An-Najah National University

Faculty of Graduate Studies

IMPACT OF VIRTUAL REALITY IMMERSION ON HABITS OF MIND IN BIOLOGY CLASSES: MEDIATING ROLES OF SELF-REGULATION, FLOW AND MOTIVATION IN EAST JERUSALEM HIGH SCHOOLS

By

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Dedication

To the souls of my beloved father and mother, whose love, sacrifices, and unwavering support in my early years continue to inspire me even in their absence.

To my dear wife and wonderful children, who patiently endured my absence and busy schedule, offering their endless support, understanding, and encouragement throughout this journey.

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Declaration

I, the undersigned, declare that I submitted the dissertation entitled:

IMPACT OF VIRTUAL REALITY IMMERSION (VRI) ON HABITS OF MIND (HoM) IN BIOLOGY CLASSES: MEDIATING ROLES OF SELF-REGULATION (SR), FLOW EXPERIENCE (FE), AND MOTIVATION (MT)

I declare that the work provided in this dissertation, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **Nader Mohammad Issa Neiroukh**

Signature:

Date: **12.06.2025**

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IMPACT OF VIRTUAL REALITY IMMERSION ON HABITS OF MIND IN BIOLOGY CLASSES: MEDIATING ROLES OF SELF-REGULATION, FLOW AND MOTIVATION IN EAST JERUSALEM HIGH SCHOOLS

By
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Abstract

The present mixed-methods study aimed to investigate the effects of virtual reality immersion on enhancing scientific habits of mind (critical and creative thinking) through the mediation of flow experience, motivation and self-regulation in biology classes of high school students in East Jerusalem high schools. The random multistage cluster sample consisted of (347) high school students from 3 different schools who learnt biology concepts constructively during the first semester using VR-based instruction complying with the Cognitive Affective Model of Immersive Learning (CAMIL). The results of PLS-SEM revealed that VRI significantly affected critical and creative thinking directly and indirectly. Cases of partial and full mediation intervened, showing the effects of mediators on enhancing habits of mind, through a sequence of mediation flowing from flow experience through motivation to self-regulation which functioned as a key intermediary factor in the relationship between virtual reality immersion and habits of mind. Based on the results of the study, the complex structure needs more future investigation. Results of the study suggested that VRI's impact on critical and creative thinking was intensified through the mediation effects. In addition, the findings confirm that FE and MT play essential roles in fostering a conducive learning environment that supports cognitive skill development. Results highlighted that enhancement of SR is a necessary step for the enhancement of critical and creative thinking. The study recommends integrating VRI in teaching biology to enhance students' higher order thinking skills. Further studies on Self-Regulation should explore adaptive interventions that strengthen self-regulatory strategies to maximize the cognitive benefits of VRI.

Keywords: Virtual reality immersion, motivation, flow experience, self-regulation, habits of mind, critical thinking, creative thinking, East-Jerusalem Schools.

Chapter One
Introduction and Theoretical Background

1.1 Introduction

A world that is mainly characterized by an over-dependence on digitized technologies will certainly pose new challenges and requirements over the shoulders of the people living it as part of the natural human adaptation process with the environment. Education, as an inevitable aspect of human life, has been undergoing rapid restructuring and development in its goals, strategies, methods, approaches, techniques, and evaluation systems to keep pace with the non-stop, fast going, and developing field of technology. Different educational requirements such as learners' competencies, learning environments, and methods of teaching and learning accompanied the emergence of every technological development. In today's world of education, learners are required to process information, rather than memorize it; they are also required to think critically, creatively, and innovatively, rather than traditionally. Higher order thinking skills became a must for future learners to be able to face the challenges of their age. Hence, education must seek more interesting and engaging methods of teaching to help learners acquire and process information intelligently as part of the adaptation process with the technological world.

During the past decade, digital transformation, and new technologies such as augmented reality (AR), virtual reality (VR), or mixed reality (MR) have greatly influenced the field of education. AR and VR technologies have witnessed significant advancements in recent years and have the potential to revolutionize various fields, including the field of education (Macchi & De Pisapia, 2024). Digital tools and new technologies keep on improving overtime. Tools like VR became of great importance in the educational field in a way that they affected every aspect of the teaching learning process as tools used to enhance learning motivation and student outcomes (Cevikbas et al., 2023). Therefore, it became critically important for educators to understand their impact on group dynamics and cognitive performance in professional settings (Macchi & De Pisapia, 2024). This awareness will enable curriculum designers, school principals and educators to effectively plan for the best strategies to be applied for a smooth and successful achievement of the goals wished for.

Constructivism is a learning theory that builds upon the limitations of behaviorism and cognitivism by emphasizing the learner's active role in constructing knowledge through personal experiences and meaning-making Constructivism is learning by making sense of personal experiences. Amineh and Asl (2015) state that it has roots in Piaget's "constructivist" views (1967), as well as in the developmental perspective of Jean Piaget (1969), and in Bruner's (1996) "constructivist" description of discovery learning. This fact makes it difficult to arrive at a unified definition of the term although it is believed nowadays that it is one of the leading theories in education (Mvududu & Thiel-Burgess, 2012).

Constructivism believes that learning is an active process (Fadli et al., 2024; Kurt & Sezek, 2021) that enhances thinking skills (Angraini et al., 2024; Vijayakumar Bharathi & Pande, 2024) and that knowledge is a quality that is built around discovery and is constructed best when the learner is free to discover and solve problems (Kurt & Sezek, 2021; Mvududu & Thiel-Burgess, 2012; Sengul, 2024; Stigall & Sharma, 2017) rather than acquired by oral transmission of information and can be implemented at any grade level (Zhao et al., 2023) either within a group or individually (Marougkas et al., 2023). It affects critical thinking (CRIT) and creativity in problem-solving and therefore, improves academic achievement (Almulla, 2023).

New technologies made the adoption and application of the principles of constructivism possible. Constructivism is a theoretical foundation for employing digital immersive technologies in education. It suggests that students actively build their understanding of the world through their experiences and interactions with their surroundings (Tang, 2024). Teachers with more constructive instructional practices were found to depend more on technology (Overbay et al., 2010). However, the philosophy and concepts of constructivism should be taken into consideration when enhancing classrooms with technology.

Ioannou-Georgiou (2002) identified the major constructivist principles of learning as an active process that occurs in authentic, interesting, and meaningful contexts. It should take place in whole activities, such as projects, and not isolated skill exercises. Therefore, VR as a device capable for bringing about active learning and enhancing thinking skills was admired by the fans of Cognitive Affective Model of Immersive Learning (CAMIL) as a promising device for the construction of knowledge.

1.2 Theoretical Background

Recent studies about engagement support the idea that interactive teaching methods generate higher levels of students' engagement (Kurt & Sezek, 2021). In a study about the use of VR in educational environments (Scavarelli et al., 2021) were optimistic about the use of VR as an educational tool. The study concluded that VR-based instruction is effective for enhancing learning outcomes.

VR activities conform to the principles of constructivism as they are whole, context-dependent activities, which allow students to be active and construct their own reality, manage their contributions, collaborate with other students, and reflect on their actions (Ioannou-Georgiou, 2002 pp. 21-23). Implementation of VR in instruction provides more immersion and engagement which facilitates the perception of complex concepts effectively and constructively (Marougkas et al., 2023). The study concluded that VR allows students to participate in immersive, interactive experiences that provide students with opportunities to explore, experiment and discover which makes VR the best educational platform.

According to Abdussemiu (2022), biology aims to study and comprehend live organisms and how they function. Students must directly observe and experience the relevant content. Biology should be learnt in a simple and engaging manner in rich biology labs to shift from teacher-centred into student-cantered classrooms. Biology helps us describe and understand natural processes in our environment through observation and experimentation. Researchers note that biology learning requires exploring and discovering the natural world. The study concluded that improving students' comprehension of biology is based on establishing rich biology labs that are equipped with technological tools. Students should have free access to them and should be provided with the required resources .

According to Etobro and Fabinu (2017), students believe that strategies for teaching biology; inadequate learning resources, and students' learning habits are some of the reasons that cause difficulties. To solve the problem, students suggested the use of various strategies using appropriate instructional materials, implementation of practical and cognitive strategies, integrating biological concepts to daily life and ensuring the availability of sufficient and effective resources.

Similarly, Hadiprayitno et al. (2019) identified some of the difficult topics in biology such as bacteria, cell structure, and nervous system. They found that students' source of difficulty is attributed to the complexity of the topic itself and students' learning habits, in addition to the abstract material. The study concluded that the reasons behind these difficulties are the monotony of teacher's style; the incomplete delivery of material; the boring level of discussion; and the unsupportive academic atmosphere. The presented material usually relies on the power of memorization and the inconducive learning environment. To solve the problem, effective learning methods to make it more concrete and enjoyable should be employed.

Kavanagh et al. (2017) pointed out that educators are encouraged to use VR in the educational environment due to its ability to increase immersion, engagement, enjoyment, and collaborative learning experiences which facilitate the application of constructivism. Teamwork is expected to be crucial in enhancing CRIT skills among students according to (Tang, 2024).

Students can engage with diverse perspectives, solve problems, and participate in analytical tasks which contribute to the development of CRIT when they work together. Collaboration among teams develops self-directed learning practices through encouraging learners to be responsible for their learning within the group. A learner-centered environment where knowledge can be constructed through actual experiences can be easily applied by the help of VR technology (Serna-Mendiburu & Guerra-Tamez, 2024; Zhao et al., 2023). Meaningful learning according to constructivism happens when learners interact with the surrounding environment, engage in exploration, experimentation, and reflection (Pande & Bharathi, 2020).

Attempts to enhance the quality of science teaching and learning process and enhancing HoM usually engage learners in scientific practices to encourage the 'how' and 'why' of the learners CRIT (Wang et al., 2024). According to constructivist principles, the enhancement of HoM focuses on actively, creatively, and productively constructing one's own understanding based on prior knowledge and experiences.

King & McCall (2024) consider HoM as the soft skills that are needed for success in our globalized world and that overlooking collaboration opportunities is a narrow-minded approach to education. On the other hand, Kingir et al. (2013) consider classroom environment as an important social context of the learning process. It impacts learners' motivation and self-regulation which is according to Zimmerman (2002) refers to self-generated thoughts, feelings and actions that are planned and cyclically adapted to achieve personal goals. Therefore, a constructivist social context of the learning environment enhances motivation through affecting learners' self-efficacy and finally enhancing their self-regulation skill.

On the other hand, flow experience, characterized by intense and focused concentration and intrinsic enjoyment during activities, is manifested in students' intrinsic motivation describing how they feel and think (N. H. Lee et al., 2022).

Richardson (2023) considers any interactive content as always preferred to a static one in terms of retention, cognition, and increased levels of engagement. Educators nowadays can integrate a combination of media in the classrooms to increase students' interaction (Chang et al., 2011), and therefore, an increased engagement or immersion, leading to better outcomes (Behmanesh et al., 2022; Haleem et al., 2022). VR in education has a great potential in providing students with immersive and interactive experiences. VRI technologies and learning experiences have been increasingly used in education settings to support a variety of instructional methods and outcomes by providing experiential and authentic learning experiences (Lowell & Yan, 2024; Marougkas et al., 2023).

HoM also need to be developed to function more effectively and meet the requirements of the age. Well-developed HoM are badly needed for survival in this constantly changing world (Karunarathne & Calma, 2024; Wang et al., 2024). Developing human resources who think, and act intelligently is the concern of nations nowadays to enable for the making of the right decision, in the right moment. Achieving this, everyone is expected to be able to overcome various complex life problems in all aspects of his daily life (Idris & Hidayati, 2017). Mind skills such as strategic reasoning, insightfulness, perseverance, creativity, and craftsmanship to resolve complex problems under pressure are urgently needed. Today's world is not interested in how much we know as much as how we behave when we don't know (Costa & Kallick, 2000; Idris & Hidayati, 2017). Kurt & Sezek (2021) prefer that students learn the main reasons underlying the events instead of learning the subjects by memorizing which guarantees their abilities to apply the knowledge in new situations. Costa and Kallick (2000) state that creating self-directed learners is the goal for teaching HoM. Idris & Hidayati (2017) believe that everyone faces problems during lifetime and needs to think intelligently about solving them. HoM are formed when facing problems with no clear-cut or definite answers and coming up with solutions. The question then, is how knowledge is remembered and constructed in the thinking process. This intelligent behavioral ability is called the habits of mind according to Costa & Kallick (2000).

It is very important to develop students' HoM to behave and act intelligently in a world that stresses productive HoM as key elements for academic, work, and social success. Students need to be equipped with a well-shaped and developed HoM (Susilowati et al., 2018). HoM is a mixture of skills, attitudes, and experiences of the past and are very supportive of students' performance in everyday life (Idris & Hidayati, 2017). They can be developed by applying specific learning models and techniques based on student-centred environments where students can freely explore their knowledge and share ideas.

Based on the above, this study aims to investigate the effects of VRI method of teaching biology on high school students' HoM based on Marzano et al. (1993)'s habits of minds, namely: SR, CRIT and CRET considering the mediating effects of flow experience and motivation.

1.2.1 Virtual Reality (VR)

VR is a three-dimensional computer-generated virtual environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with (Freina & Ott, 2015; Kamińska et al., 2019).

Kazlauskaitė (2022) defines VR by its spatial, visual, and interactive nature. It envelopes users inside a virtual environment which creates a sense of presence that makes users feel as if they are living in that environment or a part of it.

The term 'Virtual Reality' was first coined in 1938 by the French playwright Antonin Artaud in his book 'The Theatre and Its Double', but elements of VR appeared in 1960s. Imagination from Sci-fi movies introduced a new generation of VR (Kenwright, 2019). The first idea of VR was presented by Ivan Sutherland in 1965: "*make that (virtual) world in the window look real, sound real, feel real, and respond realistically to the viewer's actions*" (Mandal, 2013). The first prototype of a VR head-mounted display, The Sword of Damocles, invented by Ivan Sutherland in 1968, was influenced by the flight simulators of the 1960s (Kazlauskaitė, 2022). The Next Generation’ of VR starts in the 21st century with new worlds and universes that are both real and imaginary (multi-verses) from flying through space and standing on the surface of Mars to swimming through body or interacting with molecules on an atomic level (Kenwright, 2019).

The first wave of VR applications took place during the last two decades of the past century followed by a second wave in the market with the development of the first prototype of the Oculus Rift VR headset, which was acquired by Facebook in 2014 for $2.3 billion (Kazlauskaitė, 2022). Since then, the applications and accessibility of VR for the different sectors have continued to grow. Education as a major field of technology application started searching how to utilize the tool to improve educational outcomes.

1.2.1.1 Virtual Reality Immersion (VRI)

VRI is a state of mind that refers to the degree to which senses are absorbed in the virtual simulation with enjoyment, energy, and involvement (Berkman & Akan, 2019). Zhang (2020) provides a comprehensible definition that sums up all common elements of immersion: “Immersion in a virtual environment is a technology-mediated illusion that, through mimetic system offering priming stimuli and cues, engulfs one’s senses and leads to the alignment of one’s attentional focus to a synthetic yet perceptually authentic reality, by taking the visuo-spatial and emotional perspectives of the virtual agent(s), depending on one’s imaginative facilities and mental dispositions and tendencies.”

Implementing VR in education provides a more immersive and engaging learning experience. Villena-Taranilla et al. (2022) classify immersion into three levels based on devises: Non-immersive mood obtained by devices like computers and laptops; semi-immersive mood, by multiscreen devices and glasses, and immersion devices represented by VR headsets. VR takes the learners to difficult-to-access places, such as historical monuments, outer space or even within the human body. Students can better understand the subject and engage with the learning material (Marougkas et al., 2023).

According to Di Mitri et al. (2024) immersive learning highlights the idea of enhancing the quality of authenticity of educational experiences. It can create different levels of realism, feedback, and interaction using high-immersion VR. It has been increasingly used in the field of education for its immersive and interactive capabilities.

