very fun and good to learn chemistry.” Then she continued to elaborate, by saying: “I think it was really nice to learn, especially for people who are more hands on or visual, instead of just listening to a teacher talking in a classroom.”

Several participants explained how the hands-on aspect of their interactive experiences could lead to improvements in learning. For instance, participant PA41 shared how hands-on learning increases students’ motivation to learn:

> It is more hands-on learning. I feel if you know you are not really touching anything, I think it is really fun. Normally in class, the guys are on computers; it gets really boring and you kind of lose interest in all of it. I think doing virtual reality could hook more people's interest and kind of make them more entertained and have more fun experience with it.

Another instance was participant PA06, who described himself as a hands-on learner and shared how interacting with atoms and molecules in the VR application is beneficial:

> I thought it was great. I think that in science, sometimes, with that massive classroom, when you are looking at it, it is a little harder to describe. I am more of a hands-on learner, and I feel if I am using that app, I can really grab it and connect it, and there are so many things to choose from. I think that would be great for in-classroom learning.

In line with that, participant PA50 who used reported using marshmallows with toothpicks to build molecules previously, provided an insightful view on his interactive experience and how he thought it was helpful for learning by saying:

> It was really cool to actually act it out - I guess - rather than write it on paper like what you'd do in a normal class, so I just thought it was a unique way to teach it. I guess it was just different and I have done nothing like it before. It was helpful. It was - I guess - more hands on than other ways I learned in chemistry. I think that is a really cool way to motivate and help students with learning chemistry.

Sub-Theme 2: Virtually Present

Fourteen participants (23%) described having experiences that provided them with a sense of presence in the virtual world, reflecting on how their experiences made them feel. Participants described their experiences to have a sense of presence using different expressions such as being there, really there, or inside the virtual world. Presence is defined as "the genuine feeling of existing in a world other than the physical world in which the body is" (Bouvier et al., 2014). One instance was participant PA14, who described the feeling of being present inside the VR in reference to the virtual world that the VR application has created: "I felt I was actually inside of the VR; it was really fun actually. I was really surprised."

Another instance was participant “PA19”, who shared having a joyful sense of being there: “I felt I was there, but I did not feel comfortable, but it did not feel uncomfortable either. It was fun.” Similarly, participant “PA51” described his experience by saying: “It was fun, it really helped me learn better because I am more of a visual learner.” Then he proceeded to describe his sense of presence by saying: “I guess you are in a new world; it is a different setting. You are really there, and you are more focused.”

Both participants PA13 and PA15 used the statement “I felt I was actually there” to describe their experience with PA13 elaborating on her view by describing the features of the virtual world and how her presence in the virtual world helped her learn better: “It was really cool. I felt I was actually there. Using the controllers was really easy. While I was in it, I was able to grab things and attach them together. Even the difficulties were cool because after I got past them. I felt accomplished.”

When I asked PA13, “Based on your experience in conducting the exercise, how do you feel about using VR as a tool to learn chemistry?” she responded:

> Making things more visual for students makes it easier to learn and understand. So even at school, when you do stuff on hand, it is clearer to do it online especially in VR because you are actually there. The background and the vibe that it adds make it easier to learn. Where I was, at the lab, or wherever I was, it helped [me] to learn because it was cool to see and also to put things together. (

Similarly, participant PA15 described her experience by saying: “I felt like I was there. It was great, good. Things looked realistic. It would actually help me learn more; I am more of a physical learner. Teachers don't really explain it well. I mean all they talk about is words. I'm not a visual learner, I am a hands-on learner.”

Sub-Theme 3: Engaging

Six participants (10%) shared having an experience that was engaging, reflecting on how they felt or on the process of the experience. Participants used words such as engaging and more engaging to describe their experience. Some participants found their experience to be more engaging compared to school activities.

For example, participant PA07 found his experience to be more engaging than using worksheets and tied engagement to learning: “It was more engaging than school activities and I much prefer this to worksheets. I came knowing nothing about this subject essentially, and I can say I learned something at least.” In line with that, participant PA34 described how the engaging VR experience was better than just sitting in the classroom: “It was a good experience. I felt that it is engaging to some learners who like to use more hands on than just sitting in a chair. I felt it was different and it was a great learning opportunity.”

Simulation is a common way to teach molecule building to middle school students. Among the participants who reported using simulations to build molecules at school was participant “PA33,” who said: “In 6th grade, we used PhET simulations to build some molecules.” He described how his VR experience was more engaging than simulations: “I don’t like school, but that was actually fun. It was a lot different from the simulation because I feel it was more engaging. It was really cool, and a lot better than the simulation.”

Another group of participants reported using marshmallows and spaghetti or toothpicks to learn how to build molecules in the classroom. Among this group was participant “PA29,” who reported using spaghetti sticks and marshmallows to build molecules in the classroom. He described his VR experience as “a lot better than what I have done before. It is a lot more engaging and more fun” (PA29).

Sub-Theme 4: Educational

Five participants (8%) shared having an experience that was educational, reflecting on their experience outcome. Participants used words such as educational, opportunity for learning, and helped me learn to describe their educational experiences. For example, participant "PA47" described her experience as educational by saying: "I thought it was really fun and super educational." She proceeded to compare her VR experience to using only paper and pencil at school to study molecules, saying: "It was a lot different, but I thought it was a lot of fun. It was definitely a lot different having 3-D vs. 2-D, and I think it helps a lot to have 3-D molecules."

She also shared that using VR applications to teach chemistry "would be really helpful" and explained her view by saying: "I think learning it this way is going to be a lot more educational to kids, and it would help students learn a lot faster and easier" (PA47). In line with that, participant "PA26" thought that "using VR would be very exciting, and it is such a cool learning tactic to teach you." When asked why he thought that, he replied: "Because it is different, simple, and easier. It's a new touch on teaching that I haven't seen before. VR is new and interesting."

Theme 2: Mixed Experiences

A mixed experience refers to an experience that participants reported using both positive and negative words to describe how the experience made them feel, the process of the experience, or the outcome of the experience. Out of 62 participants, 10 participants (16%) shared having a mixed experience. They used negative words such as challenging, hard, and difficult in addition to positive words such as fun, easy, and engaging to describe their experience. Two sub-themes emerged from Theme 2: (a) positive yet challenging and (b) positive yet confusing. The two sub-themes that emerged from Theme 2 are discussed in the following sections.

Sub-Theme 1: Positive Yet Challenging

Participants shared having an experience that was positive yet challenging, reflecting on the process of the experience. Some participants elaborated on why they felt their experience was positive yet challenging, while others did not. Five participants (8%) used negative words such as challenging, hard, and difficult in addition to positive such as good, fun, and engaging to describe their experiences.

For example, participant PA01, who has an intermediate VR experience, described his experience as good but challenging: “I had a very good time. It was very fun. It did take a bit of effort. It was a bit of a challenge. I think you can improve it, but overall, I think it is pretty good.” A brief description of a mixed experience was shared by participant “PA52”, who described her experience by saying: “it was easy and hard; it was complicated.”

Grabbing the atoms and connecting them to build molecules were reported to be difficult yet challenging by a few participants. One example was participant PA09, a novice VR user, who shared that he found his experience to be engaging yet challenging, due to the struggles that he had while building the molecules:

> It is a lot more engaging, and I feel I would want to do it more than just a piece of paper. It was a little challenging to get the feeling in the controls down. Selecting the bonds to each molecule was definitely a challenge. Sometimes, grabbing the molecules to move them around was quite hard, but once I figured out some techniques to grab them, it was just hard to select the bonds. I think the technique of grabbing the bonds could be a little

> more hand on because if I was touching a finger to a bond, it wouldn't select, but if I was near it, it would select.

Similarly, participant PA57, also a novice VR user, described finding the experience to be fun but hard at the beginning: “It was pretty fun. It is a little hard to understand at first, but I think once you start learning how to do it a bit more, it is probably helpful.” In comparison with his previous experiences of building molecules using paper drawings and plastic balls and sticks, he described his VR experience by saying:

> This one was a little bit more difficult to understand off the start because there were one or two things I didn’t know before, but it was a little bit more fun. Before, it was just connecting physical pieces, but in VR, you can actually select whatever you want to select. You can try and practice with different things and learn about different molecules and their structures in a more varied way.

Sub-Theme 2: Positive Yet Confusing

Participants shared having an experience that was positive yet confusing, reflecting on the process of the experience or how the experience made them feel. Five participants (8%) used negative words such as confusing or disorienting in addition to positive words such as good, fun, and interesting to describe their experiences. The confusion seemed to be caused by the design of the VR application and its features, based on what the participants reported. One instance was participant “PA45”, who described having a very disorienting experience based on how the atoms and the hand controllers appeared in the VR application:

> My experience was alright. I do wish it was kind of like actually making them look like atoms and not having your hands at the wrist of the VR hands. It was very disorienting for me to have that happen, and trying to do thumbs up in pointer, it does that

automatically. It just does not feel right, but since it is a molecule-building simulator, I think it is pretty good first time.

Another instance was participant “PA62”, who was enjoyed her experience but was confused because of how her hands were represented using the hand controllers inside the virtual world. She said: “It was super, super fun, but also confusing because it was like "where my hands are going?", and sometimes the buttons wouldn’t click, but it was fun.” She also shared that compared to using marshmallows and sticks to build molecules, she found her VR experience to be “more fun, it is more visual, I can actually do stuff instead of writing stuff down.”

Similarly, participant PA39 found his experience to be interesting but disorienting at the beginning: “I was a little disorienting at first, but it was very interesting, I would say.” He also shared that based on his experience, he thought that using VR as a tool to learn chemistry “could be a bit hard to get used to, but other than that, it would be good.” In line with that, participant PA42 described his experience as “very fun but sometimes confusing with some of the molecules.” Table 8 shows the themes and sub-themes that emerged from the analysis of interview data as well as a description of each theme or sub-theme with an example of a participant quote that represented the sub-theme.