Recent technologies define VRI as user's engagement with a VR system resulting in a flow state. Immersion to VR systems depends on sensory immersion, which is the degree to which the range of sensory channel is engaged by the virtual simulation" (Kim & Biocca, 2018).

Digital immersive technologies according to Tang (2024) promote divergent thinking and self-directed learning. Engagement through immersion provides interaction and participatory experiences that encourage learners to engage in learning responsively and develop critical thinking by providing chances to solve problems and make decisions.

Immersion, according to Schubert et al. (2001) is a cognitive process that leads to the emergence of presence. Presence is a psychological phenomenon or a state of consciousness that generates a sense of being in the virtual environment. Whereas immersion is an objective description of the technology in terms of the extent to which the device can deliver illusions or reality to the user, presence is a subjective experience that can only be quantified by the user experiencing it and is the outcome of immersion. For presence to occur, the virtual environment should be inclusive, extensive, surrounding, and vivid. The more similar the transformations in the virtual environment are to those in the real world, the higher the presence. However, Ochs and Sonderegger (2022) explained that although immersion and presence are slightly different in terms of scope and definition, the two concepts are closely linked: if immersion is high, presence will be high and vice versa. Zhang (2020) argues that both immersion and presence can be described as a proactive function that reflects the purpose of the multimedia system or reactive psychological feedback that is perceived and experienced by the user when interacting with the system. Presence, according to Zhang (2020), is a by-product of the properties of immersion that depends on the degree of attention of the users as they displace themselves in the physical world. In short, presence in a mediated environment can be enhanced when the environment is immersive. The difference between the two terms is summarized in the difference between 'I am in this place' versus 'I am in that place'.

According to Schubert et al. (2001) presence through immersion is based on the extent to which a user feels present in, enveloped by, and interact with a virtual environment. There are three major components for presence: 1. Spatial presence: refers to the user's sense of being physically in the virtual environment. 2. Involvement: refers to the feeling of inclusion and interaction with the virtual environment. 3. (Realness) or Experiential Reality (ER): refers to the extent to which objects in the virtual environment seem authentic to the user, compared with the real world.

1.2.1.2 Virtual Reality in Education

CAMIL adopts a constructivist view of learning by emphasizing the central role of immersion and interactivity during VR instruction. Different types of constructivist paradigms, no matter how divergent, all emphasize active construction of knowledge (Mütterlein, 2018). VR provides high levels of visual immersion. Makransky et al. (2021) emphasize that interactivity refers to the amount of freedom the user is given to control the learning experience, often through handheld controllers and a virtual body.

VR has been in the field of education since the end of the past century when it was used as a flight simulator in the United States, but its widespread has been delayed for problems related to cost and limitations of the technology itself (Kavanagh et al., 2017). VR refers to human immersion in a synthetic world according to Elmqaddem (2019) and its educational value lies in its ability to improve and facilitate learning, increase memory capacity, and make better decisions while working under entertaining and stimulating conditions.

Educational VR is the construction of the desired learning environment through the simulation of computer equipment and adding real or virtual pictures in the simulated situations to live and realize that situation (Hu et al., 2016). In other words, it is visiting the subject matter virtually through technology while keeping safe, staying in place, and having the freedom to explore here and there. It provides with highly authentic interaction, allowing the users to operate and interact with the objects through the man-machine interface. Liu et al. (2013) proposed three elements to construct a VR situation which he called (3Is): Immersion, Interaction, and Imagination. Mütterlein (2018), however, noted that it is still unclear how immersion and interactivity provided by VRI contribute to the experience of learning.

According to Elmqaddem (2019), the process of comprehension through VR, compared with comprehension through reading a printed document, results in a considerable reduction of the cognitive effort of the mind in the case of VR because there are fewer symbols to interpret which makes comprehension more direct.

Ochs and Sonderegger (2022) noted that the highly immersive VR is gaining popularity in multiple application domains. In the context of learning, it has been proposed to be beneficial by increasing presence and attention in noisy and distracting environments, both factors that are considered important for learning.

In the study 'Analysis of Pop-Up Book and Biology Virtual Reality Video toward Students' Habits of Mind', Rakhmawati et al. (2020) indicated that Indonesian biology school textbooks, are usually thick, unattractive, and weak. They are full of writings with little pictures that make them incomprehensible. This reduces students' interest in learning and results in a distorted conception of biology concepts. Textbooks should be designed innovatively to meet students' needs and interests. Solmaz et al. (2024) stated that cognitive and behavioral advantages of VR can help educators reduce introductory barriers of new concepts that students usually struggle with. Many applications of VR can be useful, unique, engaging, and motivating in the field of education.

Kamińska et al. (2019) highlight the necessity of abstract thinking for learners, especially in science where concepts are not entirely tangible and might cause deficiencies in understanding fundamentals which consequently hinders further development and exploration of the learner.

Rojas-Sánchez et al. (2023) stressed that practical experiences for competent learners are difficult to apply in a traditional teacher-centred classroom environment for reasons related to time, space, danger, cost or accessibility. This diminishes the major goal of education by its inability to offer students opportunities that foster the acquisition of knowledge, skills, and positive values, particularly in situations of risk or when experiments are not easily accessible in natural classroom environments and therefore hindering active engagement with targeted concepts.

A suggested solution for this deficiency in education was offered by Kamińska et al. (2019) based on VR and its applications which can meet the diverse learners' needs through personalizing learning and tailoring education according to learners' abilities, preferences, and goals. VR allows for repeating the same experiment unlimitedly and making mistakes without imposing a high cost, allowing students to freely explore the learning contents and manipulate with the tools within the learning environment. This VRI affordance can, in turn, encourage users to acquire skills of scientific inquiry (Elme et al., 2022). This enhances constructivism as a paradigm of gaining knowledge and meaning through active, constructive methods (Kavanagh et al., 2017). VR is capable for bringing students into environments that allow for the application of uninhibited interactions in a relaxing atmosphere that enhances collaboration.

1.2.2 Habits of Mind (HoM)

The concept of habits of mind emerged from the field of brain research and education (Alhamlan et al., 2017). It refers to the way our minds behave when confronted with a challenging situation that requires strategic reasoning, insightfulness, perseverance, creativity, and craftsmanship to resolve a complex problem (Costa & Kallick, 2000; Idris & Hidayati, 2017). Alhamlan et al. (2017) define 'Habits' as instinctive behaviors that provide mental space for problem solving without recalling information. Costa & Kallick (2000) on the other hand, emphasize that it should be learnt and practiced before any specific task is accomplished easily. Perkins & Tishman (2001) also highlights that HoM are defined based on continual practice agreeing with Hidayati & Idris (2020) who stated that HoM can be influenced by the teaching and learning processes.

Costa and Kallick (2000) developed a list of sixteen learning and training Habits of Mind (HoM): (persisting; creating, imagining, and innovating; thinking and communicating with clarity and precision; managing impulsivity; listening with understanding and empathy; responding with wonderment and awe; taking responsible risks; striving for accuracy; questioning and posing problems; thinking interdependently; gathering data through all senses; applying past knowledge to new situations; finding humor; thinking flexibly; and remaining open to continuous learning (Ariyati et al., 2020; Costa & Kallick, 2000; Gloria & Darmin, 2017). Costa and Kallick (2000) highlighted that habits of an effective mind seldom appear in isolation and usually function collectively and that the list is open for more effective habits of the mind to be added. Costa and Kallick (2000) introduced HoM in 1985, then Marzano (1992) expanded on them by integrating them into learning dimensions. Marzano et al. (1993) further elaborated on their role in learning in subsequent works.

Therefore, HoM found a place within Marzano's (1993) learning framework. The dimensions of learning consist of positive attitudes and perceptions about learning, acquiring and integrating knowledge, extending and refining knowledge, using knowledge meaningfully, and productive habits of mind. Marzano (1992) as cited in (Sriyati et al., 2011) describes the interconnection between the dimensions of learning as follows: the five dimensions do not function independently but rather in conjunction with one another. The dimensions of learning are influenced by "attitudes and perceptions" in the first dimension and "habits of productive thought" (habits of mind) in the fifth dimension. The first and fifth dimensions are crucial factors that must be taken into account in the learning process. It is important that students adopt attitudes and perceptions that are conducive to learning to utilize effective habits of mind. Acquiring knowledge is important however, using productive habits of mind used by critical, creative, and self-regulated thinkers is more important. Learners need to develop mental habits that enable them to learn whatever they want and whenever they want on their own. This progression of ideas signifies the evolution of understanding in education (Hidayati & Idris, 2020). Marzano et al. (1993) categorized HoM into: SR, CRIT, and CRET.

Marzano et al. (1993) identified the most important five life-long learning outcomes as:

1. A self-directed learner who sets priorities and achievable goals; monitors and evaluates his progress; creates options for self; assumes responsibilities for actions; and creates positive vision for self. This outcome belongs to SR.
2. A collaborative worker who monitors own behavior as a group member; assesses and manages group functioning; demonstrates interactive communication; and demonstrates considerations for individual differences. This outcome belongs to CRIT.
3. A complex thinker who uses a wide variety of strategies for managing complex issues; selects strategies appropriate to the resolution of complex issues and applies the strategies with accuracy and thoroughness; and accesses and uses topic-relevant knowledge. This outcome belongs to CRIT.
4. A quality producer who creates products that achieve their purpose; creates products appropriate to their intended audience; creates products that reflect craftsmanship; and uses appropriate resources or technology. This outcome belongs to CRET.
5. Community contributor who demonstrates knowledge about his or her diverse community; takes actions; and reflects on roles as a community contributor. This outcome belongs to CRIT.

1.2.2.1 Self-Regulation (SR)

SR refers to the learner's ability to employ a set of meta skills that enable awareness, monitoring, and adaptation of learning strategies through cognitive and metacognitive processes to maintain psychophysiological balance (Baranovskaya, 2015; Mitsea et al., 2023; Zimmerman, 2002). It is the ability to judge consistency of actions with internal and external demands which enables the learner to adaptively redirect him or herself (Mitsea et al., 2023). Abdalkader (2022) defines SR as the ability to control over oneself in choosing a goal and trying to achieve it by deciding upon what to think, how to feel and what to do. Bayer et al. (2016) define SR as all goal-directed behaviours within at least a minimum temporal perspective.

De La Fuente et al. (2022) view SR as positively related to personal adjustment factors, diligence, and well-adjusted academic behavior. SR is defined as a personality-related psychological construct that describes the ability to plan, monitor, and evaluate one's behavior. SR adopts three principles: personality and metacognitive factors; contextual factors indirectly explain behavioral regulation and individuals' levels of SR are not related to the way they define it.

SR involves the interaction of personal, behavioral, and environmental factors, known as triadic reciprocal causality. Self-efficacy, a key personal factor, results from these interactions and influences behaviors like task choice, persistence, effort, and achievement. Students' progress in tasks boosts their self-efficacy through engagement and enhances their learning performance.

Zimmerman (2002) believes that SR is a self-directed process that enables learners to transform their mental abilities into academic skills. Learning which results from learners' self-generated thoughts and behaviors that are systematically oriented towards the achievement of their learning goals. Learning is a proactive rather that a covert event. Zimmerman (2002) defines SR as 'self-generated thoughts, feelings, and behaviors oriented to attaining goals'. It involves three phases:

1. The *forethought phase*: Prior to performance, when learners set goals and select strategies for meeting them.
2. The *performance phase:* during performance and refers to the processes employed while learners are working on the task. It includes self-control and self-observation.

3. The *self-reflection phase*: after performance when the task is completed. It is the learner's evaluation of their own success.

1.2.2.2 Critical Thinking (CRIT)

CRIT is the ability to look deep into the problem from different perspectives, understand it, analyze it, and finally make a decision about the best actions to be taken to handle it (Jamaludin et al., 2022; Kusmaryono, 2023; Utomo et al., 2023). It is directed towards understanding and solving problems, evaluating alternatives, and decision-making (Campo et al., 2023). Dwyer et al. (2014) define critical thinking as "a metacognitive process, that consists of sub-skills such as: analysis, evaluation, and inference which, if used appropriately, increase probabilities for arriving at logical solutions to a problem. Critical Thinking includes *self-directed, self-disciplined, self-monitored, and self-corrective* thinking (Paul & Elder, 2019). Teaching critical thinking is cognitively challenging and emotionally intimidating endeavour (Li, 2016; Yuan, 2023). The term 'critical thinking' is still abstract and difficult to define for teachers whose critical thinking skills might be humble. Even with teachers with higher levels of thinking skills, it sometimes appears to be hard to relate to their subject matter resulting in a split approach to teaching critical thinking, where the teacher handles critical thinking and content knowledge separately. On the other hand, learners are usually deprived of having the chance to be immersed in the domain of the subject knowledge through their own thinking and real-world connections, which is seen as very important for developing critical thinking according to Yuan (2023).

In a study that investigated the relationship between motivation and critical thinking, Fahim & Hajimaghsoodi (2014) confirmed that there is a significant and positive relationship between CRIT and motivation. The study employed Honey's (2000) 30-item critical thinking questionnaire to assess critical thinking skills, such as analysis, inference, evaluation, and reasoning. A revision of the 30 items of the study showed that many items belonged to self-regulation such as those assessing self-monitoring and self-evaluation, as well as goal-directed strategies.

Critical thinking depends on two components: Skills and dispositions (Fahim & Hajimaghsoodi, 2014; Valenzuela et al., 2017). Skills represent the cognitive component, such as focusing on issues, posing and answering clarifying and/or challenging questions and observing and judging assumptions. The dispositional component such as truth seeking, open-mindedness, self-confidence, inquisitiveness, and maturity of judgement. Research about dispositional components of CRIT is few (Valenzuela et al., 2017).

Prawat (1991) indicated that a common goal of most educators was to improve students' higher order thinking skills. Students' poor performance on national and international assessments resulted in the emergence of three approaches:

Stand-Alone Approach: Teaching thinking skills separated from content.

Embedding Approach: Integrates thinking skills into the regular curriculum.

Immersion Approach: Focuses on deep understanding of the content to develop thinking skills implicitly, which is the main difference from the explicit embedding approach.

The immersion approach according to Prawat (1991), helped students deeply understand the content and promoted higher-order thinking. In other words, immersion enhanced critical and creative thinking.

Orhan & Çeviker Ay (2023) experimented the effects of teaching critical thinking through general, immersion, and mixed approaches on the critical thinking skills and dispositions of high-school students. The results of the study showed that teaching critical thinking with the general approach had a large effect compared with teaching with the immersion approach which had a moderate effect, and teaching critical thinking with the mixed approach which had a small effect on improving students' critical thinking dispositions.

Kanmaz (2022) in a study about teachers' awareness towards teaching critical thinking found that teachers believed that critical thinking skills should be planned in coordination with the course content and should be taught in the context of any lesson or subject area. Critical thinking skills cannot be taught in isolation of their related contexts.

1.2.2.3 Creative Thinking (CRET)

CRET refers to the ability to produce original and appropriate work that is useful and adaptive for the task constraints. It is the ability to rearrange the existing ideas in new combinations to come up with a new design (Sternberg & Lubart, 1998). The Meriam-

Webster Dictionary defines creative thinking as a new way of seeing or doing things, characterized by fluency (generating many ideas), flexibility (shifting perspective easily), and originality (conceiving of something new). According to Usha (2009), it is the ability to conceive an innovative idea and verify its validity with scientific reasoning. Some problems require creative thinking and cannot be solved based on scientific reasoning alone. We need creative thinking because our knowledge is limited. Usha differentiated between logical thinking and creative thinking where logical thinking is selective, follows the most likely paths and seeks only relevant ideas, creative thinking on the other hand is a generative way of thinking that explores the least likely paths through utilizing irrelevant ideas.

Creativity is essential for societal development through inventions and discoveries that our modern life needs. It changes the way people relate to the world, to themselves, and to other people. It enhances decision making and problem solving as complex cognitive processes and facilitates adaptation with the demands of daily life. Creativity can be improved over time by enhancing specific skills and knowledge, and a stimulating environment for individuals' cognitive processes and personality factors, including motivations. students' creativity is assessed under three themes: *creative expression*, *knowledge creation* and *creative problem solving* (Karunarathne & Calma, 2024). Their results highlighted that giving students helpful feedback is crucial for boosting their creative thinking. The progress in students' creative thinking highlights how teachers can help students develop important job skills. The task design, including group work, and feedback processes created a supportive environment that helped students improve their subject-specific skills and knowledge, leading to better creative thinking.

In a study about creative mathematic thinking ability in problem-based learning model based on self-regulation learning, Learning based on student-centered learning principles requiring knowledge and self-confidence, motivation, goals and strategic knowledge, were indications of Self-Regulated Learning (Munahefi et al., 2018). Lindberg et al. (2017) suggest that individual skills and motivation, as well as the external environment are essential for producing creative work. They suggested that giving students chances to learn specific skills, encouraging creativity. Activities like brainstorming and self-directed learning and creating a supportive environment to enhance internal motivation can positively affect their creative skills.

1.2.2.4 Habits of Mind in Education

Habits of Mind greatly impact on success in learning. Scientific HoM need to be fostered at an early age to attract more students to take up science as their future career. To overcome this challenge, educators have been working hard to try to understand how students can best learn science. Although they used different scientific practices and instructional innovations such as coaching, scaffolding, and engaging in authentic tasks, collaboration and creating a community of science practice, still many challenges are facing them (Ariyati et al., 2024). There is a need for a multifaceted approach to face the challenge, and the solution is in technology (Saleh & Khine, 2009; Steinkuehler & Duncan, 2008). There is evidence that HoM and cognitive learning outcomes in biology are affected by learning processes (Ariyati et al., 2024). Therefore, a focus on the components of SR, CRIT, and CRET is required by educators and teachers to get insights into the cognitive and metacognitive skills of students' HoM and enhance it accordingly.

Effects of immersion through VR on HoM can be explained by three major mediating variables:

1.2.3 Flow Experience

FE is a self-reinforcing cycle of energy, motivation, and personal growth (Mirvis & Csikszentmihalyi, 1991). It is a state of complete immersion and optimal experience in an activity. Csikszentmihalyi (2000) first described the term based on qualitative research where interviews focused on activities that do not directly lead to intrinsic motivation, when finally arrived at a state of mind that he termed "Flow experience" which is a general phenomenon that is not exclusive to specific activities and therefore not limited to mere intrinsically motivated activities (Mahnke et al., 2012). It is characterized by a high level of concentration, a sense of control, a merging of action and awareness, and an intrinsic enjoyment in the task at hand. It is a kind of immersion into the experience that causes a feeling of energy and fulfillment. It creates a case of deep concentration, lack of self-consciousness, a feeling of control over what one is doing, complete focus on the task at hand, and a breakthrough in performance (Guerra-Tamez et al., 2021). When engaged in an activity, students may become so completely absorbed that they lose track of time, their surroundings, and everything else except the task at hand (E. Lee, 2005). The Flow Experience refers to the set of elements such as the sense of absorption in the activity, the right level of challenge, the lack of perception of time passing, and the spontaneity of thoughts and actions (Macchi & De Pisapia, 2024).

Nakamura & Csikszentmihalyi (2001) define flow as an experience during which individuals are fully involved in the present moment. A complete absorption in what a person does is a sign of a characteristic of a good life as perceived by them. Persisting single-mindedly on an experience and disregarding hunger, fatigue and discomfort and then losing interest as soon as it is completed is a state of 'Flow'. A synonymous term for the term 'Flow' is the Greek term 'autotelic' meaning self-goal (i.e. an activity which rewards itself, apart from any extrinsic results). Conditions of flow are: 1. Perceived challenges within the scope of the existing skills of the person and 2. Clear proximal goals and immediate feedback about the progress. Flow, when arrived at, people operate at full capacity. The state of 'flow' is characterized by the following: Intense and focused concentration on what one is doing; Merging of action and awareness; Loss of reflective self-consciousness; A sense of control on one's actions; Distortion o f temporal experience (time passed faster than normal); and Experience of the activity as intrinsically rewarding.

Macchi & De Pisapia (2024) hypothesized that VRI enhances higher levels of flow caused by its immersive and stimulating nature. VR is potential to bring about 'flow' through introducing the element of perceived challenge. According to Jackson et al. (2008) 'flow' can be measured using a shortened but validated scale that includes the following dimensions: 1. Challenge-skill balance, 2. Action-awareness merging, 3. Clear goals, 4. Unambiguous feedback, 5. Concentration on the task at hand, 6. Sense of control, 7. Loss of self-consciousness, 8. Time transformation; and 9. Autotelic experience.

According to Agarwal & Karahanna (2000), dimensions of flow included intense concentration, a sense of being in control, a loss of self-consciousness, and a transformation of time.

1.2.3.1 Flow and Immersion

Flow and immersion are used to refer almost to the same experience. Though immersion presents subtle structural differences from flow. There are apparent similarities between flow and immersion when examining popular theories of immersion (Brown & Cairns, 2004). They count some of the shared properties of the two states of mind e.g., concentration, loss of time perception, and loss of self-awareness, however, they consider immersion as a precursor or an antecedent for flow.

Csikszentmihalyi (2000) suggested that flow is an “all-or-nothing” experience. It is whether you are in or not. However, the minimum requirements for the experience to qualify as flow or immersion are still unsettled.

Immersion, however, has been viewed as sub-optimal when compared to flow. Brown & Cairns (2004) identified three levels of immersion: engagement, engrossment and total immersion, and argued that total immersion is not always achievable. The quality of the experience in virtual environments is referred to as presence or immersion. Although slightly different in terms of scope and definition, the two concepts are closely linked: if immersion is high, presence will be high and vice versa (Bowman & McMahan, 2007).

1.2.4 Motivation (MT)

MT is a driving force in the form of a strong desire, will, or tendency to achieve the highest level of success through high quality work (Lase & Noibe Halawa, 2024; Purnama et al., 2019). Motivation is a critical part of success in education and later life. In the process of teaching and learning, the motivational variable has a potentiating effect on students’ learning. Motivation gives reasons for people's actions, desires, and needs to obtain the objective of learning. Learners’ motivation is probably one of the most important elements for learning, which is inherently hard work. Learning is pushing the brain to its limits and thus can only happen with motivation (Filgona et al., 2020). Motivation can be either intrinsic or extrinsic or amotivation:

1.2.4.1 Intrinsic Motivation (IMT)

IMT happens when motivation is caused by inherent satisfaction or enjoyment of the activity or a desire to feel better (Zeng et al., 2022). Mazllami (2020) defines intrinsic motivation as an internal desire that drives a person to produce more and better. It is when a person engages in a particular activity for the sake of the activity itself or for the enjoyment and satisfaction gained from that activity. Self-efficacy, intrinsic interest, and goal orientation are essential for self-motivation and play a crucial role in motivating individuals.

Self-efficacy refers to individuals' expectations about their capability to perform a certain level within a certain domain. Efficacy beliefs are future-oriented and involve cognitive perceptions of skill towards specific tasks (Bandura & Adams, 1977). This influences different aspects of behavior, such as, goal setting, persistence, the effort required to master a task, and resistance to failure. Thompson et al. (2022) note that higher degree of self-efficacy appears to be positively associated with students' attitudes towards learning. Effective instruction has the potential to boost self-efficacy, represented as 'confidence', when listening to authentic lectures.

The stronger the individual perceives self-efficacy, the more active the coping efforts. Individuals with high self-efficacy tend to set challenging goals for themselves and consistently exert effort to achieve difficult tasks. When faced with failure, they often attribute it to a lack of effort or insufficient knowledge. Research has shown that higher levels of self-efficacy are associated with higher levels of SR (Velayutham & Aldridge, 2013).

1.2.4.2 Extrinsic Motivation (EMT)

EMT when motivation is caused by external factors like gaining rewards or avoiding punishment. Extrinsic motivation is when an external result leads to the activity (Rita et al., 2018). There two types of extrinsic motivation according to Deci and Ryan (1985):

Self-determined extrinsic motivation when individuals willingly engage in an activity because they value it and consider it important.

Non-self-determined extrinsic motivation is when individuals pressure themselves to perform an activity or when their actions are perceived to be controlled by external factors.

1.2.4.3 Amotivation

Learners become amotivated when they perceive no connection between their actions and the resulting outcomes. This lack of motivation (i.e. amotivation), neither intrinsic nor extrinsic, leads to feelings of incompetence and expectations of helplessness, potentially causing them to stop participating in actions (Vallerand et al., 1992).

According to Filgona et al. (2020) motivation is responsible for getting students to engage in academic activities, determining how much to learn from the activities they perform or the information they are exposed to. Learners who are motivated to learn something use higher cognitive processes in learning about it. Teachers should create active learning environments that enhances students' perceived autonomy and competence, and to provide them with choices and opportunities for self-directed learning and plan learning activities that might increase students feeling of mastery. VRI provides motivation that can affect cognitive skills such as decision making (Tyrrell et al., 2018).

1.2.5 Flow Experience and Motivation

People's self-determination strength is related to the type of motivation gained by the actions performed according to Lee (2005) where intrinsic motivation creates the strongest self-determination while amotivation results in the weakest form or absence of self-determination. On the other hand, self-determined extrinsic motivational actions are expected to generate more self-determination than with non-self-determined extrinsic motivational ones.

Flow is a term that refers to a case where people act with total involvement (Csikszentmihalyi, 2000). It denotes an optimal engrossing and enjoyable experience where performing the activity itself becomes self-rewarding. This explains an individual's engagement in sports and leisure activities.

One important condition of flow is motivation. This implies that flow is inherently enjoyable which directly relates to extrinsic motivation (Mills & Fullagar, 2008). Most of recent research showed that high motivation generates high levels of flow, however, they focused on leisure or sport activities chosen willingly by the individuals to be intrinsically motivating. They also noticed that previous studies focused only on the relation between intrinsic motivation and flow. However, they assumed that extrinsic motivation may also be related to flow which necessitates distinguishing between intrinsic and extrinsic motivation and their relation to flow. The results of their study showed that self-determined forms of intrinsic motivation were significantly associated with the experience of flow and engagement. However, there was no relation between extrinsic motivation and flow regardless to the degree of self-determination. Other studies, however, found a significant relation between self-determined extrinsic motivation and flow. This might be explained based on the skills and abilities needed for different activities according to them.

Mehta and Vyas (2022) stated that to achieve flow experience, one must voluntarily engage in a joyful task, otherwise, a person may work for satisfaction obtained from benefits received from outside sources. When students are in flow, it is because the task is intrinsically motivating, enjoyable, and requires effort that suits their capabilities and offers immediate feedback. Therefore, they suggested ways to increase the level of intrinsic motivation. A positive leaning environment where learners aim to learn for the sake of knowledge might pave the way for a high intrinsic motivation. Motivation in students increases as they gain a sense of accomplishment after accomplishing the task.

1.2.6 Self-Regulation as a predictor of CRIT and CRET

Zimmerman (1990) defined self-regulated learners as metacognitively, motivationally, and behaviorally active participants in their own learning. Metacognitive processes include goal setting, organization, self-monitoring, and self-evaluation at various points during the process of acquisition. Motivational processes imply that these learners report high self-efficacy, self-attributions, and intrinsic task interest. In their behavioral processes, self-regulated learners select, structure, and create environments that optimize learning. Self-regulation explains how students become masters of their own learning; they approach educational tasks with confidence, diligence, and resourcefulness. They are aware when they know a fact or possess a skill and when they do not. They proactively seek out information when needed and take the necessary steps to master it. When they encounter obstacles, they find a way to succeed. They view acquisition as a systematic and controllable process, and they accept greater responsibility for their achievement outcomes

In summary, definitions of students' self-regulated learning involve three features: their use of self-regulated learning strategies, their responsiveness to self-oriented feedback about learning effectiveness, and their interdependent motivational processes.

Ariyati and Fitriyah (2024) in a study investigating habits of minds of prospected teachers noted that self-regulation has a significant influence on controlling students' emotions, thoughts, and actions therefore, self-regulated students will have metacognitive skills that will impact self-regulation abilities and bring important contributions to learning outcomes. The study concluded that self-regulation is the predominant habitual component of the mind, followed by critical thinking, with creative thinking ranking lowest in prevalence.

In a study to gain insights into the nature of critical thinking and its connections with self-regulation skills. Hyytinen et al. (2021) found that self-regulation is crucial to critical thinking, and a function that guides this complex thinking process. Self-regulation refers to an intentional and adaptive process that allows students to plan, adapt, and monitor their thoughts, emotions, and behaviors to the demands of the task. Akcaoğlu et al. (2023) believe that self-regulation is related to metacognitive skills in that it determines the methods and timing for planning, monitoring and evaluation processes that will be carried out. Lee (2009) examined the relationships between metacognition, self-regulation and critical thinking in an experimental study and found out that self-regulation is a significant predictor of students' critical thinking dispositions. In another study about 'EFL learners' self-regulation, critical thinking and language achievement', Ghanizadeh and Mizaee (2012) found that the enhancement of self-regulatory strategies leads to the development of critical thinking abilities.

In a study exploring the predictive power of self-regulation and academic hope in the creative thinking among undergraduate students, Ghbari and Harahsheh (2024) found that self-regulation is a good predictor of creative thinking. They recommended considering students' self-regulation to foster creative thinking. Lin et al. (2024) examined the ability of two traits of self-regulation, namely, grit and curiosity, in predicting creative achievement. The results of the study showed that the perseverance dimension of grit positively predicted creative achievement, whereas the consistency of interest dimension was negatively related to creative achievement. They concluded that individuals who are persistent and able to regulate efforts to work on an idea long enough have more creative achievement. Munahefi et al. (2018) studied the effects of self-regulation leaning in a problem-based model on the ability of high school students mathematical creative thinking. The study concluded that high academic level students were able to reach the aspect of originality which was the highest aspect in the ability of mathematical creative thinking.

Ivcevic et al. (2024) studied the transformation of creative ideas into creative behavior or completed projects and found out that this transformation is facilitated by the crucial part of self-regulation of creativity.

To conclude, the present study is grounded in several frameworks that altogether provide a foundation for exploring the impact of VRI on students' Habits of Mind. First, constructivism, particularly the CAMIL model which frames learning as an active, self-directed process, aligning with the study's major focus on student higher levels of engagement in immersive environments. Second, Flow Experience Theory which is mainly explained through the lens of Csikszentmihalyi's Flow Theory and describes optimal engagement as a state of deep involvement and enjoyment when challenges and skills are balanced and how this optimal experience influence motivation (Csikszentmihalyi, 2000; Jackson et al., 2008). Moreover, VRI, as previous studies showed, can significantly foster this state of flow, through creating deep engaging learning environments (Guerra-Tamez, 2023; Makransky et al., 2021). Motivation, a key variable in this study, is conceptualized according to the work of (Deci & Ryan, 1985), who assert that learners are most motivated when their basic psychological needs for autonomy, competence, and relatedness are supported. VRI and FE serve as powerful tools to enhance motivation by stimulating interest, engagement, and cognitive involvement (Filgona et al., 2020; Tang, 2024).

The final outcomes of the study: Self-regulation, Critical and Creative thinking are crucial for variables that show how HoM is enhanced in the context of VRI. Costa and Kallick (2000) define HoM as a set of intellectual behaviours that support Critical and Creative thinking through the enhancement of Self-regulation (Gloria & Darmin, 2017; Hidayati & Idris, 2020). On the other hand, Marzano's dimensions of learning (Marzano, 1992; Marzano et al., 1993) that highlights productive habits of mind as essential outcomes of effective learning and intellectual development. Both models highlight engagement, critical and creative thinking as the intended outcomes rather than content mastery. This study views SR, CRIT and CRET as skills that can be enhanced through immersive learning. Moreover, SR as reflected in the model proposed by Zimmerman (1990) is evidenced as a bridge through which Flow Experience and Motivation enhance deeper critical and creative thinking. Hence, discussions and interpretations of the results will be mainly grounded in these theories and other related recent studies to show the connections between VRI as an immersive digital tool and the enhancement of productive habits of mind.