Table 8

Emergent Themes and Sub-Themes from Experience

Theme	Sub-theme	Description of Category	Example Response
Positive Experience (*n*=52, 84%)	Interactive (*n*=23, 37%)	Participants expressed having a positive experience that was interactive.	"It was just more interactive; it made it more fun. It made me more willing to want to do it." (PA08).
	Virtually Present (*n*=14, 23%)	Participants expressed having a positive experience with a sense of presence in the virtual world.	"It was really cool. I felt I was actually there." (PA13)
	Engaging (*n* =6, 10%)	Participants expressed having a positive experience that was engaging.	"It was a good experience. I felt that it is engaging to some learners who like to use more hands on than just sitting in a chair." (PA34).
	Educational (*n* =5, 8%)	Participants expressed having a positive experience that was educational.	"I thought it was really fun and super educational." (PA47)
Mixed Experience (*n* =10, 16%)	Positive yet Challenging (*n* =5, 8%)	Participants expressed having an experience that was positive but also challenging.	"I had a very good time. It was very fun. It did take a bit of effort. It was a bit of a challenge. I think you can improve it, but overall, I think it is pretty good." (PA01)
	Positive yet Confusing (*n* =5, 8%)	Participants expressed having an experience that was positive but also confusing.	"I was a little disorienting at first, but it was very interesting, I would say." (PA39)

Note. *N* = 62

Research Question Four

The fourth research question asked:

Q4 How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?

Two data sources were used to answer the fourth research question. The first data source was obtained from the analysis of the notes recorded by the researcher while observing participants right before, during, and right after using the VR tool to conduct the chemistry exercise, following the observation protocol. The second data source was obtained from the analysis of participants' responses to the three open-ended questions in section C: Behaviors in the student perception survey, which were completed by all 62 participants. Data from both sources were grouped based on the period specified during collection as (a) before, (b) during, and (c) after using the VR tool to conduct the chemistry exercise and analyzed using thematic analysis within a pragmatic framework (Nowell et al., 2017). After preparing and organizing the data, the researcher made herself familiar with the data by reading through it repeatedly and making notes about meaning and patterns. Then, data were coded, categorized, and grouped into themes (Lester et al., 2020).

Peer reviews were utilized to validate the congruence of the thematic analysis process and outcome by discussing and getting feedback from a colleague who has experience in conducting qualitative research and getting feedback from my research advisor. Accordingly, I revised the process of thematic analysis and improved the identification of sub-themes and the reporting of findings. Additionally, member checks were performed via e-mail to resolve the cases when responses and observations did not converge. The member checks consisted of an open dialogue between the participants and me to confirm that the findings were representative of the views of the participants. Findings and emergent themes are presented for each period by theme and include details of the findings supported by direct quotes from the participants.

Behaviors Before Using the Virtual Reality Tool to Conduct the Chemistry Exercise

Four main themes emerged from the analysis of participants' responses to the open-ended question "Describe how you felt, emotionally and physically, right before the VR experience" in section C: Behaviors in the student perception survey and the notes from the observations of participants before using the VR tool to conduct the chemistry exercise virtually. The emergent themes were: (a) exited, (b) anxious, (c) ambivalent, and (d) joyful behaviors. The emergent themes are discussed in the following sections.

Theme 1: Excited Behaviors

Twenty-two participants showed excitement right before using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling excited and were observed to be excited through their shown emotions and body language. Smiling, standing up straight, and active body movements were indicators of excitement. For example, participant PA01 who was standing up straight and moving actively, wrote in his answer about how he was feeling right before using the VR tool to conduct the chemistry exercise: “I was excited and ready to try it out.”

Similarly, participant PA16 appeared confident and reported feeling very excited: “Very excited to try this virtual reality set since this was my first time trying something like this.” Participant PA08 attributed his emotional state of excitement to his physical state of being active by saying: “Before the VR experience, emotionally, I felt really excited, and physically, I felt really active, if that makes any sense.”

Some participants attributed their excitement to the use of VR. One instance was participant PA19, who appeared excited and confident: “I felt excited to use virtual reality and be in this study.” Another instance was participant PA22, who appeared excited and confident as well: “I felt excited because it wasn’t just another boring practice on a piece of paper.”

Similarly, PA04 was observed to have an upright posture and actively moving. She shared that she was excited and looking forward to using the VR tool: “I felt excited to see how VR can help people discover things in real life. Also, how I was not going to be looking at a computer screen the whole time. I was curious on how it will be.”

In line with that was participant PA38, who was observed to be actively moving in excitement: “I was excited to get to try something that we don't usually use when learning.”

Likewise, participant PA50 was energetic and moving in excitement while waiting to get the VR set ready for her to use: “I was excited to try it since I have never done VR before.” Additionally, participant PA23, who was observed to be moving in excitement, wrote: “I was really excited to try VR for the first time. I’ve seen YouTube videos about VR.”

An interesting view was shared by participant PA13, who explained why she felt excited. She connected her excitement to taking part in a research study: “I felt excited to be doing something that grown-ups usually do. It was fun to be treated as an adult and be taken seriously for once. Before the experience, I also felt it was something big to be a part of, to change classes for students in the future.” Before using the VR tool to conduct the chemistry exercise, PA13 was smiling and verbally expressed that she was looking forward to using the VR.

Theme 2: Anxious Behaviors

Fifteen participants showed anxious behavior right before using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling anxious and were observed to be anxious through their shown emotions and body language. Anxious behavior was associated with feeling nervous or anxious in a fidgeting body. Feeling fearful, worried, or scared also indicated anxious behavior.

For instance, participant PA14 reported feeling nervous and scared before using the VR tool to conduct the chemistry exercise, and was observed to be worried, pacing while waiting, and blushing; she wrote: “I was very nervous and scared.” Another instance was participant PA24, who reported feeling worried and further explained that it was due to his lack of knowledge of molecule building and his assumption that it would be hard: “I felt worried that I wouldn't know enough about the subject and that it would be too hard.”

As I was preparing the VR set for participant PA41 to use, she said, “I feel scared”, while sitting hunched down, looking down, and cracking her knuckles. I told her that she could withdraw from participating at any time and asked her if she needed some time before participating. She asked some questions about the exercise and then decided to go forward with participating. She also reported feeling nervous and worried in her response to how she felt right before using the VR tool to conduct the chemistry exercise. She wrote: “Before the experience, I was a bit nervous and worried about what I was going to do.”

When I observed participant PA53 pacing in nervousness, I had a conversation with her, and she shared being worried about not using VR before. I assured her that previous experience with VR is not a requirement to participate and that she would be given enough time to get familiar with the VR device and the VR application. In response to how she felt before using the VR tool to conduct the chemistry exercise, she wrote: “I felt scared, I didn’t know how to interact before the experience.”

Theme 3: Ambivalent Behaviors

Thirteen participants showed ambivalent behaviors right before using the VR tool to conduct the chemistry exercise virtually. Participants reported mixed feelings and were observed to have ambivalent behavior through their shown emotions and body language. Ambivalent behavior was associated with conflicting feelings and actions.

Although participants were briefed about what the research study was about and how it would be conducted, some participants had mixed feelings of excitement and anxiety. For instance, participant PA28 expressed feeling excited but nervous and overwhelmed due to the uncertainty about what was coming. She was observed to be excited then anxious. She wrote: “Emotionally, I was nervous and a little overwhelmed because I wasn't sure what I would have to do, but at the same time, I was still very excited." Similarly, participant PA20 displayed mixed feelings of excitement and anxiety and shared how he felt excited and anxious at the same time: "I felt excited, and maybe a little bit anxious."

Some participants reported an ambivalent behavior that began with confusion or anxiety and then changed to excitement. For instance, PA06 reported feeling confused at first but then excited. He wrote: "Before, I was a little confused on what the program would be about, but after I got it explained, I became excited to do it and really wanted to put the headset on." His body language showed active movement that was interpreted by me as impatiently waiting out of excitement, but I wasn't able to observe his confusion. To have a clear understanding of PA06's behavior, he was contacted via e-mail to perform a member check. He explained that he was wandering out of confusion, not excitement.

Another instance was participant PA32, who reported feeling nervous and excited. He displayed ambivalent behavior that varied from being fidgety to showing excitement through smiling and active movement: "Right before the VR experience, I was a little nervous since I had never used one before. Shortly after seeing someone else do it, I started to get excited and wanting to use the VR a lot."

Reflecting on previous experiences, participant PA09 shared having mixed feelings of nervousness and excitement:

> I was a little nervous because I haven't done virtual reality in a while, and the only type I have done is where you hold up the goggles to your face and look around with only a couple of controls. Other than that, I was really excited because I think VR is cool, and I've had good experiences in the past.

He was observed to smile nervously.

Using VR only once before, participant PA37 appeared nervous and shared mixed feelings of nervousness and slight excitement: “I was nervous but ready. It would be the second time in my life using virtual reality, but I was sort of excited for the experience.” Some participants shared having mixed feelings briefly, such as PA59: “a little nervous but excited” and participant PA60 who wrote: “I felt a bit nervous but slightly excited.” Both participants appeared slightly anxious.

Theme 4: Joyful Behaviors

Six participants showed joyful behavior right before using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling joyful and were observed to be joyful through their shown emotions and body language. Joyful behavior is associated with being happy and feeling good. Smiling, verbal expressions and relaxed body movements were indicators of joy.

For example, participant PA10 expressed joyful behavior through feeling happy and good: “Before I tried the VR, I was feeling good and happy.” PA10’s behavior was described as cheerful in the observation notes based on the observed emotion of happiness and open posture. Another example was participant PA21, who displayed joyful behavior during observation, which was confirmed in his response to how he felt right before the exercise: “I was happy because I got to experience something like this, and I hope they do it in classes.”

While observing participant PA48, she showed joyful behavior that was captured through relaxed body movements and smiling as she shared: “I felt calm and good before.” Similarly, participant PA49 was moving in a relaxed body and smiling while waiting to get the VR ready. In her response to how she felt right before the VR exercise, she wrote: “normal and happy” (PA49).

Standing with a balanced body and a shy smile, participant PA39 waited while I was setting up the VR device for her. She shared feeling “well and balanced” before using the VR tool to conduct the chemistry exercise. Table 9 shows the emergent themes from participants’ behaviors before using the VR tool to conduct the chemistry exercise as well as a description of each theme with an example of a participant quote that represents the theme.