1.3 Problem Statement

The limitations of traditional classroom environments in teaching abstract scientific concepts have contributed to a decline in high school students' enrollment in the scientific stream. One of the weak points of the Palestinian Educational System, according to the Ministry of Education and Higher Education (2010) is that 74% of the students are enrolled in the literary stream, while only 20% are in the scientific stream. Broco and Trad (2011), considered this imbalance as worrying and attributed it to constraints. The Ministry of Education of the State of Palestine (2022) became more concerned about the shrinking number of students choosing to enroll in the scientific stream.

Ochs & Sonderegger (2022) noted that VR as a learning tool has been demonstrated as a promising tool to overcome the traditional constraints by increasing presence and attention in noisy and distracting environments, both factors that are considered important for learning. According to Elmqaddem (2019) the process of comprehension through VR, compared with other methods of teaching, reduces much of the cognitive effort because there are fewer symbols to interpret. VR transforms abstract concepts, such as cellular structures and nerve impulses, into interactive, immersive experiences, allowing students to explore them safely and in detail. VR can help educators reduce introductory barriers of new concepts which students usually struggle with according to Solmaz et al. (2024).

VRI is a new opportunity for the application of experiential learning where students build their knowledge based on experiencing and interacting with their surroundings according to the principles of CAMIL. Immersed learners enjoyably fall in complete absorption in what they are performing, a state derived from enjoyment and engagement through VR and termed FE. This state of FE is characterized by a high level of concentration, a sense of control, and an intrinsic enjoyment in the task at hand which enhances students MT according to Mills and Fullagar (2008). VR-based biology classes are thought to be autotelic for the fun it provides to the learner. It is a hope for out-of-school experiences within the school where students can discover, collaborate and contribute within a safe and convenient environment. VR outperforms interactive screens and computers by giving each student a sufficient opportunity to engage, explore and discover freely while fully immersed and enhances retention and understanding of difficult concepts. VRI has an impact on students' motivation and therefore, affects their SR as an outcome and as a predictor for critical and creative thinking.

Although recent research highlights VRI as a promising educational tool for enhancing immersion, engagement, and motivation, its impact on learners' higher order thinking skills remains underexplored. Further investigation is needed to understand how these cognitive changes translate into improved learning outcomes across different subjects. The qualitative part of the study explains how HoM can be developed by employing VR as a method of teaching. It aims to shed light on its usefulness and effectiveness in shaping and improving students' HoM which might help educators interpret and understand the improved outcomes and encourage more students to confidently follow the scientific stream.

1.4 Research Objective and Questions

The objective of the research is to examine the impact of virtual reality immersion in Biology classes, on East Jerusalem High school students' habits of mind mediated by motivation, flow experience and self-regulation.

Based on the above, the following research questions have been formulated:

RQ1: Are there statistically significant direct effects of VRI as a method of teaching biology on students' HoM?

RQ2: Are there statistically significant indirect effects of VRI as a method of teaching biology on students' HoM through the mediation of FE, MT and SR?

RQ3: How do students perceive the role of mediators FE, MT, and SR in developing their HoM through VRI-based biology classes?

RQ4: How do students perceive the overall impact of VRI-based biology classes on their HoM?

1.5 Significance of the study

The significance of the study lies in its explanation of the potential benefits of VRI method of teaching and learning on high school students' biology education and its effects on shaping their HoM. The study contributes to the underexplored research of VRI in the field of education while the technology is becoming more advanced and widespread as a tool for improving educational outcomes. Through examining the effects of VRI on the cognitive and affective processes of the learner during biology lessons, educators might be enlightened on when and how to employ the tool to gain maximum benefits and how to affect students HoM to meet the requirements of the age.

Explaining the way VRI affects students' HoM during biology classes provides insights to biology teachers for innovative approaches when challenged by scientific complex concepts. Moreover, other educators can get insights about the cognitive and metacognitive benefits of immersion in education in general. As a result, a strategy for enhancing the needed 21st century skills (HoM) is provided with informed use.

In addition, expected practical implications of this study could affect strategies for teaching and learning biology, curriculum design, policy making, and might be extended on other school subjects to improve students' comprehension and achievement through the enhancement of students HoM. This might help create students with enhanced HoM and increase the pool of candidates for science and technology programs.

To conclude, VRI as a promising educational tool that provides immersion, engagement, motivation, and potentially results in enhanced learners' outcomes, emerge as key solution to many educational problems such as improving enrollment in the scientific stream, one of the major concerns of the Ministry of Education, the State of Palestine (2022).

1.6 Study Hypotheses

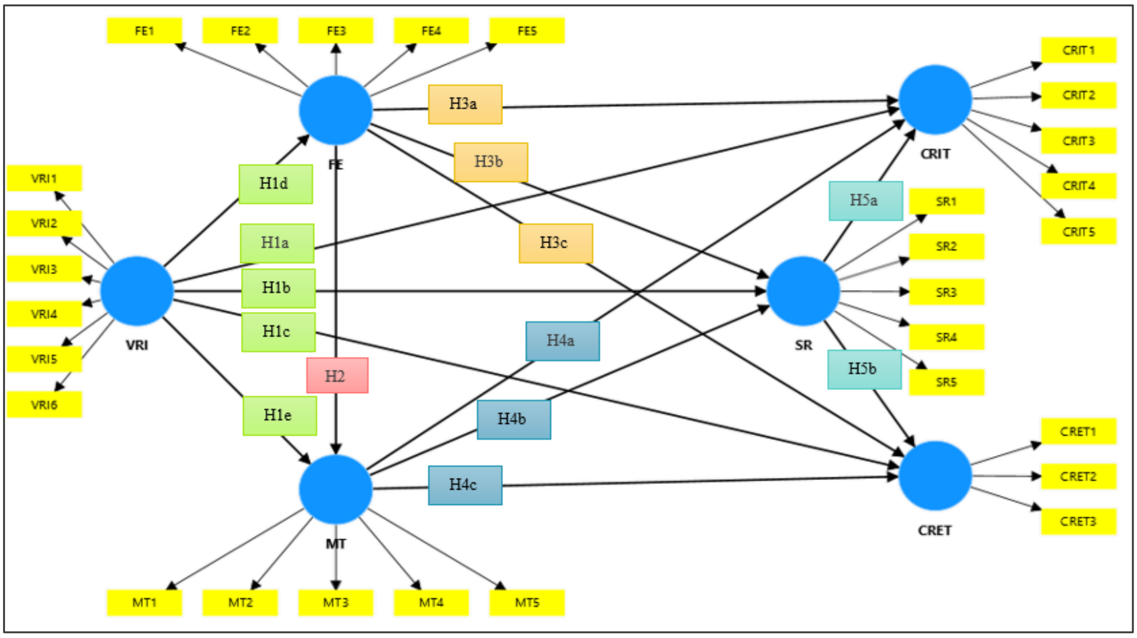
My initial proposed SEM: Virtual Reality Immersion impact on Habits of Mind (Self-regulation, Critical Thinking and Creative Thinking) mediated by flow experience, motivation, and self-regulation was hypothesized based on different theoretical frameworks and empirical studies. VRI as the independent variable of the current study, grounded in theories of immersive learning such CAMIL which adopts a constructivist view of learning by emphasizing the central role of immersion and engagement during VRI instruction. The mediating variables: FE which was included as a mediator between VRI and HoM and between VRI and MT based on Mirvis and Csikszentmihalyi (1991) and Nakamura and Csikszentmihalyi (2001) theory of flow. FE emphasizes that immersed learners enjoyably fall in complete absorption in what they are performing, a state derived from enjoyment and engagement. The second mediating variable MT resulting from autotelic nature of performance which generates the state of flow according to Csikszentmihalyi (2000), explained how VRI and flow add to the levels of MT according to Deci and Ryan (1985). The dual role of SR as the final sequential mediator and part of HoM variables is a key variable in the study. HoM encompassing (SR, CRIT, and CRET) as the dependent variables of the study were grounded in Marzano et al. (1993) most important five life-long dimensions of learning.

Locke (1987) in his Social Cognitive Theory explained how SR functions as a mediator between the components in triadic reciprocal causation model: personal factors, behavioral patterns and environmental influences. This enhances the ability for SR to function as a sequential mediator between VRI and HoM. Many recent studies such as, (Ghanizadeh & Mizaee, 2012; Ghbari & Harahsheh, 2024; Ivcevic et al., 2024; S. Lee, 2009; Lin et al., 2024) found that SR functions as a precursor, indicator, or a mediator for CRIT and CRET.

The following figure depicts the conceptual model for the proposed relationships between the independent variable VRI and the dependent variable HoM mediated by flow experience, motivation and self-regulation:

Figure 1

A proposed conceptual model



Based on Figure 1, research hypotheses about the relationships between VRI and enhanced HoM and the mediating roles of FE, MT and SR are:

1.6.1 Direct effects

There are 14 direct effects in the relationship between VRI and HoM when including mediators:

1.6.1.1 Direct Effects Hypotheses

H1a: Higher levels of VRI enhance CRIT.

H1b: Higher levels of VRI enhance SR.

H1c: Higher levels of VRI enhance CRET.

H1d: Higher levels of VRI enhance FE.

H1e: Higher levels of VRI enhance MT.

H2: FE directly enhances MT.

H3a: FE directly enhances CRIT

H3b: FE directly enhances SR.

H3c: FE directly enhances CRET.

H4a: MT directly enhances CRIT

H4b: MT directly enhances SR.

H4c: MT directly enhances CRET.

H5a: SR directly enhances CRIT.

H5b: SR directly enhances CRET.

1.6.2 Indirect Effect Hypotheses

There are three types of indirect hypotheses based on the number of mediators included in the relationships:

1. Primary mediation: include only one mediator.
2. Secondary mediation: include two mediators.
3. Tertiary mediation: include three mediators.

1.6.2.1 Primary Mediation Hypotheses

There are 14 primary-mediation hypotheses that include one mediator:

Primary Mediation Hypotheses (One Mediator)

H6: The relationship between VRI and SR is partially mediated by FE.

H7: The relationship between VRI and CRIT is partially mediated by FE

H8: The relationship between VRI and CRET is partially mediated by FE.

H9: The relationship between VRI and SR is partially mediated by MT.

H10: The relationship between VRI and CRIT is partially mediated by MT.

H11: The relationship between VRI and CRET is partially mediated by MT.

H12: The relationship between VRI and CRIT is partially mediated by SR.

H13: The relationship between VRI and CRET is partially mediated by SR.

H14: The relationship between VRI and MT is partially mediated by FE.

H15: The relationship between FE and SR is partially mediated by MT.

H16: The relationship between FE and CRIT is partially mediated by MT.

H17: The relationship between FE and CRET is partially mediated by MT.

H18: The relationship between MT and CRIT is partially mediated by SR.

H19: The relationship between MT and CRET is partially mediated by SR.

1.6.2.2 Secondary-Mediation Hypotheses (two mediators)

There are 7 secondary-mediation hypotheses that include two mediators:

Secondary-Mediation Hypotheses (Two Mediator)

H20: VRI enhances CRIT through FE and MT.

H21: VRI enhances CRET through FE and MT.

H22: VRI enhances CRIT through MT and SR.

H23: VRI enhances CRET through MT and SR.

H24: VRI enhances SR through FE and MT.

H25: FE enhances CRIT through MT and SR.

H26: FE enhances CRET through MT and SR.

1.6.2.3 Tertiary-Mediation (Three mediators)

There are two cases of tertiary mediation:

Tertiary Mediation Hypotheses (Three Mediator)

H27: VRI enhances CRIT through FE, MT, and SR.

H28: VRI enhances CRET through FE, MT, and SR.

Chapter Two
Methodology

2.1 Research Design

This descriptive explanatory study is a mixed methods design to allow for the explanation of the goals of the study, and the exact nature of the relationships in the SEM that causes VRI to enhance students' HoM through FE, MT and SR during biology classes. This integration of quantitative data with qualitative insights helps address both the measurable effects and the underlying experiences and perceptions of the students about VRI and achieve methodological triangulation. Triangulation enables a rich understanding of the phenomenon under study by examining it from different angles. The validity and reliability of the findings were also achieved through employing data source triangulation which involved combining data from semi-structured interviews with participating students and common insights from focus groups, and classroom observations. Data source triangulation was achieved by gathering perspectives from students to understand the impact of VRI on HoM comprehensively.

For the quantitative part, a comprehensive questionnaire used a Likert scale with five answer choices. For the qualitative part, data was gathered through different methods: Classroom observations during application were followed by focus group sessions to allow for immediate data and shared perceptions while the experience is still fresh in the students' minds. Later, semi-structured interviews were conducted with 13 representative students from the different participating groups until saturation was achieved. The deductive approach was followed based on Marzano et al. (1993)'s rubrics for HoM standards for the fifth and most important dimension for learning, namely 'Productive HoM'. VRI was based on Schubert et al. (2001) validated Igroup Presence Questionnaire – Short (IPQ-S). Finally, the mediating variables, (FE and MT) were based on the tool validated by Guerra-Tamez (2023).

2.2 Research Context

The experiment was exclusively conducted on East Jerusalem government High School Students (10th – 12th graders) based on random cluster sampling. The choice of secondary school students was based on the belief that students during this age (15 – 18) still have more flexibility to change their HoM than during later ages when cognitive characteristics are more fossilized and harder to change.

During high school, teens show an increasing ability to reason and sort facts from fiction. They start thinking abstractly and manipulate hypothetical situations. They become able to set their future goals and take other opinions into consideration while making their own decisions. They understand the future consequences of their present actions and have a clear sense of what is right and what is wrong. They can write with complexity about a variety of content areas in science, social studies and literature. They can employ strategies to search for, use and compare information from multiple sources (Assari, 2020). Moreover, Cottrell (2013) believes that the transformational experience of studying in Higher Education can be life changing. Most graduates look back on this time with great fondness. In part, this is because of the unique opportunities it offers such as feeling intellectually stretched, exploration of new ideas, and engaging in a wide range of new activities which cannot be easily obtained elsewhere.

East Jerusalem government high schools adopt either the Palestinian curriculum (tawjihi) where schools are usually separated based on gender (either male or female) and include three stages: 10th to 12th grades. Schools adopting the Israeli curriculum (Bagrut), on the other hand, are usually mixed and include four stages: 9th – 12th grades. Nevertheless, coursebooks of both types of schools present the same biology content with little variations. This study aims for the schools adopting the Palestinian curriculum; therefore, a random multistage cluster sampling method was used to recruit participants for this study. First, three secondary schools were randomly selected from a total of 7 schools that implemented the Tawjihi curriculum. These schools represented primary clusters in the sampling process. In the second stage, students were selected from grades 10, 11, and 12 within each school. In schools with a large student population, participants were selected using simple random sampling from each grade level. However, in schools with smaller enrollment numbers, all students from the relevant grades were included to ensure adequate representation.

2.3 Ethical Approval

This study was conducted in compliance with ethical research guidelines. Ethical approval was obtained from An-Najah National University Institutional Review Board (IRB) before data collection. The approval was granted under reference number [IRB: Fgs/Hum. Feb. 2025/70] (Appendix C). All participants provided informed consent before participating in the study, ensuring voluntary participation, anonymity, and confidentiality.

2.4 Quantitative Methods

2.4.1 Study Sample

Due to the novelty of VR as an educational tool, and the limited availability of VR-furnished digital labs in East Jerusalem high schools; lack of technical support; trained schoolteachers and convenient access to cites which provide relevant 3D lessons, an initial agreement with the sample's school principals and biology teachers to involve in a short training session about VR basics and implementation was achieved. Teachers of the sample showed willingness to learn and apply the experiment.

Participating teachers and students were separately given an orientation session to familiarize them with VR as an educational tool. Then VRI classes were applied on students during formal biology classes. Specific topics for each grade level were agreed on by the participating teachers to be covered during the first semester of the scholastic year 2024 / 2025.

The sample included 349 students taught by 4 biology teachers from 3 different high schools (2 male and 1 female school) from East Jerusalem Municipality high schools were randomly chosen by the computer for the experiment. Biology teachers (2 male and 2 female) of the sample were all highly qualified with a BA degree in Biology and an MA degree in methods of teaching science and an experience of more than ten years of teaching biology for high school students. Table A1 (Appendix A) shows the demographic information of the quantitative sample.

VR biology classes were planned according to the principles of constructivism (Fadli et al., 2024; Kurt & Sezek, 2021). This is believed to enhance HoM, especially SR, CRIT and CRET (Angraini et al., 2024; Kurt & Sezek, 2021; Mvududu & Thiel-Burgess, 2012;

Pande & Bharathi, 2020, 2020; Sengul, 2024; Stigall & Sharma, 2017; Vijayakumar Bharathi & Pande, 2024). Roughly speaking, each of the VR sessions had almost the same plan with little variation depending on the topic, its complexity and the length of the interactive or explanatory videos or scenes.

For every VRI-based biology lesson, three to five Intended Learning Outcomes (ILOs) were given to students in advance. Each ILO states what learners will discover on their own competently. Activities, VR scenes and assessments were then selected or designed to align with these outcomes (Biggs & Tang, 2011). A general framework for planning VR-based biology lessons that was followed by all participating teachers can be seen in Appendix D. Contents of the secondary biology coursebooks were scanned by competent biology teachers from the participating schools to decide upon the relevant educational Arabic 3D scenes to be employed for the experiment. Several basic biology topics were chosen to be covered within 6 – 8 sessions each. Biology teachers stressed topics including abstract concepts that usually were challenging for students. Teachers noted that VRI-based biology sessions as proposed might provide a solution for abstract concepts that usually cause students to struggle with.

Groups of 20 – 34 students attended the 50-minutes sessions regularly until the assigned topics were fully covered under the instructions of the trained teachers and the presence of technical support. Meta Quest 3 VR sets were used which offers high-resolution visuals, immersive 3D environments, and interactive hand controllers suitable for educational purposes. The choice of biology content was based on the coursebooks of each grade level and the availability of videos and interactive scenes or simulations in www.youtube.com and/or www.mozaweb.com.

Table 1

Biology contents and number of sessions for each grade level

Grade	Topics	Number of Session
10^{th}	The Cell / The DNA	8
11^{th}	The Nervous System: Nerve Impulse	8
12^{th}	Photosynthesis	6

The above topics were also supported by Hadiprayitno et al. (2019) as topics challenging secondary students for their abstract nature. However, the effects of VRI on these abstract challenging topics are measurable and can be measured within the range of time available for the study. The study took place during the first semester of the scholastic year 2024 / 2025: from September 2024 – January 2025.

2.4.2 Study Tools

A comprehensive questionnaire used a Likert scale with five answer choices namely, strongly agree, agree, neutral, disagree and strongly disagree, combining three validated tools to measure the different constructs related to the study:

1. The independent construct VRI: Schubert et al. (2001) Igroup Presence Questionnaire – Short (IPQ-S) to measure students' level of immersion during biology classes. The scale included 6 items and had undergone validation processes to ensure its reliability and validity in measuring presence in virtual environments. The process included factor analyses that supported the dimensional structure of the scale, including Spatial Presence, Involvement, and Experienced Realism. Subsequent research validated the IPQ-S's psychometric properties, showing high internal consistency with Cronbach's alpha values above 0.70. The IPQ-S has also been validated across different cultural contexts, demonstrating its reliability and generalizability in measuring presence in diverse populations.
2. The dependent constructs of HoM (SR, CRIT and CRET): The study employed a questionnaire of HoM developed by Sriyati et al. (2011) and based on Marzano (1992) and Marzano et al. (1993) habits of mind. The scale was validated for measuring HoM through a multi-step process. A combination of reliability and validity testing methods, including Cronbach's alpha for internal consistency and factor analysis to confirm the scale's structure was applied. Validation involved a diverse sample to ensure the scale's applicability across different educational contexts. Additionally, the scale's discriminant validity was tested to ensure it could effectively differentiate between varying levels of student cognitive behaviors. The process confirmed the scale's robustness and utility in educational assessment and research. The questionnaire was validated constructively by experts and empirically using the Pearson Product Moment. The validity test indicated that all the items were valid, and the reliability of the instrument was reliable 0.724 (Hidayati & Idris, 2020).
3. The mediating variables (FE and MT): Guerra-Tamez (2023) validated and advanced questionnaire of FE and MT that measures the partial effects of the mediating variables FE and MT on HoM was adopted: It consists of 5 statements on each variable. Each statement is rated by the students who experienced VRI during their biology classes.

Table 2

Constructs and their items adapted from previous studies and their outer loading

Construct	#	Item	Source	Outer Loadings and *p* values
Immersion VR	1	I felt that I had a sense of being there.	(Schubert et al., 2001)	0.79 (0.00)
	2	I felt that VR world surrounded me.		0.74 (0.00)
	3	I was completely captivated by the virtual world.		0.66 (0.00)
	4	I was aware of my real environment during the experience.		0.27 (0.00)
	5	The virtual world seemed very realistic to me.		0.68 (0.00)
	6	I felt the objects in the virtual world looked realistic.		0.71 (0.00)
Flow Experience	1	I enjoyed the experience through VR technology.	(Guerra-Tamez, 2023)	0.69 (0.00)
	2	I found the VR experience gratifying.		0.66 (0.00)
	3	I felt in total concentration during the experience.		0.66 (0.00)
	4	I felt that time passed too fast.		0.66 (0.00)
	5	This class through VR technology exceeds my expectations.		0.78 (0.00)
Motivation	1	I was interested to use VR technology in class.	(Guerra-Tamez, 2023)	0.55 (0.00)
	2	My performance was good using VR technology.		0.777 (0.00)
	3	I felt competent after using VR for a while.		0.79 (0.00)
	4	I was very relaxed while using VR technology.		0.78 (0.00)
	5	I am skilled while I use VR technology in class.		0.79 (0.00)
Self-Regulation	1	Recognizing self-thinking	(Sriyati et al., 2011)	0.77 (0.00)
	2	Making effective plans		0.79 (0.00)
	3	Understanding and using the needed information		0.80 (0.00)
	4	Becoming sensitive toward feedback		0.77 (0.00)
	5	Evaluating the effectiveness of acts		0.74 (0.00)
Critical Thinking	1	Being accurate and able to look for accuracy	(Sriyati et al., 2011)	0.79 (0.00)
	2	Being clear and able to look for clarity		0.78 (0.00)
	3	Being open		0.74 (0.00)
	4	Being able to position oneself when there is a guarantee		0.78 (0.00)
	5	Being sensitive and able to recognize friends' abilities		0.74 (0.00)
Creative Thinking	1	Being able to involve oneself in tasks although the answer and solution has not yet to be found	(Sriyati et al., 2011)	0.84 (0.00)
	2	Trying hard to expand one's skills and knowledge		0.83 (0.00)
	3	Creating new ways or point of view outside the common knowledge		0.78 (0.00)

The integration process of the three scales involved a detailed review of the three works to ensure that the final tool retained both integrity and comprehensibility of the original ones.

2.4.3 Validity and Reliability

Validity of the combined questionnaire was maintained through expert reviews and pilot testing, ensuring that the instrument accurately measured the intended constructs. Reliability tests, such as Cronbach's alpha, were conducted to confirm the consistency of the combined tool.

2.4.3.1 Translation Process

The final English form of the questionnaire including a 29-items was translated into Arabic by two competent English teachers from two different schools and one English supervisor to make sure about the precision of translation and the suitability of the Arabic form to meet the level of high-school students. A competent Arabic teacher revised the translation to make sure it suits the language of high school students. Then, a back translation was performed by a fourth English teacher to compare with the original version and to check consistency and conceptual accuracy of the tool. A pilot test of the final form of the tool was conducted on a small representative sample from different schools and grade levels to check the clarity, difficulty and appropriateness of the items. Finally, some minimal changes on the final Arabic form of the tool were made based on feedback given from the pilot group (Appendix E).

2.4.4 Quantitative Data Collection

The final Arabic form of the questionnaire as a google form with obligation to answer all the fields except for the name was sent to the participating biology teachers in different schools at the end of the experiment. Biology teachers sent the questionnaire to the participating groups via WhatsApp groups which were created for the experiment. 347 participants out of 349 successfully submitted the questionnaire. Data was stored, ensuring the anonymity of the participants and confidentiality of information.

2.4.5 Quantitative Data Analysis

To allow examining the complex cause-effect relationships between different constructs of the study, Partial Least Squares (PLS4) statistical software, which is designed for

Structural Equation Modeling (SEM) was employed. The software combines factor analysis and multiple regression analysis, maximizing the explained variance of the dependent variable to enable more general representations of measurement and latent variable models. SEM is a robust statistical method used to examine hypotheses regarding the causal relationships between both observed and latent variables (Sarstedt et al., 2022).

These methods helped in analyzing quantitative data and interpreting the relationships between the variables.

2.5 Qualitative Methods

Qualitative methods included observations, semi-structured interviews and focus groups to ensure triangulation of the data source.

2.5.1 Study Sample

A representative sample consisting of 10 students and 3 focus groups (8 participants each) aiming to cover the three participating schools with different grade-levels, was purposively chosen. Table A2 (Appendix A) summarizes the demographic information of the qualitative sample:

2.5.2 Study Tools

To explore students' insights and perceptions of experiencing VRI in biology classes, and the effects it had on their HoM through the mediation of FE, MT, and SR the following tools were used:

Semi-Structured Interviews

The interview was designed to include all types of questions recommended by Qu and Dumay (2011), with the purpose of systematically delineating the topics in an interconnected manner. This facilitates obtaining more detailed responses, allowing the interviewee the freedom to expound upon the question posed, and allowing flexibility to delve into secondary inquiries contingent on the context. Each question is geared toward eliciting comprehensive knowledge necessary to address the study's questions (Saunders et al., 2018).

An interview guide, to identify the most suitable questions that would answer the research questions, was developed and revised by experts and colleagues. The final version of the guide consisted of very specific procedures to conduct interviews, trying as much as possible to get students' insights about the experiment and achieve saturation. The guide consisted of five major sections as can be seen in Appendix F:

- The opening section included salutation and introduction to elicit personal as well as demographic information, consent and ethical considerations.
- Sections two through four focused on questions related to the independent variable VRI; dependent variables HoM and the mediating variables: MT and FE. Sample questions from the different parts included:

VRI: How has the VRI method in biology classes affected your learning process?

How do you think learning through VR differs from other learning methods?

SR: Has the learning experience through VR influenced your self-monitoring of thinking? How?

How has immersion affected your learning behavior in general?

CRIT: How has immersion VR affected your problem-solving ability?

How has immersion in VR affected your problem-solving ability?

CRET: Can you provide an example where VR helped you think outside the box?

How has VR stimulated your imagination and visualization compared to other teaching methods?

- Section five was intended to close the interview by thanking the participants and asking for any additional piece of information the interviewee wished to add. All interviews were conducted face to face with a representative sample of the students to explore their subjective experiences and perceptions of VRI, MT, FE, and HoM.

Focus Groups

After specific VR sessions, focus groups with random participants were held to allow for a deeper delve into the information and valuable common fresh insights reflected by the participants. The content of the discussion revolved around the research major questions and related to VRI, MT, FE and HoM (Appendix G).

Observations

To provide a comprehensive understanding of how VRI impacts students in real-time, complementing the data from interviews and focus groups, observations were also taken into consideration. A checklist, derived from the questionnaire, included signs of immersion in VR; MT; FE; SR; CRIT; and CRET, was prepared for the purpose (Appendix H). During application, observations were recorded according to the checklist. This helped gather more in-depth, real-time data that enhanced the overall understanding and explanations of the impact of VR immersion on students' HoM, mediated by MT, and FE. Figures B1 and B2 (Appendix B) Show images of students during immersion.

2.5.3 Qualitative Data Collection

Qualitative data consisting of observations, interviews, and focus groups was gathered and analyzed through a systematic coding process that combined both In Vivo and descriptive coding to identify and report patterns within the data (Braun & Clarke, 2006). The coding process employed MAXQDA to facilitate the integration of theoretical and emergent codes. To ensure consistency, an intercoder, who was familiarized with the study constructs, helped in coding samples of the interviews' and focus groups' scripts independently. An agreement on 26 out 29 deductive subcategories (90%) was achieved. Observations, being less text-based, were discussed separately based on pictures and notes taken during the sessions (Mannay, 2015). The results of coding were compared and discussed until arriving at an agreement. The coding framework was refined accordingly. Initial codes and primary categories were shared with the participants to enhance accuracy (O'Connor & Joffe, 2020). Data was recorded and stored, ensuring the anonymity of the participants and confidentiality of information.

2.5.4 Qualitative Data Analysis

Participants' narratives from interviews and focus groups were transcribed and revised, then a codebook was prepared (Appendix I).

Deductive and inductive strategies for data analysis were adopted and incorporated within the thematic analysis methodology. Deductive codes for the first cycle were derived from the framework based on the primary categories and subcategories discussed in the theoretical frameworks of: Guerra-Tamez (2023); Marzano et al. (1993); and Schubert et al. (2001).

The first cycle of coding revealed two emergent codes: Generation of a dynamic Conceptual Visualization, a process that learners employ to transform abstract ideas into visual representations to enhance understanding and communication (DeCaro et al., 2023). Exploratory Oriented where students explore novel activities in the form of problem solving before actual formal teaching takes place, enabling them to integrate new information with prior knowledge (DeCaro et al., 2023; Sandrone & Schneider, 2020). The new emerging codes were added to the codebook under CRET and CRIT respectively.

Both deductive and inductive codes arising from participants' narratives were systematically managed within MAXQDA. Pattern coding in the second cycle was also conducted using the software, ensuring a structured and replicable categorization of themes.

In Vivo coding extracted interviewees statements, followed by descriptive coding whereby each statement was labelled with a brief description (Saldaña, 2021). This yielded numerous codes under thematic categories including inductive subcategories. The second cycle of coding included pattern coding where similar groups of descriptive codes were classified under suitable sub-categories. Finally, thematic coding was employed to clarify the relationships between primary categories and their sub-categories.

Table 3

Example of the first cycle coding

In Vivo Coding	Descriptive Coding	Sub-category	Category
“I felt I was inside the cell”	A sense of being there	Spatial Presence	Immersion
"Time seemed to fly during VR sessions.”	Time distortion, where time seems to fly due to deep engagement and absorption in an activity.	Time passing fast	Flow Experience

2.5.5 Trustworthiness of the research findings

To validate the rigor and reliability of the findings, trustworthiness was achieved through emphasizing elements of credibility, transferability, dependability and confirmability throughout the research process. These elements were systematically incorporated into the research design to provide a robust framework for understanding the impact of VR immersion on students’ Habits of Mind.

Credibility

To ensure that the research findings represent accurate reflections of the participants according to (Ahmed, 2024), credibility was achieved through employing different strategies throughout the research process: A prolonged time was spent with the participants during the application of VR in biology sessions in different topics for the sake of observations resulted in building up a comfortable, supportive, and respectful educational atmosphere. Personal trust emerged between me, as the researcher, and the teachers, and the participants over time which allowed for gaining detailed insights of the participants’ experiences, beliefs and behaviors which finally helped to understand their perspectives about the use of VR in their biology classes. Reflexivity was achieved throughout documenting my assumptions, decisions, and interactions with participants during observations, interviews and analysis, which helped to keep continuous self-awareness and to identify areas where personal perspectives could influence data interpretation.