Table 9

Emergent Themes from Participant Behaviors Before Using the Virtual Reality Tool to Conduct the Chemistry Exercise

Theme	Description of Category	Example Response
Excited Behaviors (*n*=22, 35%)	Participants expressed a feeling of excitement and appeared to be excited.	“I was excited to get to try something that we don't usually use when learning” (PA38).
Anxious Behaviors (*n* =15, 24%)	Participants expressed a feeling of anxiety and appeared to be anxious.	“Before the experience, I was a bit nervous and worried about what I was going to do” (PA41).
Ambivalent Behaviors (*n* =13, 21%)	Participants expressed having mixed feelings and appeared to show ambivalent feelings and actions.	“Emotionally, I was nervous and a little overwhelmed because I wasn't sure what I would have to do, but at the same time, I was still very excited” (PA28).
Joyful Behaviors (*n* =6, 10%)	Participants expressed a feeling of joy and appeared to be joyful.	“Before I tried the VR, I was feeling good and happy” (PA10).

Behaviors During the Use of the Virtual Reality Tool to Conduct the Chemistry Exercise

Four main themes emerged from the analysis of participants’ responses to the open-ended question “Describe how you felt, emotionally and physically, during the VR experience” in section C: Behaviors in the student perception survey and the notes from the observations of participants during the use of the VR tool to conduct the chemistry exercise virtually. The emergent themes were (a) joyful, (b) engaged, (c) virtually present, and (d) ambivalent behaviors. The emergent themes are discussed in the following sections.

Theme 1: Joyful Behaviors

Twenty-nine participants showed joyful behavior during the use of the VR tool to conduct the chemistry exercise virtually. Participants reported feeling joyful and were observed to be joyful through their shown emotions and body language. Joyful behavior is associated with being happy, having fun, or enjoying doing something. For example, participant PA09 displayed joyful behavior as he giggled when he built his first molecule correctly. He reported having fun and feeling happy because he likes technology, and he is good at it: “It was really fun, and I felt happy using technology because I am kind of a tech nerd. Physically, I was relaxed and had no nausea from the VR.”

Some participants attributed their joyful behavior during the exercise to feeling that it was like playing a game. For instance, participant PA24 wrote: “I felt like I was playing a game and so, I was having a good time.” Another instance was participant PA35, who was observed to behave joyfully as she giggled whenever she completed a task successfully. She reported feeling happy during the exercise: “I was very excited and happy because it made sense, and I didn’t feel like I was being taught. I felt like I was playing a game. I also forgot that I was tired.” Similarly, participant PA62, who appeared happy and excited wrote: “I found it entertaining. I was focused because it was like I was on a mission in some game, like Overwatch or Fortnite.”

Some participants shared how fun it was to use the VR tool to conduct the chemistry exercise. For example, participant PA32 wrote: “During the VR experience, I was having a lot of fun connecting molecules and electrons. I think that it was truly a great experience and would easily do it again.” In line with that, participant PA59 wrote: “It was so much fun and exhilarating." Bothe participants, PA32 and PA59, appeared to be joyful and actively moving with confidence.

Several participants shared feeling happy in their response to how they felt emotionally during the use of the VR tool, such as participant PA25, who wrote: "Happy. It was really fun." Similarly, participant PA37 responded: "Relaxed and happy. This was fun and really neat to learn off of" and participant PA31 briefly wrote: "Happy and ready to learn."

Theme 2: Engaged Behaviors

Fourteen participants showed engaged behavior during the use of the VR tool to conduct the chemistry exercise virtually. Participants reported feeling engaged, focused, and involved and were observed to display engaged behaviors. In the context of virtual reality, engaged behavior is characterized by engagement, interest, and focus (Bouvier et al., 2014). While observing participants during the exercise, the majority of them appeared to display engaged behaviors.

For example, participant PA22 was observed to be focused and reported feeling engaged: "During it, I felt engaged and excited to keep going, because I was able to learn in a more fun and [enjoying] environment." Another example was participant PA40, who was observed to be calm and focused: "During the VR experience, I was really engaged with it and enjoyed everything that was going on." Similarly, participant PA51, who was observed to be balanced and focused, shared: "During the VR experience, I felt more focused on what I was doing. Physically, I felt fine."

When PA41 began using the VR tool, she appeared to be focused and moved gently while building the molecules. She shared: "I felt engaged and excited to try out some virtual reality with molecules. I felt eager as well to try to put some new things through virtual reality and try to see how the atoms work together."

Some participants briefly shared feeling "engaged" during the use of the VR tool to build the molecules, such as PA48 and PA49. Both participants appeared to be engaged, and their body movements were fluent and focused. Likewise, participant PA46 described herself during the use of VR as "I was pretty happy and engaged." (

Theme 3: Virtually Present Behaviors

Presence is "the sense of being in a virtual environment rather than the place in which the participant's body is actually located" (Sanchez-Vives & Slater, 2005, p. 333). Presence in a behavioral sense can be measured or evaluated (Sanchez-Vives & Slater, 2005; Slater et al., 1995). In this study, virtual presence as behavior was identified using subjective self-reporting by participants and subjective observation of participants' behavior. Participants display virtual presence when they report having a sense of "being there" (Sanchez-Vives & Slater, 2005). Virtual presence as a behavior can be observed when participants behave in a virtual environment as if they are in an equivalent real environment (Sanchez-Vives & Slater, 2005).

Ten participants shared feeling virtually present while using the VR tool to conduct the chemistry exercise and used a spectrum of descriptions to express their sense of presence in the virtual world. Some participants reported feeling virtually present using the term "be/being there". For example, participant PA03 reported an actual feeling of being there: "It was very surreal as it felt as if I was actually there." Another participant, PA19, wrote: "I felt like I was in the experience, and I was actually there."

Some participants described how they felt being present in a different place other than the place where they actually were in. For example, some participants reported being in a lab or a science lab, such as PA04: "I felt as if I was in a real lab connecting molecules and moving them around. I was a bit nervous to see if I was right or wrong after checking, and how some things weren't connecting. I felt like I was in a new reality."

Similarly, participant PA13 described being drawn into the virtual world that she described as a lab: "I felt happy and drawn into it as if I was actually there in the lab. I also felt calm and easygoing for this. In other words, I'm all for VR!" Participant PA23 had a unique description of the virtual world he experienced, referring to it as an electronic world: "I felt like I was in the electronic world while it was a real lifestyle." (

Other participants described being immersed in the virtual environment rather than the real world. For instance, participant PA38 described her virtual presence through her engrossment in the virtual world and her ability to separate herself from the real world: "I was completely engrossed in the experience, especially, when I got the hang of things, and didn't really focus on what was happening in the outside world." Another interesting description of virtual presence was reported by participant PA06, who referred to his sense of presence as "being submerged" into the virtual world: "During the VR experience, I kept thinking, 'why didn't other people do this first'. It was truly a game-changer for me, and I wished I had grown up with it. I felt submerged into the world and loved how fun it was as well as it is helping my knowledge."

Theme 4: Ambivalent Behaviors

Five participants showed ambivalent behaviors during the use of the VR tool to conduct the chemistry exercise virtually. Participants reported having mixed feelings and were observed to have ambivalent behavior through their shown emotions and body language. Ambivalent behavior was associated with conflicting emotions and reactions. Some participants shared having fun but feeling confused at the same time without further explaining why. For example, participant PA12 was observed to be happy, but her body movements were unbalanced: “I was having fun, but I was confused.” Similarly, participant PA42 appeared to pause and look around a few times, although he had good control and smooth movement in the virtual world: “I felt kind of confused, but I got it.”

Some participants shared having mixed feelings and explained the reason behind that. One instance is participant PA57, who shared having mixed feelings of curiosity and confusion at the same time. He attributed his confusion to not knowing how to perform the required tasks: “I felt curious, but a little confused about what to do and how to connect the atoms.”

In line with that, participant PA01 shared feeling curious and nervous at the same time. He was observed to be anxious and unbalanced at the beginning, then became focused and interested as time went by. He wrote: “I felt curious and kind of nervous to mess something up.” Table 10 shows the emergent themes from participants’ behaviors during the use of the VR tool to conduct the chemistry exercise. The table includes a description of each theme with an example of a participant quote that represents the theme.

Table 10

Emergent Themes from Participant Behaviors During the Use of the Virtual Reality Tool to Conduct the Chemistry Exercise

Theme	Description of Category	Example Response
Joyful Behaviors (*n* =29, 47%)	Participants expressed a feeling of joy and appeared to be joyful.	"It was really fun, and I felt happy using technology because I am kind of a tech nerd. Physically, I was relaxed and had no nausea from the VR." (PA09).
Engaged Behaviors (*n* =14, 23%)	Participants expressed a feeling of engagement and appeared to be engaged.	"During the VR experience, I was really engaged with it and enjoyed everything that was going on." (PA40).
Virtually Present Behaviors (*n* =10, 16%)	Participants expressed a feeling of presence and appeared to be present in the virtual world.	"I felt like I was in the experience, and I was actually there." (PA19).
Ambivalent Behaviors (*n* =5, 8%)	Participants expressed having mixed feelings and showed mixed reactions.	"I was having fun, but I was confused." (PA12)

Behaviors After Using the Virtual Reality Tool to Conduct the Chemistry Exercise

Five main themes emerged from the analysis of participants' responses to the open-ended question "Describe how you felt, emotionally and physically, right after the VR experience" in section C: Behaviors in the student perception survey and the notes from the observations of participants after using the VR tool to conduct the chemistry exercise. The emergent themes were: (a) motivated, (b) joyful, (c) accomplished, (d) surprised, and (e) dissociated. The emergent themes are discussed in the following sections.

Theme 1: Motivated Behaviors

Twenty-five participants showed motivated behavior right after using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling motivated and were observed to be motivated through their shown emotions and body language. Motivated behavior is associated with showing excitement and expressing the desire to wanting to continue or do more.

After completing the VR exercise, some participants shared having the desire to keep using the VR application or use it again to build molecules. To describe how she felt right after the VR exercise, participant PA16 wrote: “I felt the urge to try the VR experience again. It was an amazing experience. It made education look fun, and I think a lot of people my age will want to try it out as well.”

Both participants, PA17 and PA18, shared similar feelings. Participant PA17 wrote: “I was ready to go again, and I am really excited to do it again” and participant PA18 wrote: “I felt good. It was really cool, and I wanted to do it again.” Similarly, participant PA62 appeared to be happy and excited: “I felt like I wanted to do more, and kind of just playing around with it. I was happy.”