Triangulation was achieved by reverting to multiple data resources to validate the findings. Data resources for the qualitative part were based on observations, interviews with participants and teachers and on focus groups. This diversity of qualitative data resources was incorporated with quantitative data from SEM using smart PLS4. This integration of quantitative data with qualitative insights helped address both the measurable effects and the underlying experiences and perceptions of the students about VRI and achieve methodological triangulation (Ahmed, 2024). MAXQDA's visualization tools enabled clear presentation of thematic connections, which were later shared with participants to validate the accuracy of findings. Using MAXQDA also ensured bias avoidance in the selection of codes or themes.

Transferability

Through quotations, comparisons, and continuous validation of interpretations ensured quality according to (Chowdhury, 2015; Lincoln et al., 1985). To make the findings of the study applicable in other contexts, a deep, rich and detailed description of the study context was provided. Details about municipality secondary schools in East Jerusalem, participants’ demographic characteristics, and the nature of VRI experiences during biology classes help reader evaluate the relevance of the findings to other contexts. It can also allow for the replication of the study under different contexts. Illustrative visualizations generated in MAXQDA offered rich and clear descriptions of the data, to allow readers to evaluate applicability in other contexts.

Dependability

To ensure stability and consistency of the research process over time. A detailed methodology description and a record of all research activities (Chowdhury, 2015) such as, the design and implementation of the VR immersion sessions were consulted with competent technology teachers who also attended VR application to provide any necessary technical help; the choice of the VR biology content was agreed upon after consulting with competent biology teachers from the participating schools; the collection and analysis of data, and the rationale behind methodological decisions. For example, the decision to use validated tools to measure motivation, flow experience, and Habits of Mind was documented to demonstrate alignment with research standards. Moreover, peer-debriefing with experts and colleagues continued throughout the different phases of the study to ensure a refined methodology for the study and a systematic approach to data collection and analysis. MAXQDA documented all coding and analytical decisions to facilitate peer debriefing sessions, where two expert colleagues reviewed the coding framework and agreed on 90% of the thematic categories, as indicated by Holsti's method.

Confirmability

To avoid biased findings and to make sure that the findings are inferred directly and objectively through the participants' experiences, different measures were employed to enhance confirmability (Ahmed, 2024). Participants' feedback during observations, interviews and focus groups was integrated to ensure the authenticity of the findings. The systematic organization of data in MAXQDA provided an objective basis for interpretations, minimizing the influence of personal bias. The ability to cross-reference data sources within the software ensured that findings were grounded in participants' experiences. Peer debriefing sessions with experts and colleagues helped to critically examine the data analysis and interpretation. Two expert colleagues, for example, revised the process of data coding. The Holisti's method showed an agreement of 90% where 26 out 29 categories were agreed on among coders.

Chapter Three

Results

3.1 Quantitative Results

Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed to assess both the direct and indirect effects of VRI on HoM through FE, MT and SR as sequential mediating variables. PLS is an effective software for analyzing complex relationships with mediating variables. The analysis aims to test the hypothesized model and evaluate the predictive relevance of the constructs.

PLS preliminary analysis of the original hypothesized model showed non-significant direct relationships between constructs:

Figure 2

Initial hypothesized model with non-significant direct relationships

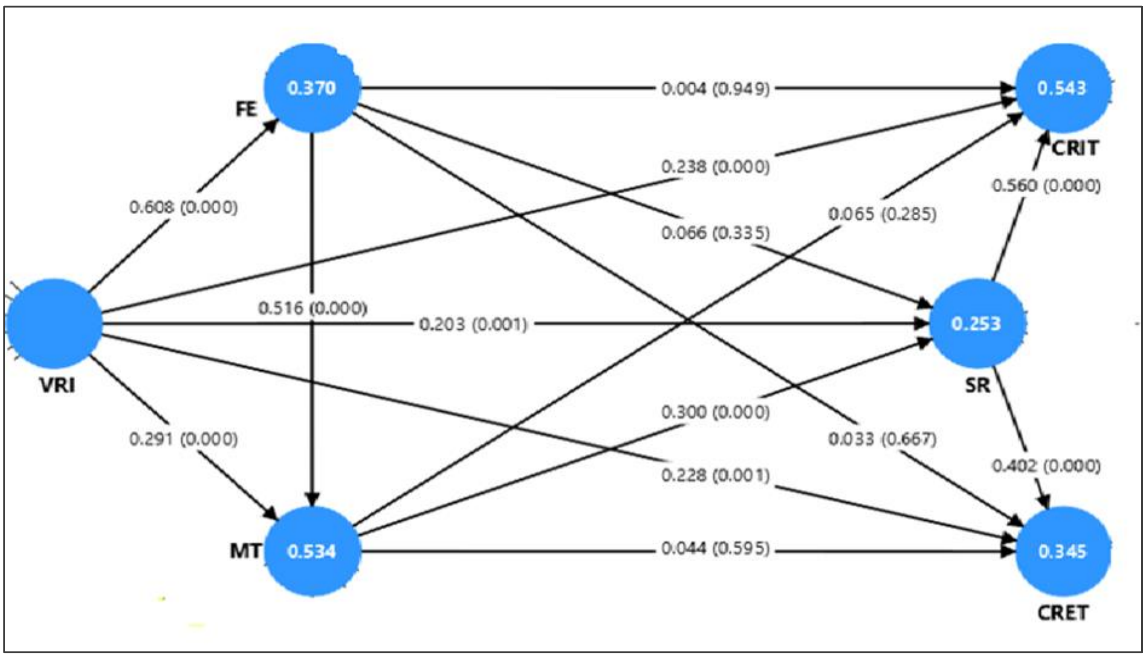


Figure 2 shows that all direct effects between FE and SR (p = 0.335), CRIT (p = 0.949) and CRET (p = 0.667) were not significant. It also shows that MT has insignificant direct effects on both CRIT (p = 0.285) and CRET (p = 0.595). This required model refinement and hypotheses revision. Therefore, the following hypotheses were rejected for being non-significant or for missing the only valid indirect path to CRIT and CRET through (SR) (Hair et al., 2021):

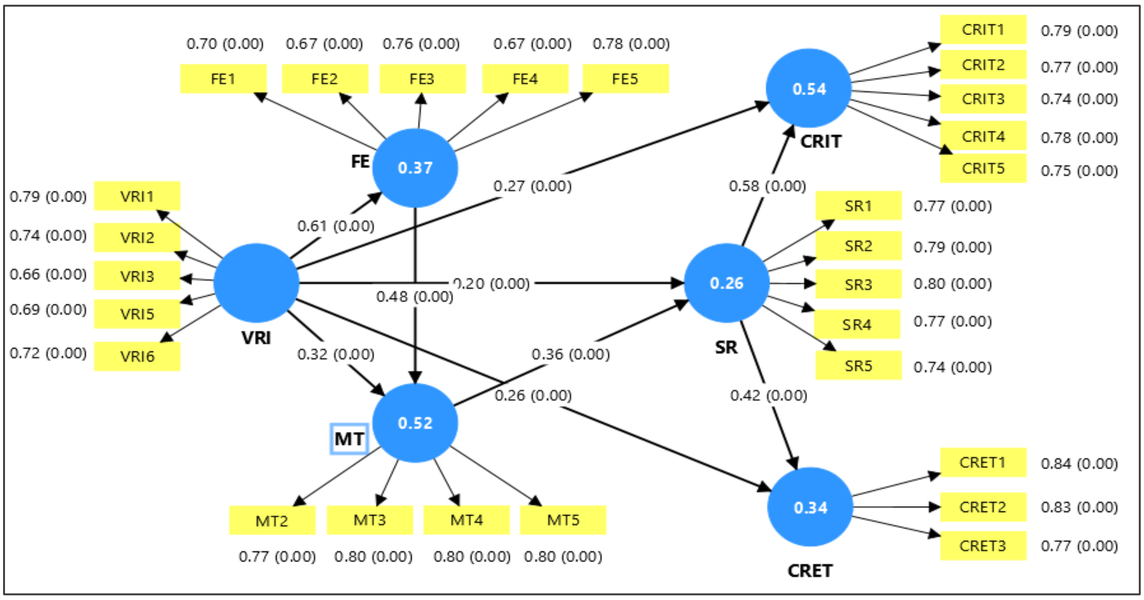
3.1.1 Model Refinement

Based on the preliminary PLS-SEM analysis, non-significant paths were removed to enhance model fit, leading to the refined model presented in Figure 3.

Figure 3 below shows the final refined model including only significant pathways. Insignificant pathways were deleted.

Figure 3

A refined model with significant relationships



3.1.1.1 Hypotheses-Testing Results

This section contrasts the originally hypothesized model with the empirically refined one. For each block of hypotheses, results of which paths remained significant, and which were unsupported will be discussed.

Significant Direct Relationships

Five out of fourteen direct-effect hypotheses were rejected for being non-significant, resulting in 9 significant ones:

Direct Effect Hypotheses

H1a: Higher levels of VRI enhance CRIT.

H1b: Higher levels of VRI enhance SR.

H1c: Higher levels of VRI enhance CRET.

H1d: Higher levels of VRI enhance FE.

H1e: Higher levels of VRI enhance MT.
H2: FE directly enhances MT.
H4b: MT directly enhances SR.
H5a: SR directly enhances CRIT.
H5b: SR directly enhances CRET.

There are no significant direct effects between FE and HoM: Therefore, (H3a, H3b, H3c) hypotheses were rejected for being insignificant ($p > 0.05$). In addition, the results showed insignificant direct effects between MT → CRIT and CRET, which resulted in the rejection of (H4a, H4c). The modified SEM in Figure 3 shows the absence of the rejected direct hypotheses.

Indirect Effects Overview

Indirect relationships were evaluated, and all paths that excluded SR as a primary or final sequential mediator were unsupported.

Significant Primary Mediation Paths

Revision of primary mediation effects resulted in 7 significant relationships:

Primary Mediation Hypotheses (One Mediator)

H9: The relationship between VRI and SR is partially mediated by MT.
H12: The relationship between VRI and CRIT is partially mediated by SR.
H13: The relationship between VRI and CRET is partially mediated by SR.
H14: The relationship between VRI and MT is partially mediated by FE.
H15: The relationship between FE and SR is partially mediated by MT.
H18: The relationship between MT and CRIT is partially mediated by SR.
H19: The relationship between MT and CRET is partially mediated by SR.

As can be seen, H6, H7, H8, were rejected for having FE as the primary mediator directly mediating the relationship between VRI and HoM. H10 and H11, were also rejected for having MT as a primary mediator directly mediating the relationship between VRI and CRIT/CRET. H16 and H17 were rejected for having MT as the primary mediator between FE and CRIT/CRET.

Significant Secondary Mediation Paths

Revision of secondary mediation hypotheses resulted in 5 significant relationships:

Secondary Mediation Hypotheses (Two Mediator)

H22: VRI enhances CRIT through MT and SR.

H23: VRI enhances CRET through MT and SR.

H24: VRI enhances SR through FE and MT.

H25: FE enhances CRIT through MT and SR.

H26: FE enhances CRET through MT and SR.

H20 and H21 were rejected for having FE and MT as mediating the relationships between VRI and CRIT/CRET without including SR as part of the relationship.

Significant Tertiary Mediation Paths

Both tertiary mediation hypotheses remained significant:

Tertiary Mediation Hypotheses (Three Mediator)

H27: VRI enhances CRIT through FE, MT, and SR.

H28: VRI enhances CRET through FE, MT, and SR.

Both tertiary mediation hypotheses were accepted for including mediators FE, MT, and SR as sequentially affecting HoM. The results of revising hypotheses revealed 23 significant pathways from VRI to HoM.

3.1.2 Measurement of Model Assessment

To ensure that the observed indicators reliably and validly measure the latent constructs, validity and reliability were examined.

Reliability and Convergent Validity

To assess the measurement model and internal consistency reliability, Cronbach's alpha and composite reliability were examined.

Table 4

Reliability and Convergent Validity

Variable	Cronbach's α	Rho_a	Rho_c	AVE	*p*
CRET	0.74	0.75	0.85	0.66	0.00
CRIT	0.83	0.83	0.88	0.59	0.00
FE	0.76	0.77	0.84	0.51	0.00
MT	0.8	0.81	0.87	0.63	0.00
SR	0.83	0.83	0.88	0.6	0.00
VRI	0.77	0.77	0.84	0.52	0.00

Constructs of the study showed acceptable consistency with Cronbach's alpha values > 0.65 except for two: (VR4 = 0.27 and MT1 = 0.55) therefore, they were deleted (Hair et al., 2019). Composite reliability values ranged between 0.75 and 0.83, indicating good consistent measures of the constructs (Hair et al., 2019). Convergent validity was also supported by the average variance extracted (AVE) for different constructs which were higher than 0.50 (Hair et al., 2019).

Discriminant Validity

HTMT ratio and Fornell-Larcker criterion were used to check the uniqueness of the constructs of the study:

Table 5

HTMT and Fornell-Larcher for Discriminant validity

Variable	CRET	CRIT	FE	MT	SR	VRI
CRET	0.81	0.84	0.46	0.51	0.67	0.57
CRIT	0.66	0.77	0.51	0.60	0.83	0.65
FE	0.36	0.41	0.72	0.85	0.48	0.80
MT	0.4	0.49	0.68	0.79	0.60	0.78
SR	0.53	0.69	0.39	0.49	0.77	0.53
VRI	0.44	0.52	0.61	0.62	0.43	0.72

The diagonal italicized bold elements are the square roots of the average variance extracted (AVE).

Above the diagonal, the elements represent the correlations between the constructs. Below the diagonal are the HTMT values (Ayyoub et al., 2023).

Heterotrait-Monotrait HTMT

It is recommended to use the HTMT threshold of 0.90 when the constructs are conceptually comparable (Ayyoub et al., 2023). HTMT is a sensitive measure for detecting lack of discriminant validity which provides a straightforward ratio that can be interpreted directly. Discriminant validity values were less than conservative threshold

0.9 according to Henseler et al. (2016), with all constructs maintaining sufficient distinction.

Fornell-Larcker criterion (Bold Diagonal Values)

The square root of the AVE (diagonal values) for each construct exceeds its highest correlation with any other construct (off-diagonal values). This confirms that all constructs meet the discriminant validity criterion, indicating that each construct is conceptually distinct within the model. This result supports the robustness of the measurement model and confirms that each latent variable represents a unique construct, free from significant overlap with other variables.

3.1.3 Structural Model Assessment

Model fit

Goodness-of-fit refers to how well a proposed structural equation model (SEM) aligns with the observed data. It indicates whether the hypothesized relationships among variables are supported by empirical evidence. Bollen-Stine bootstrapping was conducted to check model fit (Bollen & Stine, 1992). Results of analysis are illustrated in Table A3 (Appendix A). Bollen-Stine test indicated that the discrepancy between the observed and predicted correlations is small (< 0.08). The values of Chi-square and NFI also indicated a good model fit with more than 70% NFI (Bollen & Stine, 1992).

Collinearity Assessment (VIF Values)

The variance inflation factor (VIF) is used to evaluate collinearity of the formative indicators. Ideally, values of VIF should be close to 3 or below (Hair et al., 2019). Results of multicollinearity at the construct level ranged between (1.31 – 1.73) < 3.3 indicating low multicollinearity among all predictor variables and their ability to contribute independently in explaining the variance of the dependable variables (Hair et al., 2019). This supports the HTMT and Fornell-Larcker results by providing additional evidence that the constructs are distinct, despite the high correlation between CRET and CRIT.