To describe how motivated he was to use the VR application, participant PA24 shared his desire to get the molecule application: “I felt that I wanted to get this game on my brother’s VR and play more because it was fun.” In line with that, participant PA14, who appeared to be excited, shared his desire to keep using the VR application: “I did not want to leave. I just wanted to stay forever.” Likewise, participant PA34 showed a very highly motivated behavior by sharing that his VR experience made him willing to pursue a chemistry degree: “After using this application, it made me more willing to pursue chemistry in school and when I graduate. This was a new type of learning I have never seen before, and I think it should definitely be a part of the modern learning system today.”

Some participants attributed their motivation to the use of VR as a learning tool. For example, participant PA30 wrote: “Interested to do more. This is the type of learning I would do all day. I really enjoyed it." Similarly, participant PA37 elaborated on her motivated behavior by comparing her desire to continue learning using VR to being bored in class: "I wish it would have lasted longer! In class, I get bored, and I look forward for school to end, and It's rare for me to want to keep learning even after I am told to stop. But with VR, I wished I could have kept learning and exploring!"

Theme 2: Joyful Behaviors

Thirteen participants showed joyful behaviors right after using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling joyful and were observed to be joyful through their shown emotions and body language. Joyful behavior is associated with being happy, having fun, and enjoying doing something.

In his response to how he felt right after the exercise, participant PA10 wrote: "After the VR experience, I am still happy and feeling good, and the VR experience was very fun and engaging." Participant PA10 was observed to have a satisfied look and a smile on his face. Sharing a similar view, participant PA19 wrote: "Right after the VR experience, I felt good, and I felt like the app was fun." Elaborating on her joyful behavior, participant PA 28 shared: "Physically, I felt comfortable, and emotionally, I felt relieved that it wasn't something super hard to do/understand. I was happy to experience VR in this way."

Some participants connected their joyful behavior to finding VR useful for learning. For instance, participant PA26 wrote: "Happy and good that I got to try something new that could help me and other students in school." Another instance was participant PA03, who shared: "It was a very fun, interesting, and engaging experience. I feel that all classes should use virtual reality to teach chemistry as well as other subjects." He was observed to display joyful behavior with a smile on his face and balanced body movements.

Furthermore, participant PA02 appeared to be happy and confident after the exercise. She shared her preference for VR over other learning methods: “I felt good, and I would much rather that than the way we do in school.” Both participants, PA05 and PA49, briefly shared having joyful behaviors after the exercise. They both wrote “normal and happy” to describe how they felt. Similarly, participant PA27 shared: “I felt almost the same as when I started; happy and calm.”

Theme 3: Accomplished Behaviors

Seven participants shared feeling accomplished right after using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling accomplished and were observed to be accomplished through their shown emotions and body language. Accomplished behavior is associated with showing pride and smiling with expanded posture.

For example, participant PA60 shared: “I felt accomplished.” He was observed to smile with pride right after the exercise. Similarly, participant PA43 described an accomplished behavior through the feeling of happiness and fulfillment: “I felt calm, happy, and somewhat fulfilled.” Participant PA43 was observed to be relaxed and proud after the exercise.

Some participants connected their accomplished behavior to what they had learned during the exercise. For example, participant PA56 was observed to have an expanded posture and verbally expressed pride in the successful completion of all tasks right after the exercise. He shared that he learned something new by writing: “I felt like I walked away knowing more than I came in with.”

Another example was participant PA59, who also shared learning something new and was observed to have an expanded posture and verbally by saying “wow!” right after completing the exercise. In her response to how she felt right after the exercise, she wrote: “I felt like I learned a lot of stuff that I wouldn't have known." One more example was participant PA15, who was observed to be nodding her head and expressing her pride right after the exercise: "Happy, felt like I've "learned" something."

Theme 4: Surprised Behaviors

Six participants displayed surprised behavior right after using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling surprised and were observed to be surprised through their shown emotions and body language. Surprised behavior is associated with being surprised, amazed, and in awe. Raised eyebrows and open mouth are examples of body language associated with surprised behavior.

Some participants appeared surprised and connected their surprised behavior to how the VR device and application worked. For instance, participant PA47 wrote: "I was really amazed at the VR process, and I hope to use it more in the future." Another instance was participant PA61, who wrote in her response about how she felt right after using the VR tool to conduct the chemistry exercise: "I was really blown away by how cool the technology was." In line with that, participant PA06 shared: "After the VR experience, I felt really excited for things like this to come out in the future, and I was truly amazed at how amazing the program was. I wanted to do it again and felt like I learned much more than I would have with anything else."

One participant, PA04, attributed her surprised behavior to the features of the virtual world. Right after the exercise, her eyebrows were raised, and she said, "wow!" while taking off the VR head-mounted set: "It felt amazing right after taking off the goggles and returning back to reality. Because, as I said before, using the VR felt like I was in an actual lab, conducting experiments and seeing if they worked or not. Overall, this experience was amazing."

Theme 5: Dissociated Behaviors

Four participants displayed dissociated behaviors right after using the VR tool to conduct the chemistry exercise virtually. Participants reported feeling confused or detached from the real world and were observed to be dissociated through their shown emotions and body language. Dissociated behavior was associated with feeling confused and displaying disorientation in facial expressions or body movements. Dissociation is defined as “the sense of detachment and of unreality toward oneself or the external world” (Mondellini et al., 2021). Dissociation can be induced immediately after experiencing an immersive virtual reality environment and usually fades away after a period of time (Mondellini et al., 2021).

For instance, participant PA08 provided a detailed description of his emotional and physical states right after conducting the exercise. He described feeling that the real world was unreal and felt conflicted. During observation, he displayed dissociated behavior through his unbalanced movement and commented: “After the VR experience, physically, I felt like reality wasn’t real; very weird, if that makes sense. I kept tripping a little bit for about a minute. Emotionally, I felt conflicted a little, but mostly surprised and amazed.”

Another instance was participant PA40, who was observed to be wondering and checking her surroundings. She reported feeling disoriented for a short amount of time after the exercise: “Afterwards, I kind of forgot where I was, and it took me a second to realize that it was all just a virtual reality experience.”

Similarly, participant PA51 also experienced dissociative behavior and reported experiencing a hard time recognizing the real world: “After the experience, I felt like I was transported back into a different world.” Table 11 shows the emergent themes from participants’ behaviors after using the VR tool to conduct the chemistry exercise. A description of each theme with an example of a participant quote that represents the theme is provided.

Table 11

Emergent Themes from Participant Behaviors After Using the Virtual Reality Tool to Conduct the Chemistry Exercise

Theme	Description of Category	Example Response
Motivated Behaviors (*n*=25, 40%)	Participants expressed feeling motivated and appeared to be motivated.	"I felt that I wanted to get this game on my brother's VR and play more because it was fun" (PA24).
Joyful Behaviors (*n* =13, 21%)	Participants expressed a feeling of joy and appeared to be joyful.	"After the VR experience, I am still happy and feeling good, and the VR experience was very fun and engaging" (PA10).
Accomplished Behaviors (*n* =7, 11%)	Participants expressed a feeling of accomplishment and appeared to be accomplished.	"I felt accomplished" (PA06).
Surprised Behaviors (*n* =6, 10%)	Participants expressed feeling surprised and appeared to be surprised.	"I was really blown away by how cool the technology was" (PA61).
Dissociated Behaviors (*n* =4, 6%)	Participants expressed a feeling of dissociation and appeared to be dissociated.	"After the VR experience, physically, I felt like reality wasn't real; very weird, if that makes sense. I kept tripping a little bit for about a minute. Emotionally, I felt conflicted a little, but mostly surprised and amazed" (PA08).

Finally, a summary of participants' behaviors identified before, during, and after using the VR tool to conduct the chemistry exercise is provided in Table 12. Excited and anxious behaviors were the most common two behaviors before the exercise. Joyful behaviors were a common theme among behaviors for the three periods but dominated behaviors during the exercise along with engaged behaviors. Motivated behaviors were the most common behaviors after the exercise, followed by joyful behaviors. While ambivalent behaviors were a common theme before and during the exercise, they were not displayed by any participant after the exercise. Some behaviors were displayed during one period only, such as excited and anxious behaviors, which appeared only before the exercise. Similarly, engaged and virtually present behaviors only appeared during the exercise, while motivated, accomplished, surprised, and dissociated behaviors were displayed only after the exercise.

Table 12

Themes from Participant Behaviors Before, During, and After Using the Virtual Reality Tool to Conduct the Chemistry Exercise

Before	During	After
Excited Behaviors (*n*=22, 35%)	Joyful Behaviors (*n*=29, 47%)	Motivated Behaviors (*n* =25, 40%)
Anxious Behaviors (*n*=15, 24%)	Engaged Behaviors (*n*=14, 23%)	Joyful Behaviors (*n*=13, 21%)
Ambivalent Behaviors (*n* =13, 21%)	Virtually Present Behaviors (*n* =10, 16%)	Accomplished Behaviors (*n* =7, 11%)
Joyful Behaviors (*n* =6, 10%)	Ambivalent Behaviors (*n* =5, 8%)	Surprised Behaviors (*n* =6, 10%)
		Dissociated Behaviors (*n* =4, 6%)

Summary

The purpose of this study was to explore middle school students' perceptions, experiences, and behaviors towards using VR as a learning tool. In this chapter, I reported the results and findings from the four research questions. Data utilized to answer the research questions were generated from 62 middle school student participants as well as from observations I collected during the study period.

The data collected from the participants came in both quantitative and qualitative forms, and findings were integrated by merging the results from both the qualitative and the qualitative data. The qualitative data were derived by conducting observations and interviews prior to the acquisition of the survey results. I conducted observations and individual interviews with all 62 student participants. The quantitative data were acquired through the use of a demographic survey and a 24-item Likert-scale survey that was adapted from four validated questionnaires conducted by Huang and Liaw (2018), Huang et al. (2010), and Huang et al. (2016).

The results and findings revealed that the majority of participants had positive perceptions towards the use of virtual reality as a tool to learn chemistry. Additionally, the results showed that females and males shared similar perceptions and gender was not a determinant factor in participants' perceptions. In regard to experiences, the results revealed that participants had positive experiences while using the VR tool to conduct the chemistry exercise, with fewer participants having mixed experiences that were positive but challenging or confusing.

A major contribution of this study was in exploring participants' behaviors associated with the use of VR for learning before, during, and after the exercise. The results revealed that positive behaviors were the leading behaviors at each period of data collection. Also, the results revealed a positive change in participants' behaviors as participants moved from one period to the next one.

In chapter V, I provide a discussion of the results and findings of the results and findings as they pertain to each research question. Comparisons of the results and findings is also provided as they relate to current research in the area and across different participant groups. Finally, a conclusion is made, which includes recommendations for future research and how this information can be utilized in the integration of virtual reality technology into education.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The purpose of this exploratory mixed methods study was to explore the perceptions, experiences, and behaviors of middle school students in the state of Colorado towards the use of virtual reality technology in chemistry education. A total of 62 middle school students agreed to take part in the study. The driving questions behind this research were the following.

Q1 What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Q2 Are there any differences between female and male middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?

Q3 How do middle school students describe their experience during the chemistry exercise using the VR tool?

Q4 How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?

This study was based on a pragmatic theoretical framework and an epistemology of subjectivism, and this framework was held consistent throughout the study. Overall, the student participants shared a sense of positive perceptions, experiences, and behaviors towards the use of virtual reality as a tool to learn chemistry. This overall sense of positivity was consistent across all four research questions, with only a few exceptions.

In this chapter, I discuss the results and findings acquired through the analysis of observation notes, interview responses, and survey data. This discussion includes the connections between the findings and existing literature, limitations of the study, recommendations for future research, and how this information can be utilized within the integration of virtual reality technology into education. Finally, I provide a summary and concluding remarks at the end of the chapter.

Research Question One

The first research question asked: "What are middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise?". This question was answered using two data sources: results from the 24 Likert-scale items in section A: Perceptions in the student perception survey and findings from participant responses to the five open-ended questions in section B: Reflections in the student perception survey. The results and finding across both modes of data collection and analysis showed that the student participants' perceptions of the use of VR as a tool to learn chemistry were positive. The discussion for research question one first addresses the quantitative results and qualitative findings separately. Then a side-by-side comparison is used to merge the results from both the quantitative and the qualitative findings for this research question (Creswell & Creswell, 2017).

Interpretation of Quantitative Results

The section A: Perceptions in the student perception survey was created to address student participants' perceptions toward using VR technology as a learning tool in chemistry. This section had 24 Likert-scale items that were housed under six factors of perceptions: (a) ease of use, (b) interaction, (c) imagination, (d) immersion, (e) motivation, and (f) intention to use. The findings are discussed by the overall mean, six factors of perceptions, and 24 Likert-scale items in the following section.

The overall mean of student participant response to perceptions was 4.58, and all six factors of perceptions received positive responses (*M*>=4.37) with mean scores ranging from 4.37 to 4.71. These numbers indicate that student participants, overall, had very positive perceptions of using VR technology as a learning tool in the chemistry exercise. These results confirm the findings of previous research studies (Alfalah et al., 2017; Hagge, 2021; Huang & Liaw, 2018; Kim & Ahn, 2021; Shim et al., 2003).

Within the scope of the six factors of perceptions, the student participants revealed that they felt most positive toward the intention to use (*M*=4.71) and the motivation (*M* =4.69) factors. These numbers suggest that student participants highly intended to use VR as a learning tool in the future and felt motivated to learn using VR. The result of highly positive perceptions toward the intention to use is in line with a previous study's findings by Alfalah et al. (2017), who reported that 92% of the student participants intended to use VR as a learning medium if implemented in their classrooms (Alfalah et al., 2017).

In contrast, student participants revealed that they felt least positive toward the interaction (*M* =4.37) and the ease of use (*M* =4.47) factors. These numbers suggest that some of the student participants found it was not easy to interact inside the VR application and not easy to use the VR equipment, the VR application, or both. These results confirm the findings of a previous study conducted by Shim et al. (2003), where the majority of middle school students reported finding VR easy to use in biology education, except for a few students who thought it was not that easy to use (Shim et al., 2003).

In the student perception survey, all 24 survey items had mean scores greater or equal to 4.20. These numbers suggest that student participants perceived all items very positively. The results from the five items with the highest mean scores (survey items 14, 17, 24, 21, and 22).

Among the five items with the highest mean, three items (survey items 21, 22, and 24) were from the intention to use factor, which suggests that the features of the VR application and equipment positively impacted the student participants' intention to use VR in the future.

In contrast, the results from the five items with the lowest mean scores (survey items 2, 3, 8, 9, and 13). Among the five items with the lowest mean, two items (survey items 2 and 3) were from the ease of use factor and two items (survey items 8 and 9) were from the interaction factor, which suggest that student participants' perceptions were slightly impacted by the difficulty of using the Molecule Builder application and technical issues they faced while they were building molecules. However, most student participants maintained positive perceptions and strong intentions toward the use of VR as a tool for learning.

Interpretation of Qualitative Findings

The three themes identified during the thematic analysis of student participant responses to the open-ended questions in section B: Reflections in the student perceptions survey were: (a) advantages of using VR as a tool to learn chemistry, (b) disadvantages of using VR as a tool to learn chemistry, and (c) and suggestions about using VR applications for teaching chemistry.

Among the reported advantages of using VR as a tool to learn chemistry (theme 1), the first sub-theme of "provide 3-D visualizations" was the most predominant advantage reported by student participants (*N*=20, 32%). This result suggests that 3-D visualizations made it easier for participants to understand the structure of molecules by making them visible and touchable. This supports and confirms previous findings of a study conducted by Bennie et al. (2019), in which students acknowledged the educational value of using 3-D virtual environments in teaching and reported positive perceptions of 3-D visualizations in VR (Bennie et al., 2019). Overall, the sub-theme of "provide 3-D visualizations" that emerged from this study was aligned with the findings from previous studies conducted by Santos Garduño et al. (2021), Limniou et al. (2008), and Won et al. (2019) that addressed the use of VR applications in teaching chemistry and reported positive perceptions of the provision of 3-D visualizations in educational VR applications.

Virtual reality's support of interactive and hands-on learning was also recognized by participants (*N*=17, 27%) as the second prominent sub-theme of "support interactive learning" among the reported advantages of using VR as a tool to learn chemistry (theme 1). In this study, interactive learning was found to increase students' motivation and interest, which is aligned with existing literature (Abdinejad et al., 2021; Santos Garduño et al., 2021). In this study, VR's provision of interaction was found to improve engagement and help students focus, specifically when learning chemistry. Within psychology and neuroscience, research has shown that multisensory processing increases attention (Talsma, 2015). Interactive learning that utilized hands-on activities was associated in this study with improved learning outcomes through retention and recollection of information, which confirms the findings of two research studies conducted by Bennie et al. (2019) and Gabunilas et al. (2018) which both reported the benefits of interactive learning provided by VR applications.

Additionally, the sub-theme of "enhance student attention" was reported as an advantage of using VR as a tool to learn chemistry (theme 1) by student participants (*N*=15, 24%). This finding shows that features of VR enhanced students' focus and helped them maintain their attention, as another advantage (theme 1). This result confirmed the findings of a study conducted by Santos Garduño et al. (2021), who evaluated the impact of virtual reality on high school students' attention and found that the majority of students reported that VR enhanced their attention. As students often do not maintain their attention throughout an entire class or lecture, one successful approach in literature to hold students' attention is through using interactive learning instead of passive learning (Bunce et al., 2010).

Although most student participants reported advantages to the use of VR as a learning tool (theme 1) in this study, some disadvantages of using VR as a tool to learn chemistry (theme 2) were also reported. Among the reported disadvantages of using VR as a tool to learn chemistry (theme 2), the predominant sub-theme was "encounter technical issues" as 15 student participants (24%) reported experiencing difficulties that are associated with the way the VR application is designed and built. In the literature, it is reported that encountering technical issues while using VR systems could negatively affect users' perceptions and experiences (Domingo & Bradley, 2018).

In this study, participants found it was not easy to grab and connect the atoms. Sometimes, that was due to some participants' lack of experience in using VR. Another reason was the glitches in the application itself. While participants were using the VR to conduct the chemistry exercise, I was able to watch what participants were doing inside the virtual world on my laptop screen, using the VR casting feature. I noticed that some participants failed multiple times to grab and connect the atoms due to glitches in the application but not because they were doing it incorrectly. Sometimes atoms would disappear even when they were placed in the right place. Another contributing reason was the use of wireless connections and wireless devices in VR systems, which can cause technological glitches. This study was conducted at a local library, and the wireless internet connection was not always strong or stable. Technological glitches with wireless connections were reported in previous studies as challenges (Han, 2021; Sprenger & Schwaninger, 2021; Xie et al., 2019) and were confirmed in this study.

Another reported disadvantage of using VR as a tool to learn chemistry (theme 2) was the sub-theme of “receiving insufficient feedback,” which was reported by 12 student participants (14%). This result revealed the importance of providing feedback and guidance to students in the learning process. Existing literature points out that students expect and appreciate receiving helpful information, detailed instructions, and sufficient feedback when using VR applications (Kim & Ke, 2016; Merchant et al., 2013; Reeves et al., 2021; Zacharia et al., 2015). Providing sufficient and helpful feedback offers students an effective and positive learning experience. Furthermore, student participants in this study also reported a lack of embedded guidance within the application used in this study to direct students on how to perform certain functions. Some student participants went through the tutorial quickly and did not practice all of the provided examples. This might have contributed to some students feeling that there was not enough guidance within the VR application, since some instructions were given only in the tutorial.

Among the suggestions about using VR applications for teaching chemistry (theme 3), the predominant sub-theme was “recommend using VR as a learning tool” which was reported by 35 student participants (56%). This sub-theme aligned with the overall positive perceptions of using VR as a learning tool in this study. Student participants shared their enthusiasm to integrate VR in teaching chemistry and other subjects and based their recommendation on the benefits of using VR as a learning tool, such as interactive learning, visualizations, and engagement. This result is in line with the findings from previous research studies by Domingo and Bradley (2018) and Soto et al. (2020) that reported the recommendation of using VR for learning by student participants.

Integrating Quantitative and Qualitative Results

In this section, a side-by-side comparison is used to merge the results from both the quantitative and the qualitative findings for research question one. In convergent mixed methods design, both quantitative and qualitative data are collected and analyzed separately, and results are integrated during the discussion using a side-by-side approach (Creswell & Creswell, 2017). A comparison was provided when a correspondence between the quantitative and the qualitative findings was possible.