Path Coefficients: (Direct Effects and Hypotheses Testing)

Results of path coefficients reflect the strong and positive relationships between constructs of the study as illustrated in Table A4 (Appendix A). As can be seen from both Figure 3 and Table A4 (Appendix A), results of the PLS-SEM of the structural model showed that all hypothesized direct effects of the model were positive and significant. The results were evaluated based on path coefficients (β), t-statistics, and p-values, following the significance criteria of (Hair et al., 2021) where:

$\beta < 0.10 \rightarrow$ Small effect

$0.10 \geq \beta < 0.30 \rightarrow$ Moderate effect

$\beta \geq 0.30 \rightarrow$ Strong effect

The results of all p-values ($p < 0.05$) and all t-values for all pathways were mainly higher than 1.96: ($t > 1.96$, $p = 0.00$) which supported the significance and strength of the reported paths. Hence, all direct hypotheses (H1a - H5b) were positive and significantly effective:

H1a: The direct effect of VRI on CRIT ($\beta = 0.27$, $t = 7.074$, $p < 0.05$) indicated a positive moderate significant effect. This indicates that VRI-based biology classes affected students' critical thinking. Hence, H1a was supported.

H1b: The direct effect of VRI on SR ($\beta = 0.20$, $t = 6.002$, $p < 0.05$) also rendered a moderate significant direct effect, highlighting the direct impact of VRI on enhancing students' self-regulation. Hence, H1b was also supported.

H1c: The direct effect of VRI on CRET ($\beta = 0.26$, $t = 5.11$, $p < 0.05$) revealing a moderate positive direct effect of VRI on students' creative thinking. Hence, H1c was supported.

H1a, H1b, and H1c directly appeal to the first research question:

RQ1: Are there statistically significant direct effects of VRI as a method of teaching biology on students' HoM?

PLS-SEM analysis confirmed that VRI impacts students CRIT, SR, and CRET which was evidenced by the moderate positive significance of H1a, H1b, and H1c.

However, further analysis of direct effects of VRI on mediators reflected stronger effects:

H1d: The direct effect of VRI on FE ($\beta = 0.61$, $t = 13.768$, $p < 0.05$) revealed a strong, positive, significant direct effect. Immersion through VR during biology classes, strongly enhanced students' flow experience. Hence, H1d was supported.

H1e: The direct effect of VRI on MT ($\beta = 0.32$, $t = 6$, $p < 0.05$) also revealed a strong effect of VRI on students' motivation.

Other direct effect hypotheses: H2: FE → MT ($\beta = 0.48$, $t = 8.56$, $p < 0.05$) and H4: MT → SR ($\beta = 0.36$, $t = 6.61$, $p < 0.05$), H5a: SR → CRIT ($\beta = 0.58$, $t = 14.11$, $p < 0.05$) and H5b: SR → CRET ($\beta = 0.42$, $t = 0.322$, $p < 0.05$) were all strong and significant. Hence, they were all supported.

RQ1: Direct effects: Results of analysis of direct effects support that VRI has a moderate direct effect on CRIT ($\beta = 0.27$, $t = 7.074$, $p < 0.05$), SR ($\beta = 0.202$, $t = 6.002$, $p < 0.05$), and on CRET ($\beta = 0.26$, $t = 5.11$, $p < 0.05$). Therefore, VRI is confirmed as having a significant direct effect on HoM. Hence, RQ1 is supported.

Absence of significant relationships between FE → SR, or FE → CRIT/CRET, or MT → CRIT/CRET, highlighted the role of sequential mediators FE, MT, and SR in enhancing the total effects of VRI on HoM. It also underscored the crucial effect of SR as the final sequential mediator in transmitting the effects of VRI on CRIT/CRET through mediators. This required examining the role of mediation through indirect effects.

Total Indirect Effects

To evaluate indirect effects of VRI on CRIT and CRET through mediators FE, MT and SR, analysis of indirect pathways was conducted: The results of all p-values ($p < 0.05$) and all t-values for all pathways were mainly higher than 1.96: ($t > 1.96$, $p = 0.00$) which supported the significance and strength of the reported following paths.

Primary indirect effects (one mediator)

The seven primary mediated pathways ranged between weak to moderate magnitudes of impact. Table A5 (Appendix A) summarizes the results:

1. H9: VRI → MT → SR ($\beta\_indirect = 0.12$, $p < 0.05$; $\beta\_direct = 0.20$, $p < 0.05$). VRI influences SR directly and indirectly through the partial mediation of MT. The total effect of VRI on SR is $\beta = 0.32$ indicating that while motivation is an important mediator, VRI still has a notable direct impact on SR. Therefore, H9 is supported.

2. H12. VRI → SR → CRIT (β_indirect = 0.12, $p < 0.05$; β_direct 0.27, $p < 0.05$). Hence, H12 was supported. VRI affects students' critical thinking both directly and indirectly through the partial mediation of SR. The total effect of VRI on CRIT is $\beta = 0.39$, indicating that while part of the effect occurs directly, a meaningful portion is explained through SR.
3. H13: VRI → SR → CRET (β_indirect = 0.09, $p < 0.05$; β _direct = 0.26, $p <0.05$). The direct effect of VRI on CRET remains significant, indicating the partial mediating role of SR. Therefore, H13 was supported. VRI affects students' creative thinking both directly and indirectly via a partial mediation of SR. The total effect of VRI on CRET is $\beta = 0.35$, showing that while VRI directly promotes creativity, part of its effect is mediated by SR.
4. H14: VRI → FE → MT (β_indirect = 0.29, $p < 0.05$; β_direct = 0.32, $p < 0.05$). Hence, H14 was supported. VRI influences students' MT both directly and indirectly via the partial mediation FE.
5. H15, H18, H19 were supported as having full mediating effect. H15: FE → MT → SR for example, the path FE → SR was not significant ($p > 0,05$) implying that FE can only affect SR through MT indicating a full mediation case of MT. The indirect path via MT ($\beta = 0.17$, $t = 4.957$, $p < 0.05$) reflects a moderate indirect magnitude of FE on SR through full mediation of MT. Therefore, H15 was supported. FE cannot directly enhance SR. FE enhances students' MT, which fully mediates the relationship between FE and SR.

Secondary indirect effects (Two mediators)

Five pathways in the model included two mediators. Table A6 (Appendix A) summarizes the results:

1. H22: VRI → MT → SR → CRIT: The direct effect of VRI on CRIT was ($\beta = 0.27$, $t = 7.07$, $p < 0.05$). However, VRI has a small significant partial indirect effect on CRIT through MT and SR ($\beta = 0.05$, $t = 4.275$, $p < 0.05$). The total significant effect of the direct and indirect path ($\beta = 0.32$, $t = 4.42$, $p < 0.05$) revealed a strong significant partial effect of VRI on CRIT through the mediators MT and SR.
2. H23: VRI → MT → SR → CRET: The direct effect of VRI on CRET was ($\beta = 0.26$, $t = 5.11$, $p < 0.05$). However, VRI has a small significant partial indirect effect on CRET through the sequential mediators MT and SR ($\beta = 0.05$, $t = 4.275$, $p < 0.05$).

The total significant effect of the direct and indirect path ($\beta = 0.31$, $p < 0.05$) reflects a strong effect of VRI on CRET. Therefore, H23 was supported.

3. H24: VRI → FE → MT → SR the direct effect of VRI on SR ($\beta = 0.20$, $t = 6.002$, $p < 0.05$) was enhanced by the indirect path FE → MT ($\beta = 0.11$, $t = 4.57$, $p < 0.05$): This path also resulted in a strong indirect effect of VRI on SR partially mediated by FE→ MT. ($\beta = 0.31$, $t = 6.002$, $p < 0.05$)
4. H25: FE → MT → SR → CRIT ($\beta = 0.05$, $t = 4.275$, $p < 0.05$): results revealed a small indirect effect of FE through the sequence of mediators MT → SR on CRIT this mediation can be classified as **full** mediation. This indicates that FE does not directly impact CRIT but rather enhances students' MT, which subsequently improves their SR, ultimately leading to enhanced CRIT.
5. H26: FE → MT → SR → CRET ($\beta = 0.07$, $t = 4.416$, $p < 0.05$): results reflected a small significant indirect effect of FE on CRET fully mediated by the sequence FE→ MT → SR. Hypotheses H23 through H26 were supported as indirectly affecting CRIT and CRET only through SR.

Analysis of secondary pathways explained the mechanisms of sequential mediation of FE → MT → SR, emphasizing the role of SR as the only and final channel through which indirect effects of VRI can affect CRIT and CRET.

Tertiary indirect effects (three mediators)

Table A7 (Appendix A) shows two cases of tertiary mediation between VRI and HoM (CRIT and CRET). Both pathways reflected a small but significant impact on CRET: (H27: $\beta = 0.05$, $t = 3.778$, $p < 0.05$) and on CRIT (H28: $\beta = 0.06$, $t = 4.139$, $p < 0.05$). Therefore, (H27 and H28) were supported. These indirect significant effects of VRI on CRIT/CRET, though small, provide a comprehensive understanding of the mechanisms through which mediators function sequentially and underscore the crucial function of SR as the final sequential mediator.

Indirect-effect analysis revealed that VRI significantly enhances HoM through the sequential mediators (FE→ MT→ SR). The strongest indirect effect is VRI → SR → CRIT ($\beta = 0.25$, $p < 0.05$), confirming the key mediating role of SR.

Total Effects

The impact of both direct and indirect effects together on dependent variables in the model reflects a comprehensive view of the strength of the different pathways in the model connecting between endogenous VRI and exogenous variables.

Table A8 (Appendix A) shows that all p-values < 0.05 and all T statistics >1.96 indicating the significance of all paths (Hair et al., 2019). The total magnitude of independent variables on the dependent ones varied between moderate to strong except for the path FE → CRET ($\beta = 0.07$, $t = 3.983$, $p < 0.05$) which showed a small effect.

The total effects of VRI on CRIT ($\beta = 0.52$, $t = 12.713$, $p < 0.05$), on CRET ($\beta = 0.44$, $t = 9.588$, $p < 0.05$) and on SR ($\beta = 0.43$, $t = 9.571$, $p < 0.05$) were significantly stronger that the direct effects VRI → CRIT ($\beta = 0.27$, $t = 7.074$, $p < 0.05$), VRI → CRET ($\beta = 0.26$, $t = 5.11$, $p < 0.05$) VRI → SR ($\beta = 0.20$, $t = 3.55$, $p < 0.05$) which highlights the crucial role of mediators in enhancing the total effects. The amplification of the total effects into strong highlights the critical effect caused by sequential mediators FE, MT, and SR in developing higher cognitive skills such as CRIT and CRET.

Coefficient of Determination (R2)

Effectiveness of the ability of the independent variable to explain the variance in the dependent variables in the study ranged between small and large. Table 6 illustrates the results of R2:

Table 6

Coefficient of Determiners R2

Variable	R^2	R^2 adjusted	*p*
CRET	0.34	0.33	0.00
CRIT	0.54	0.54	0.00
FE	0.37	0.37	0.00
MT	0.52	0.52	0.00
SR	0.26	0.26	0.00

According to Cohen (1988), R2 values of 0.02, 0.13, and 0.26 corresponds to **small, medium, and large** effect sizes, respectively. These criteria are widely used in social and behavioral sciences for evaluating the explanatory power of models. Based on (Cohen, 1988) these criteria:

CRIT and MT demonstrate a moderate to large explanatory power, highlighting the model's effectiveness in predicting these variables.

CRET and FE fall within the medium effect size range, suggesting that while the predictors provide a reasonable level of explanation for CRET and FE, additional factors might enhance their explanatory power.

SR (0.26) meets Cohen's threshold for a large effect size, implying that its variance is meaningfully explained by the predictors. However, given that it is at the lower bound of the large effect range, further improvements to the model, such as incorporating additional predictors, may strengthen its explanation.

However, the statistical significance ($p = 0.00$) across all variables confirms the importance of the relationships in the model.

The results indicate that the model provides strong explanatory power for CRIT and MT, while CRET, FE, and SR show moderate to strong predictive capabilities based on Cohen's (1988) benchmarks.

Predictive Relevance Q^2

Predictive Q2 evaluates how well an independent variable can predict an outcome variable beyond what would be expected by chance (Hair et al., 2019). Thresholds for Q^2 values according to (Hair et al., 2019) are:

$Q^2 > 0.35$: Strong predictive relevance
$0.15 \leq Q^2 < 0.35$: Moderate predictive relevance
$0.02 \leq Q^2 < 0.15$: Weak predictive relevance
$Q^2 < 0.02$: No predictive relevance

All constructs of the current study have Q2 > 0 confirming the model's predictive relevance according to Hair et al. (2019). CRET 1-3 Q2 ranged between (0.110 – 0.180), CRIT 1 – 5: (0.133 – 0.153), FE 1-5: (0.152 – 0.226), MT 2-5: (0.166 – 0.296), and SR 2-5: (0.03 – 0.190). This validates the model's predictive capability for most constructs. Table 7 summarizes predictors according to relevance strength (Hair et al., 2019):

Table 7

Q² predict

Variable	Q^2predict	RMSE	MAE	Interpretation	Prediction Errors
CRET	0.185	0.91	0.715	Medium	Moderate Error
CRIT	0.262	0.866	0.684	Medium	Moderate Error
FE	0.366	0.805	0.616	Large	Low Error
MT	0.372	0.803	0.599	Large	Lowest Error
SR	0.173	0.917	0.729	Medium	Highest Error

As the table shows, MT (Q^2 = 0.372) and FE (Q^2 = 0.366) demonstrate the strongest predictive relevance which reinforces their mediation roles. CRIT (Q^2 = 0.262) and CRET (Q^2 = 0.185) as the endogenous variables in the study demonstrate a medium predictive relevance indicating that the model can predict their outcomes very well. SR also demonstrates a medium predictive relevance which is critical for its mediation role. The highest and lowest results of items for each construct are summarized in Table 8:

Table 8

Predict MV

Construct	CRET 1	CRET 3	CRIT 4	CRIT 1	FE 3	FE 4	MT 3	MT 2	SR 4	SR 5
Q^2 predict	0.15	0.10	0.18	0.13	0.23	0.14	0.28	0.18	0.15	0.05
RMSE	0.90	0.86	0.77	0.78	0.78	0.93	0.72	0.74	0.86	0.75

The results of comparing the RMSE (or MAE) values with the LM values showed that the majority (18- 22) of indicators yielded smaller prediction errors compared to the LM indicating a medium predictive power (Shmueli et al., 2016). Only FE1, FE5, MT4, and SR5 yielded larger prediction errors.

Though the model requires minor refinement to elevate indicators with small predictive power to moderate or from moderate to strong, predicative relevance analysis highlighted the practical applicability of the model through its meaningful predicative ability. This aligns with the study's goal in structuring a framework to explain the effects of VRI on HoM (CRIT and CRET) through a series of mediators (FE → MT → SR). Hence, RQ1 and RQ2 are further supported as the model explains a significant variance in HoM validated by effect sizes and predictive power.

Effect Size (f^2)

Effect size (f2) is a measure of the relative impact of an independent variable on a dependent variable in (PLS-SEM). It quantifies how much an exogenous (predictor) variable contributes to explaining the variance of an endogenous (outcome) variable when added to the model. A particular endogenous construct can be determined such that (0.02).

Table 9

Effect Size

Path	f^2	t	p	Power
FE → MT	0.3	3.29	0.00	Large
MT→ SR	0.11	2.85	0.00	Small to Medium
SR → CRET	0.22	3.34	0.00	Medium
SR → CRIT	0.59	4.59	0.00	Large
VRI → CRET	0.08	2.36	0.02	Small
VRI → CRIT	0.13	3.33	0.00	Small to Medium
VRI → FE	0.6	4.13	0.00	Large
VRI → MT	0.14	2.69	0.01	Small to Medium
VRI → SR	0.03	1.64	0.10	Small

Table 9 summarizes the effects based on (Cohen, 2013). According to Cohen (1988), the f^2 effect size indicates the magnitude of the impact an independent variable has on an endogenous dependent variable in terms of explaining variance. The interpretation of f^2 values is categorized as follows:

An f^2 value of 0.02 is considered a small effect size, meaning the predictor contributes a minimal amount to the explanation of the endogenous variable's variance.