The quantitative findings led to overall positive perceptions towards using VR as a tool to learn chemistry with a positive overall mean score equal to 4.58, positive mean scores for all six factors of perceptions ($M >= 4.37$), and positive mean scores for all 24-Likert scale items ($M >= 4.20$). Qualitatively, the majority of participants reported advantages of VR as a tool to learn chemistry (theme 1) and contributed to the sub-theme of "recommend using VR as a learning tool" ($N=35$, 56%) in the suggestions about using VR to teach chemistry (theme 3), which indicate participants' positive perceptions towards the use of VR as a tool to learn chemistry.

The factor with the highest mean score among the six factors of perceptions was the intention to use factor ($M = 4.71$). Three of the five highest mean scores among individual survey items in the student perception survey (survey items 21, 22, and 24) belonged to the intention to use factor. These results align with the most predominant sub-theme of "recommend using VR as a learning tool" in the suggestions about using VR to teach chemistry (theme 3). Also, student participants recommended using VR as a learning tool assuming the role of a teacher, which indicates that they intended to use VR if they were the teacher.

Another plausible interpretation is based on the fact that the provision of 3-D visualizations enhances students' understanding of concepts, engagement, and learning overall.

When students reported the sub-theme of “provide 3-D visualizations” (*N*=20, 32%) as a major advantage among the advantages of using VR for learning chemistry (theme 1), followed by the sub-theme of “support interactive learning” (*N*=17, 27%) and the sub-theme of “enhance student attention” (*N*=15, 24%), that led them to consider using VR as a learning tool in the future and to be motivated for this form of learning. This finding aligns the reported advantages of VR as a tool to learn chemistry (theme 1) with the two factors with the highest overall mean scores: intention to use (*M* =4.71) and motivation (*M* =4.69).

The two factors with the lowest mean scores among the six factors of perceptions were interaction (*M* =4.37) and ease of use (4.47). Among the five items with the lowest mean scores, two items (survey items 2 and 3) belonged to the ease of use factor and two items (survey items 8 and 9) belonged to the interaction factor. These results are congruent with the first two sub-themes of “encounter technical issues” (*N*=15, 24%) and “receive insufficient feedback” (*N*=12, 19%) that belong to the disadvantages of VR as a tool to learn chemistry (theme 2). Based on the items associated with the ease of use and the interaction factors, technical issues and insufficient feedback might lead participants to feel that the VR application was not easy to use and hard to interact with.

In terms of the reported disadvantages of using VR as a tool to learn chemistry (theme 2), participants reported the predominant sub-themes of “encounter technical issues” (*N*=12, 24%) and “receive insufficient feedback”. Also, the sub-theme of “improve the VR application” under the suggestions about using VR applications for teaching chemistry (theme 3) was reported by eight student participants (13%). These findings were aligned with the relatively lower mean score for the ease of use factor (*M* =4.47) among all six factors of perceptions, as the sub-theme of “improve the VR application” referred mostly to the sub-theme of “receive insufficient feedback” under the disadvantages of using VR as a tool to learn chemistry (theme 2).

Research Question Two

The second research question asked: “Are there any differences between female and male middle school students’ perceptions toward using VR technology as a learning tool in the chemistry exercise?” Three data sources were used to answer this question: (a) participants’ responses to the 24 Likert-scale questions in Section A: Perceptions in the student perception survey, (b) demographic data from the demographic survey, and (c) participants’ responses to five open-ended questions in Section B: Reflections in the student perception survey. Both qualitative and quantitative data were used to address the second research question. The results and finding across both modes of data collection and analysis revealed that both females and males shared similar perceptions towards using VR as a tool to learn chemistry.

The statistical analysis indicated a non-statistically significant difference between female (M =4.64) and male (M =4.57) students’ perceptions towards using VR as a tool to learn chemistry based on gender. Among the six factors, females perceived five factors of perceptions (ease of use, interaction, imagination, immersion, and motivation) higher than males, except for the intention to use factor. Females scored the highest mean value in motivation (M =4.78), while males scored the highest mean value in intention to use (M =4.75). These numbers indicated that females were more motivated to use VR than males, while males intended to use VR in the future more than females. Both females and males scored the lowest mean value in the interaction factor. This result could be attributed to the technical issues that participants reported while interacting with the atoms and molecules inside the VR application, which were represented in the sub-theme of “encounter technical issues” from the disadvantages of using VR as a tool to learn chemistry (theme 2). The biggest difference between males and females was in interaction and immersion, where females scored 0.13 higher mean value than males in both factors. The smallest difference between males and females was in intention to use, where males scored 0.04 higher mean value than females. This result shows that females and males perceived the intention to use factor similarly.

Among the 24 individual survey items, results revealed that female and male students had three survey items (14, 22, and 24) with the highest mean scores. Item 14—“I paid more attention when using 3-D molecules” which belongs to the immersion factor is tied to the inherent benefits of 3-D molecules in enhancing students’ attention and focus, which was the sub-theme of “enhance student attention” from the advantages of using VR as a tool to learn chemistry (theme 1) reported by eight females (13%) and seven males (11%) in this study. Furthermore, item 22— “I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry” and item 24— “Overall, I think that the Molecule Builder application is worth being a good learning tool,” both belong to the intention to use factor, are tied to the sub-theme of “recommend using VR as a learning tool” from the suggestions about using VR applications for teaching chemistry (theme 3).

The individual survey item results also showed that female and male students had four survey items (2, 3, 8, and 9) with the lowest mean scores among the 24 survey items. Item 2—“Learning how to use the Molecules Builder application was easy” and item 3— I was able to accomplish the exercise using the Molecules Builder application easily” belong to the ease of use factor, while item 8—“Using the Molecule Builder application, I was able to move 3-D molecules easily” and item 9—“Using the Molecule Builder application, I was able to rotate 3-D molecules easily” belong to the interaction factor. These low scores can be explained by the technical issues that participants reported in grabbing and connecting the atoms to build the molecules, which were represented in the sub-theme of “encounter technical issues” under the disadvantages of using VR as a tool to learn chemistry (theme 2).

In addition, the biggest mean value difference between males and females was in survey item 13— The Molecule Builder application created a realistic-looking learning environment” which belongs to the immersion factor, where females scored 0.47 higher mean value than males. This result showed that females and males perceived the virtual environment as being realistic slightly different. However, there is no mean value difference between males and females in survey item 11 (I feel the Molecule Builder application improved my understanding by the imagination of the molecule structure), which reflects a common view of females and males on the benefit of providing a visual representation of invisible elements to students in this study.

Qualitatively, females and males shared similar perceptions on all three themes and most sub-themes of perceptions toward using VR as a learning tool with few exceptions. Females reported slightly more advantages of using VR as a tool to learn chemistry (theme 1: *N*=28, 45%) compared to males (*N*=24, 39%). In contrast, males reported slightly more disadvantages of using VR as a tool to learn chemistry (theme 2: *N*=23, 37%) and the suggestions about using VR applications for teaching chemistry (theme 3: *N*=27, 44%) compared to females (*N*=19, 30%, and *N*=25, 40%, respectively).

Among the reported advantages of using VR as a tool to learn chemistry (theme 1), the “Provide 3-D visualization” was the most reported sub-theme by both females and males, which is congruent with survey item 14— I paid more attention when using 3-D molecules” with the highest mean scores among all survey items by both genders. This result confirms that both females and males perceived 3-D visualizations highly positively.

On the other hand, among the reported disadvantages of using VR as a tool to learn chemistry (theme 2), the "encounter technical issues" was the most reported sub-theme by both females and males. This result is congruent with the four survey items (2, 3, 8, and 9) that had the lowest mean scores among the 24 survey items by females and males in this study. The reported technical issues highly influenced how participants perceived the ease of use and the interaction of the VR application.

Despite reporting some disadvantages of using VR as a tool to learn chemistry, student participants of both genders highly recommended using VR as a learning tool in this study. In the suggestions about using VR application for teaching chemistry (theme 3), the sub-theme of "recommend using VR as a learning tool" was the most reported suggestion by both females (*N*=18, 29%) and males (*N*=17, 27%). This shows that the advantages outweighed the disadvantages of VR based on student participants' perceptions in this study.

A closer look shows that females and males contributed to most sub-themes equally or almost equally, with two exceptions. The first exception was for the sub-theme of "requires a learning curve" under the disadvantages of using VR as a tool to learn chemistry (theme 2), which was suggested by one female (2%) compared to four males (7%). This result showed that the learning curve was a bigger concern for males compared to females. Additionally, three females (5%) suggested the sub-theme of "provide user training" under the suggestions about using VR applications for teaching chemistry (theme 3) compared to six males (10%). This showed that males seemed to be more aware of the need for training compared to females in this study. The results confirmed the findings of a previous research study that assessed the perceptions of college students towards the use of VR in education based on gender and found that female participants perceived their VR experience slightly more positively than male participants (Pröbster & Marsden, 2021).

Research into gender differences in the use of VR as a tool for learning is scant, but previous research on gender differences in the use of other technologies can provide some insight into the phenomenon. Additionally, research into gender differences in the use of VR as a tool for learning is focused on VR effectiveness and students' efficacy, not students' perceptions (Dayarathna et al., 2020; Madden et al., 2020). The results for research question two attest to the disappearance of the digital divide between females and males as gender was not a significant determinant of students' perceptions towards using VR as a tool to learn chemistry.

Research Question Three

The third research question asked: "How do middle school students describe their experience during the chemistry exercise using the VR tool?". Experiences of middle school students in using the VR tool to build molecules came only from one data source: individual interviews with all 62 participants. Two themes emerged from the interviews: (a) positive experiences (*N*=52, 84%) and (b) mixed experiences (*N*=10, 16%). Overall, student participants expressed an overall sense of positive experiences in using the VR tool for the chemistry exercise.

Positive experiences (theme 1) were dominated by interactive experiences (*N*=23, 37%) and virtually present (*N*=14, 23%) experiences, followed by engaging experiences (*N*=6, 10%) and educational (*N*=5, 8%) experiences. It is not surprising to have the interactive experiences dominating the positive experiences (*N*=14, 23%), as the VR application provided 3-D visualizations of atoms and molecules and enabled students to interact with them. This result was consistent with the quantitative results and qualitative findings from the perceptions in research question one in this study, in which student participants scored the highest mean for survey item 14 (I paid more attention when using 3-D molecules) and the sub-themes of “provide 3-D visualizations” and “support interactive learning” dominated the reported advantages of using VR as a tool to learn chemistry (theme 1).

Similarly, virtually present experiences (*N*=14, 23%) were the second dominant experiences among the reported positive experiences (theme 1). Virtual presence is a distinguishing feature of VR compared to other technologies. This result shows that the features of the VR application used in this study have succeeded in leading the participants to feel virtually present and recognize their sense of virtual presence in the virtual environment with a positive feeling towards the experience.

The reported mixed experiences (theme 2) included experiences that were positive yet challenging experiences (*N*=5, 8%) or positive yet confusing experiences (*N*=5, 8%). The results of this study indicated that student participants had mostly positive experiences during the chemistry exercise using the VR tool, which confirms the findings of previous research studies (Chang & Lai, 2021; Edwards et al., 2019; Hill & du Preez, 2021; Pröbster & Marsden, 2021; Ross, 2020; Santos Garduño et al., 2021).

However, no negative experiences were reported by any participant in this study, which was contrary to other research studies (Hill & du Preez, 2021; Santos Garduño et al., 2021). After a VR teaching intervention, Hill and du Preez (2021) evaluated students’ experiences and found that most students (73.3%) reported having positive experiences of using VR for learning, but 4.4% of student participants reported negative experiences. In addition, Santos Garduño et al. (2021) evaluated students’ experience of using VR based on the perceived sense of accomplishment, pleasure, enjoyment in interacting with VR, and their attitude towards having more of these activities. They found that most participants (71%) reported having positive experiences. However, 8% of participants reported negative experiences (Santos Garduño et al., 2021).

Research Question Four

The fourth research question asked: "How do middle school students behave before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions?" Two data sources were used to answer this question: observation notes and participants' responses to three open-ended questions in section C: Behaviors in the student perception survey. The researcher recorded observations notes while observing participants right before, during, and right after using the VR tool to conduct the chemistry exercise.

The results showed that before the exercise, the predominant behaviors were excited (*N*=22, 35%) followed by anxious (*N*=15, 24%) behaviors as most participants were excited to try the VR while other participants were nervous about trying something new for the first time. During the exercise, joyful (*N*=29, 47%) and engaged (*N*=14, 23%) behaviors were predominant as participants were happy and focused while experiencing and interacting with the virtual world. After the exercise, participants were predominantly motivated (*N*=25, 40%) to continue using the VR application based on their positive experiences and were joyful (*N*=13, 21%) about what they had done during the exercise.

The theme of joyful behaviors emerged three times throughout the three different periods of the chemistry exercise. A noticeable increase in joyful behaviors was apparent from before the exercise (*N*=6, 10%) to during the exercise (*N*=29, 47%). While preparing the VR equipment for participants right before the exercise, they appeared excited or anxious, but during the exercise, participants became more joyful while they were experiencing the virtual world and completing the tasks. After the exercise, joyful behaviors appeared (*N*=13, 21%) fewer times than during the exercise.

The theme of ambivalent behaviors emerged before and during the chemistry exercise. A closer look shows before the exercise, ambivalent behaviors (*N*=13, 21%) appeared as some participants were excited yet nervous about participating because they wanted to try the VR equipment and application for the first time but were unsure what to expect or how well they would do in the exercise. However, during the exercise, ambivalent behaviors appeared much less (*N*=5, 8%) than before the exercise. The display of ambivalent behaviors during the exercise could be due to the technical issues reported by a few student participants as they were trying to grab and connect the molecules unsuccessfully, which confused some participants. As expected, ambivalent behaviors were not present after the exercise.

The theme of virtually present behaviors (*N*=10, 16%) only appeared once during the exercise, as virtual presence is tied to being in the virtual world. Similarly, the theme of accomplished behaviors (*N*=7, 11%) appeared only once after the exercise, could be because accomplishment was a result of completing the exercise. Additionally, the theme of dissociated behaviors (*N*=4, 6%) exclusively appeared after the exercise, as dissociation or the sense of detachment is experienced after moving back from the virtual world to the real world (Mondellini et al., 2021).

Overall, the change in behaviors across the three periods was characterized by a shift toward more positive behaviors and less negative behaviors. Positive behaviors include excited, joyful, engaged, virtually present, motivated, accomplished, and surprised, while negative behaviors include anxious, ambivalent, and dissociated behaviors. The results from this study contribute to addressing the existing gap in literature stemming from the lack of research studies that investigate students' behavior associated with the use of VR for learning. The results from this study align with the results from a study conducted by Edwards et al. (2019), in which participants were demonstrated joyful and engaged behaviors during the use of VR to build molecules.

Limitations of the Study

This study was not without limitations. This study had four limitations that are discussed. The first limitation of this study was the single opportunity for a brief time period that each participant had in the VR immersive environment, which created different levels of comfort. As a result, the overall perceptions, experiences, and behaviors of students could be impacted.

The second limitation of this study was the use of the survey instrument. The survey had two sets of questions: Likert-scale questions, and open-ended questions. Although the Likert-scale items were adapted from previously validated questionnaires, a few of the survey items were modified to fit within the context of this study. Therefore, the validity of these modified items could not be verified.

The third limitation of this study was the size of the sample. Only 62 student participants took part in this study. Data collection occurred during the COVID-19 pandemic, which was a challenging time to recruit participants due to the concern of in-person contact. It was also challenging to get approval from school districts to gain access to school students as potential participants.

The final limitation was the use of a commercial application. The application was an off-the-shelf product that was not designed specifically for this study. The features of the application could impact the perceptions and experiences of students. As a result of these limitations, the transferability of this study to other student groups or VR applications could be limited.

Recommendations for Future Research

The primary objective of this research study was to explore the perceptions, experiences, and behaviors of middle school students towards using a virtual reality application to build molecules. Four recommendations for future research are provided.

First, this study focused on using VR as a tool to learn chemistry and used a molecule-building application. Future research could integrate VR as a learning tool in other subjects, including STEM and non-STEM subjects. Second, this study explored how middle school students behave when using VR for learning during different periods. The behavioral data revealed a change in student participants' behaviors across different periods. However, the evaluation of behaviors was done through subjective self-reporting reporting by student participants and objective observations by the researcher. Future research could investigate students' behavior associated with VR for learning with additional objective measures of physiological reactivity such as heart rate variability and skin conductance.

Third, in this study, student participants only had a single opportunity with a limited amount of time to use the VR equipment and to experience the virtual environment. Future research could evaluate students' perceptions, experiences, and behaviors through a series of VR sessions that span a more extended period for more in-depth studies. Finally, the participants in this study included 62 middle school students. Future research could investigate the use of VR that focuses on different student populations and with larger sample sizes to improve the transferability of the results and findings.

Summary

In this chapter, I discussed the results and findings of an exploratory mixed methods study designed to evaluate the perceptions, experiences, and behaviors of middle school students towards using virtual reality technology as a learning tool. Four research questions were addressed in this chapter. Research question one addressed the perceptions of students toward using VR technology as a learning tool in the chemistry exercise. The discussion addressed quantitative results of 24-Likert-scale items in section A: Perceptions in the student perception survey and qualitative findings from participants' responses to the five open-ended questions in section B: Reflections in the student perception survey. Research question two addressed the differences between female and male middle school students' perceptions toward using VR technology as a learning tool in the chemistry exercise. The discussion addressed the comparison of quantitative results of 24-Likert-scale items in section A: Perceptions in the student perception survey and qualitative findings from participants' responses to the five open-ended questions in section B: Reflections in the student perception survey based on gender. Research question three addressed middle school students' experiences during the VR chemistry exercise. The discussion addressed qualitative findings from individual interviews with each student participant. Research question four addressed middle school students' behaviors before, during, and after using the VR tool to conduct the chemistry exercise regarding emotions, body language, and any apparent reactions. The discussion addressed qualitative findings from participants' responses to the three open-ended questions in section C: Reflections in the student perception survey and observation notes recorded by the researcher while observing participants right before, during, and right after using the VR tool to conduct the chemistry exercise. This chapter also included a discussion of the limitations of this study and recommendations for future research.

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APPENDIX A

DEMOGRAPHIC SURVEY

Pseudonym:

Please check the box that best describes you in each of the following:

1. Age:
    - 12
    - 13
    - 14
    - 15
2. Grade (completed in 2020-2021school year):
    - 7th
    - 8th
3. Gender:
    - Female
    - Male
    - Other
4. VR Experience: How much virtual reality experience do you have?
    - Never used it
    - Fundamental (common knowledge only)
    - Novice (can use it with help)
    - Intermediate (can use it independently)
    - Expert

APPENDIX B

OBSERVATION PROTOCOL

Time of Observation: Date:

Place:

Participant's Pseudonym:

Observation	Before	During	After
Emotion			
Behavior			
Other			
Researcher's Reflective Notes			

APPENDIX C

INTERVIEW PROTOCOL

Time of Interview: Date:

Place:

Interviewee's Pseudonym:

Interview Questions:

1. Describe your experience of using VR in the chemistry exercise.
2. What models have you used before, inside or outside the classroom, to build molecules?
3. How is your experience of building molecules in 3-D using VR is different from previous experiences of building molecules?
4. Based on your experience in conducting the exercise, how do you feel about using VR as a tool to learn chemistry?
5. Why do you feel that way?

APPENDIX D

STUDENT PERCEPTION SURVEY

Student Perception Survey

Section A: Perceptions
Rate your level of agreement with each statement below, please:

Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Ease of Use					
1. Learning how to use the VR device was easy.					
2. Learning how to use the Molecules Builder application was easy.					
3. I was able to accomplish the exercise using the Molecules Builder application easily.					
4. The Molecules Builder application provided me with the features I needed to complete the exercise.					
5. Using the Molecule Builder application for creating molecules was convenient for me.					
6. Using the Molecule Builder application for testing molecule correctness was convenient for me.					
Interaction					
7. Using the Molecule Builder application, I was able to observe 3-D objects from various perspectives easily.					
8. Using the Molecule Builder application, I was able to move 3-D molecules easily.					

9. Using the Molecule Builder application, I was able to rotate 3-D molecules easily.					
Imagination					
10. The VR application gave me more engagement to help me understand molecules.					
11. I feel the Molecule Builder application improved my understanding by the imagination of the molecule structure.					
12. I feel the Molecule Builder application helped me better understand by the imagination of the relative positions of atoms.					
Immersion					
13. The Molecule Builder application created a realistic-looking learning environment.					
14. I paid more attention when using 3-D molecules.					
15. I felt immersed in the 3-D Molecules VR experience.					
Motivation					
16. I feel that using virtual reality to build 3-D molecules is impressive.					
17. The Molecule Builder application can enhance my learning interest.					

18. The Molecule Builder application can enhance my learning motivation.					
19. I felt that the 3-D simulated chemistry lab made me concentrate more while learning.					
Intention to Use					
20. I think this system can strengthen my intentions to learn.					
21. I am willing to use virtual reality for learning in the future.					
22. I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry.					
23. I wish that teachers adopt virtual reality technology to facilitate my learning of other subjects.					
24. Overall, I think that the Molecule Builder application is worth being a good learning tool.					

Section B: Reflections

25. What did you like most about conducting the chemistry exercise through the virtual reality application?
26. What did you like least about conducting the chemistry exercise through the virtual reality application?
27. What was the most helpful thing about building molecules using the virtual reality application?
28. What was the least helpful thing about building molecules using the virtual reality application?
29. If you were a teacher, what suggestions would you make about using virtual reality applications for teaching chemistry?

Section C: Behaviors

30. Describe how you felt, emotionally and physically, right before the VR experience.
31. Describe how you felt, emotionally and physically, during the VR experience.
32. Describe how you felt, emotionally and physically, right after the VR experience.

APPENDIX E

STUDENT PERCEPTIONS SURVEY BY MEAN

	Item	Mean	SD
Ease of Use		4.47	0.64
1.	Learning how to use the VR device was easy.	4.50	0.57
2.	Learning how to use the Molecules Builder application was easy.	4.32	0.70
3.	I was able to accomplish the exercise using the Molecules Builder application easily.	4.44	0.67
4.	The Molecules Builder application provided me with the features I needed to complete the exercise.	4.56	0.59
5.	Using the Molecule Builder application for creating molecules was convenient for me.	4.50	0.62
6.	Using the Molecule Builder application for testing molecule correctness was convenient for me.	4.52	0.67
Interaction		4.37	0.76
7.	Using the Molecule Builder application, I was able to observe 3-D objects from various perspectives easily.	4.51	0.62
8.	Using the Molecule Builder application, I was able to move 3-D molecules easily.	4.39	0.76
9.	Using the Molecule Builder application, I was able to rotate 3-D molecules easily.	4.20	0.89
Imagination		4.63	0.66
10.	The VR application gave me more engagement to help me understand molecules.	4.71	0.66
11.	I feel the Molecule Builder application improved my understanding by the imagination of the molecule structure.	4.66	0.65
12.	I feel the Molecule Builder application helped me better understand by the imagination of the relative positions of atoms.	4.52	0.67
Immersion		4.61	0.60
13.	The Molecule Builder application created a realistic-looking learning environment.	4.32	0.72
14.	I paid more attention when using 3-D molecules.	4.87	0.38
15.	I felt immersed in the 3-D Molecules VR experience.	4.65	0.70
Motivation		4.69	0.58
16.	I feel that using virtual reality to build 3-D molecules is impressive.	4.70	0.59
17.	The Molecule Builder application can enhance my learning interest.	4.74	0.58
18.	The Molecule Builder application can enhance my learning motivation.	4.66	0.60

19.	I felt that the 3-D simulated chemistry lab made me concentrate more while learning.	4.69	0.56
Intention to Use		4.71	0.58
20.	I think this system can strengthen my intentions to learn.	4.56	0.69
21.	I am willing to use virtual reality for learning in the future.	4.76	0.62
22.	I wish that teachers adopt virtual reality technology to facilitate my learning of chemistry.	4.76	0.50
23.	I wish that teachers adopt virtual reality technology to facilitate my learning of other subjects.	4.69	0.62
24.	Overall, I think that the Molecule Builder application is worth being a good learning tool.	4.77	0.46

APPENDIX F

TESTING ONE-WAY MULTIVARIATE ANALYSIS OF VARIANCE ASSUMPTIONS

Assumption	Met or not
Assumption #1: The two or more dependent variables are measured at the interval or ratio level (i.e., they are continuous).	Student perception is measured by a 5-point Likert-scale (1 to 5).
Assumption #2: The independent variable consists of two or more categorical, independent groups.	The independent variable is gender: male, female, and others.
Assumption #3: Independence of observations.	There was not any participant in more than one group.
Assumption #4: Adequate sample size.	The sample size was 60, with 30 females and 30 males.
Assumption #5: There are no univariate or multivariate outliers.	There are no significant outliers based on the Boxplots. When the system pointed to outliers, a manual diagnosis was performed. All numbers are in the range of 1-5.
Assumption #6: There is multivariate normality.	The data **is not normally** distributed, because: Shapiro-Wilk test value (male, Overall Ease of Use), p = .007 <.05 Shapiro-Wilk test value (male, Overall Interaction), p = .014 <.05 Shapiro-Wilk test value (male, Overall Imagination), p = .000<.05 Shapiro-Wilk test value (male, Overall Immersion), p = .000<.05 Shapiro-Wilk test value (male, Overall Motivation), p = .000<.05 Shapiro-Wilk test value (male, Overall Intention to Use), p = .000<.05 Shapiro-Wilk test value (female, Overall Ease of Use), p = .001 <.05 Shapiro-Wilk test value (female, Overall Interaction), p = .001 <.05 Shapiro-Wilk test value (female, Overall Imagination), p = .000<.05 Shapiro-Wilk test value (female, Overall Immersion), p = .000<.05 Shapiro-Wilk test value (female, Overall Motivation), p = .000<.05 Shapiro-Wilk test value (female, Overall Intention to Use), p = .000<.05 ***The rule:*** *if p >0.05 tells the distribution is not significantly different from normal distribution (it is probably normal).*
Assumption #7: There is a linear relationship between each pair of dependent variables for each group of the independent variable.	The scatterplot for each group with each dependent variable showed some of the relationships of males group are linear and the other once are not. For the female group, all the relationships are almost linear.
Assumption #8: There is homogeneity of variance. In order to meet the assumption of homogeneity of variance, the p-value for Levene's Test should be above .05. If Levene's Test yields a p-value below .05, then the assumption of homogeneity of variance has been violated.	There was homogeneity of variance. Levene's Test has been executed. Overall Ease of Use, p = .766 Overall Interaction, p = .480 Overall Imagination, p =.429 Overall Immersion, p =.473 Overall Motivation, p =.247 Overall Intention to Use, p =.253

Assumption #9: There is no multicollinearity. Dependent variables should be moderately correlated with each other.	The correlations between the dependent variables were almost moderate. Values are: .458 .315 .299 .437 .379 .505 .348 .504 .410 .470 .697 .580 .594 .514 .585

APPENDIX G

CORRELATION ANALYSIS RESULTS

Correlations

		Ease of Use	Interaction	Imagination	Immersion	Motivation	Intention To Use
Ease of Use	Pearson Correlation	1	.458**	.315*	.299*	.437**	.379**
	Sig. (2-tailed)		.000	.014	.020	.000	.003
	N	60	60	60	60	60	60
Interaction	Pearson Correlation	.458**	1	.505**	.348**	.504**	.410**
	Sig. (2-tailed)	.000		.000	.006	.000	.001
	N	60	60	60	60	60	60
Imagination	Pearson Correlation	.315*	.505**	1	.470**	.697**	.580**
	Sig. (2-tailed)	.014	.000		.000	.000	.000
	N	60	60	60	60	60	60
Immersion	Pearson Correlation	.299*	.348**	.470**	1	.594**	.514**
	Sig. (2-tailed)	.020	.006	.000		.000	.000
	N	60	60	60	60	60	60
Motivation	Pearson Correlation	.437**	.504**	.697**	.594**	1	.585**
	Sig. (2-tailed)	.000	.000	.000	.000		.000
	N	60	60	60	60	60	60
Intention To Use	Pearson Correlation	.379**	.410**	.580**	.514**	.585**	1
	Sig. (2-tailed)	.003	.001	.000	.000	.000	
	N	60	60	60	60	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX H

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF NORTHERN COLORADO

Institutional Review Board

Date:	08/18/2021
Principal Investigator:	Dalal Alrmuny
Committee Action:	**IRB EXEMPT DETERMINATION – New Protocol**
Action Date:	08/18/2021
Protocol Number:	2108028182
Protocol Title:	Middle School Students Perceptions, Experiences, and Behaviors Towards Using a Virtual Reality Application to Build Molecules
Expiration Date:	

The University of Northern Colorado Institutional Review Board has reviewed your protocol and determined your project to be exempt under 45 CFR 46.104(d)(701) for research involving

Category 1 (2018): RESEARCH CONDUCTED IN EDUCATIONAL SETTINGS. Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

You may begin conducting your research as outlined in your protocol. Your study does not require further review from the IRB, unless changes need to be made to your approved protocol.

As the Principal Investigator (PI), you are still responsible for contacting the UNC IRB office if and when:

- You wish to deviate from the described protocol and would like to formally submit a modification request. Prior IRB approval must be obtained before any changes can be implemented (except to eliminate an immediate hazard to research participants).
- You make changes to the research personnel working on this study (add or drop research staff on this protocol).

UNIVERSITY OF NORTHERN COLORADO

Institutional Review Board

- At the end of the study or before you leave The University of Northern Colorado and are no longer a student or employee, to request your protocol be closed. *You cannot continue to reference UNC on any documents (including the informed consent form) or conduct the study under the auspices of UNC if you are no longer a student/employee of this university.
- You have received or have been made aware of any complaints, problems, or adverse events that are related or possibly related to participation in the research.

If you have any questions, please contact the Research Compliance Manager, Nicole Morse, at 970-351-1910 or via e-mail at nicole.morse@unco.edu. Additional information concerning the requirements for the protection of human subjects may be found at the Office of Human Research Protection website - http://hhs.gov/ohrp/ and https://www.unco.edu/research/research-integrity-and-compliance/institutional-review-board/.

Sincerely,

Nicole Morse
Research Compliance Manager

University of Northern Colorado: FWA00000784