An f^2 value of 0.15 is interpreted as a medium effect size, indicating a moderate contribution of the predictor variable.

The table shows that f^2 results in the relation between FE and MT ($f^2 = 0.3$) indicating that FE has a large contribution in explaining MT. MT has a small to medium significant contribution to the explanation of SR with an ($f^2 = 0.11$). SR can largely contribute to the explanation of CRIT with an ($f^2 = 0.59$) but a medium contribution on CRET with an ($f^2 = 0.22$). VRI has a small significant contribution to explaining CRET with an ($f^2 = 0.08$), but it contributes largely to explaining FE with an ($f^2 = 0.60$). Moreover, VRI has a small to medium significant contribution to explaining MT with an ($f^2 = 0.14$). Finally, VRI has an insignificant small contribution in explaining SR with an ($f^2 = 0.03$). This suggests that VRI alone may not significantly explain changes in SR directly. Indirect analysis showed that specific indirect effects including mediators such as MT: (VRI → MT →

SR) or (VRI → FE → MT → SR) significantly contribute to the explanation of the relationship.

Hence, the research second question: RQ2: Are there statistically significant indirect effects of VRI as a method of teaching biology on students' HoM through the sequential mediation of FE, MT and SR? is positively answered.

3.2 Qualitative Results

The qualitative study aimed to explain the impact of (VRI) on students' HoM including SE, CRIT, and CRET, while examining the mediating roles of SR, MT and FE based on CAMIL which adopts constructivist views. CAMIL provides explanations of the way VRI affects cognitive outcomes through active participation in actual experiences according to Tang (2024). The data for the study was collected from direct observations of the participating students during VRI-based biology classes aiming to study participants' natural behaviors and to allow for insights into authentic behaviors and interactions that might not be gained through interviews or focus groups. Semi-structured interviews with participating students as well as focus groups aimed to capture students' experiences, perceptions, and reflections on how immersion in virtual environments influenced their learning processes and cognitive development.

The following table from MAXQDA summarizes deductive and inductive results of the coding process extracted from semi-structured interviews with ten students and three focus groups from different grade levels of the participating schools:

Table 10

Primary categories and sub-categories (frequences and percentages)

Code System	Frequency	Percentage of primary categories	Subcategory	Frequency	Percentage of Subcategory
Total Codes				1373	100%
Virtual Reality Immersion (VRI)	184	13%	Spatial Presence (SP)	74	40%
			Involvement (INV.)	81	44%
			Experiential Reality (ER)	29	16%
Flow Experience (FE)	214	16%	Exceeding expectations	36	17%
			Total Concentration	48	22%
			Time passed too fast.	36	17%
			gratifying experience	47	22%
			Enjoy experience through VR technology	47	22%
Motivation (MT)	228	17%	Feeling skillful using VR	34	15%
			Feeling relaxed while using VR	40	18%
			Feeling competent	72	32%
			Performing well using VR technology in class.	34	15%
			Feeling Interested to use VR technology in class	48	21%
Self-Regulation (SR)	236	17%	Becoming Sensitive to feedback	28	12%
			Self-evaluating of effectiveness	52	22%
			Managing resources	51	22%
			Planning effectively	41	17%
			Being Aware of own thinking	64	27%
Critical Thinking (CRIT)	233	17%	Taking positions assertively	26	11%
			Restraining Impulsivity	30	13%
			Being open minded	27	12%
			Being clarity-driven	32	14%
			Being accuracy-oriented	63	27%
			Showing empathy with others' feelings and knowledge	29	12%
			Exploratory Oriented (Inductive)	26	11%
Creative Thinking (CRET)	278	20%	Generating new ways for viewing situations	78	28%
			Generating their own standards for evaluation	51	18%
			Pushing the limits of own knowledge and ability	52	19%
			Engaging in tasks with no clear solutions	48	17%
			Generating Conceptual Visualization (Inductive)	49	18%

Deductive analysis revealed the same primary categories of VRI, HoM: (SR, CRIT, CRET), MT an d FE. However, inductive analysis revealed two subcategories emerging under CRIT and CRET. Generation of Conceptual Visualization emerged as a dominant subcategory of CRET with a frequency of 49 instances representing 18% of the CRET primary category, and Exploratory Oriented emerged as a subcategory of CRIT with a frequency of 26 instances representing 11% of the primary category.

3.2.1 Immersion in Virtual reality (VRI)

Integrating VRI in biology classes revealed numerous manifestations of three subcategories. The first is related to 'spatial presence' and signifies the level to which students felt physically present in the virtual environment. The second relates to 'Involvement' and signifies the level of engagement and attention of students within the VR environment and the third pertains to 'experiential reality' and signifies the level to which virtual reality and its objects seemed real to the participant. Numerous instances from direct observations, focus groups and semi-structured interviews illustrate students' deep level of immersion and engagement in the virtual world during different VR-based biology classes.

Spatial Presence

SP emerged through students' physical and verbal interactions with the virtual environment. Observations highlighted students' movements trying to reach toward virtual objects, stepping forward and backward, and synchronized behaviors across groups. For example, students bent down simultaneously during 3D scene exploration, creating a sense of shared immersion. Verbal comments further emphasized this, with one student stating, "*I feel a bit dizzy climbing the DNA ladder*" and another noting, "*The weather is fine here*" while immersed in a photosynthesis simulation. A common reflection among FG2 was "*We interacted with the nerve impulse because we felt like we were part of it.*" These behaviors, expressions, and shared sentiments underscore the depth of SP, where students perceived virtual space as a real, tangible environment.

Involvement

INV was reflected through the deep engagement, attentiveness and persistence of students to complete VR tasks. Even weaker students reflected strong motivation to actively participate. For instance, one student expressed frustration at not having enough time, remarking, "*You said we have 5 minutes to finish the activity, but it's been only half a minute. Give me a chance to try another way to do it.*" Students in FG1 agreed that "*While interacting with the virtual environment, you forget whether you are sitting or standing, and you might bump into things because of how focused you are".* This highlights how VR activities enhanced intrinsic motivation and problem-solving focus, keeping students immersed and willing to invest time and effort beyond traditional class limits.

Experiential Reality

ER was observed through students' descriptions of the virtual environment as reality itself. Many students commented, "*It felt real*." or "*I feel I am in a real cell.*" A shy, academically weak student vividly recounted his immersive experience: "*I was inside the cell, seeing detailed interactions between ribosomes, the endoplasmic reticulum, and the Golgi apparatus. This helped me understand better than ever.*" Discussion with students in FG2 reinforced the same idea "*We saw the inside of the cell, and everything was moving around us. We were inside it, seeing things up close*." Such reflections demonstrate how VR transformed abstract concepts into vivid, interactive experiences, enhancing engagement, understanding and retention.

The findings reflect how VRI enhanced learning through fostering SP, INV, and ER. This immersion created by VR kept students engaged, motivated, and connected to the learning environment through the transformation of abstract concepts into visualized experiences that enhanced understanding.

3.2.2 Flow Experience

Findings proved that FE was evidently a result of VRI. The integration of VRI in biology lessons revealed numerous manifestations of the five key elements of FE:

An Experience Exceeding Expectations

After application, students realized that the outcomes of VRI as an educational tool far surpassed their initial assumptions. K. AH7 expressed, "*It was a beautiful and wonderful experience that exceeded all our expectations. Through it, I learned about photosynthesis in an enjoyable and engaging way, and I understood more than I ever imagined.*"

Students in FG1 highlighted the idea, "*An enjoyable and extremely beneficial experience.*" This highlights the learning experience exceeded students' initial expectations.

Total Concentration

Concentration was observed through students deep focus and immersion in the task at hand. Their attention was fully directed toward the activity. Interviews showed this deep concentration clearly when O. AS9 emphasized, "*VRI helps a lot with focus. It's like you're concentrating without even trying.*" The idea of total concentration was highlighted through discussions with FGs. Studetns of FG3 described their state of deep concentration as, "*It's as if you enter a sealed room by yourself, where you see and hear only what you're meant to focus on.*" This shows how VRI naturally generated the flow experience.

Time passed too fast

This subcategory was observed through students' surprise when the sessions ended, and they were required to stop immersion. Phrases like, "*the session has just started!*" or "*Is my time up!*" clearly reflected students' unawareness of time. The idea was intensely highlighted during interviews. K. AH6 illustrated, "*In VR, time passes so quickly. You barely start, and it's already over—it feels like time just flies.*" Students in FG3 emphasized "*compared to traditional classes, time flies during VRI.*" This shows how students lose track of time during VRI sessions.

Gratifying experience

After the experience, students reflected satisfaction and fulfillment about the value gained from VRI. Sh. I4 reflected her gratification for the experience, "*It was a truly amazing experience. I learnt a lot in a very enjoyable way and felt mentally comfortable because my understanding was deep, which greatly helped with comprehension and retention.*" Discussion about gratification with FG3 resulted in many students expressing gratification using different expressions such as, "*VR is a unique experience, and we feel lucky to have learnt through it. I hope its use can be expanded to other subjects, not just biology.*" Such insights reflect students' gratification for the use of VRI during biology classes.

Enjoy experience through VR technology

Due to the novelty of VR, students were intrinsically motivated to use it. Interacting with 3D videos and scenes, students found pleasure and were satisfied with the experience. Students' interviews reflected their pleasure using the VR. K. Ah6 illustrated,

"*You feel like you're on a journey in the virtual world. You enjoy beautiful views in the forest and nature, seeing trees in ways you wouldn't in the classroom. Sometimes, you find yourself underground near the roots, in the forest, inside a leaf, and in various other places.*". Most students in different FGs also expressed their pleasure using the tool, "*it is just like as if you are playing a game.*" They agreed.

It was clear that VRI fully involved students in the biology content. They were completely absorbed in what they were doing. Interacting with the biology content through VR was self-rewarding by itself. This case of total involvement enhanced students' self-efficacy and therefore their self-determination to complete the biology tasks. Tasks through VRI seemed like self-rewarding leisure activities and resulted in generating high levels of motivation.

3.2.3 Motivation

Findings revealed that VRI enhanced students' intrinsic as well as extrinsic motivation and improved their performance. Intrinsic motivation was manifest through expressions like: M. K3 "*VR, first of all, not only makes you love studying, but the experience itself is enjoyable and fun.*" Students also reflected extrinsic motivation such as, SH. I4 "*VR is a good way to pass biology tests easily*." However, no signs of non-self-determined motivation or amotivation surfaced in the study. The data revealed that key elements of motivation such as, feeling skillful using VR; or feeling relaxed; competent; satisfied of their performance; and feeling that VR is interesting prevailed during VRI applications during biology classes.

Feeling Skillful using the VR

Since the second week on, most students exhibited excellent control of the tool. During interviews, students mentioned that the tool is easy to control. E.Z2 for example informed, "*VR is easy to use. I quickly learnt how to use it. Now, I can even help others with it.*" Discussion with FGs also showed that the tool is easily and quickly controlled over, as long as basic computer knowledge exists. Most of FG3 agreed that "*VR is a great tool for learning. It's very easy to use, especially if you are familiar with computers*." This shows how students quickly learnt to use VR and coped with the learning environment.

Feeling relaxed while using VR

Students were tension-free during VR-based biology classes and reflected relaxation *through their happiness*, joy, and laughs. Interviews reflected this feeling of relaxation clearly. O. AS9 reflected, *"You enter a world where 99% of the time, you leave the class understanding everything. You feel comfortable, happy, and immersed."* Discussions with FGs highlighted this feeling of relaxation. "*VR releases your stress, and lets you enjoy learning.*" This reflects the relaxed atmosphere of the VRI learning environment.

Feeling competent

Arriving at solutions to the tasks at the end of the sessions enhanced students' self-confidence about their abilities. Continuous success to achieve goals or accomplishing missions during VRI promoted students' confidence and feeling of competence. K. Ah6 remarked, *"…with VR, my abilities to complete tasks and understand improved, my confidence in myself and my knowledge increased, and I started feeling like I understood more."* Most students in different FGs highlighted the idea and suggested, "*expanding the use of VRI to other subjects so that their confidence would increase, and we could understand and apply better.*" Such insights reflect an improved level of students' self-confidence and feelings of better competence.

Performance was good using VR technology in class

Students' performance during VRI was notable through their deep engagement with the activities and intense participation after interaction. The discussion part of the sessions was very active and reflected students' accomplishments of the tasks which notably increased their motivation. A. H10 remarked,

"I was the nerve impulse, moving between cells and body parts. The experiences were comfortable to understand, unique, and enjoyable. I felt a deep understanding, solved the activities easily, and became more engaged in class participation."

Most FGs stressed the idea that, *"our performance during and after VRI was much better."* These insights highlight how VR enhanced students' understanding, motivation, and active participation.

Interesting to use VR technology in class

The enjoyment of using VR was one of the most noticeable aspects observed among the students. Students showed excitement when they found out that a biology lesson is going to be VR-based. They cooperated with their teachers to arrange the class so that they started as soon as possible. During application, they were deeply engaged and captivated during VRI. They expressed much enjoyment exploring through VRI. Student M. K3 expressed, *"You feel happy and engaged, and, on the contrary, you don't want to leave."* These signs of enjoyment, happiness, relaxation, skillfulness and concentration were clear signs of students' high level of motivation.

3.2.4 Habits of Mind

The objective of this study is to explore the effects of VRI on high school students' HoM during VR-based biology classes. The term HoM represents cognitive and behavioral patterns that influence problem solving, decision making, and learning. Therefore, it encompasses three primary categories: SR, CRIT and CRET.

3.2.4.1 Self-Regulation

Students' ability to employ meta skills that enable awareness, monitoring and adaptation of learning strategies through cognitive and meta cognitive processes is referred to as self-regulation. It is a way to control oneself while goal directed. Analysis of interview results highlighted five subcategories within the Self-Regulation primary category:

Sensitivity to Feedback

Students' awareness of feedback from their teachers and peers during the VRI sessions was apparent in their comments. During sessions, students needed immediate feedback to adjust their actions in the virtual environment to achieve their goals. Student E. Z2 remarked, "*If I faced difficulty, I would ask the teacher or the students, listen to their guidance, and find the solution after trying."* One shared insight of FG2 was, *"the teacher is indispensable. You need someone to explain the material and provide the necessary guidance to complete the tasks during interaction with VR."* This shows how

VRI encourages students to seek and use feedback when they are goal-directed, driven by the force of intrinsic motivation to achieve a specific goal.

Evaluating own effectiveness of acts

Responding to feedback and quickly adjusting ineffective methods or seeking guidance from experts was a common act among students during interaction. Students paused during VR activities, sought feedback, and made necessary adjustments before re-immersing in the virtual world. Students' interview results also reflected their mature levels of self-evaluation, students Sh. I4 noted, "*In VR, I followed the cell step by step, and whenever I felt lost, I would ask my classmate or the teacher. When I returned, I felt much closer to finding the solution.*" In FG1, several participants shared the idea that, "*Now I believe that Biology is better understood than memorized, VR helped me understand and now I can express my understanding using my own language.*" This reflects students' ability to evaluate their performance through closely watching over their actions during and after VR sessions and making necessary adjustments to ensure achievement of objectives.

Management of Resources

VR as an educational tool, exposed students to a new source of knowledge. Students' ability to carefully assess resource needs, review available options, and anticipate potential demands before starting a task are signs of effective management of resources. Many students were observed checking their books before VRI sessions to identify what they might need to achieve their goals successfully. In many cases, they asked clarifying questions that aimed to solve a conflicting idea. Interviews also showed numerous instances reflecting awareness of the differing resources. Student K. Ah6 noted, *"you start reviewing the teacher's explanation and the textbook by yourself, then you begin comparing before and after the interaction in VR."* In FG2, most students highlighted the idea that, "*Interactive VR videos effectively enabled them to bridge the gaps in their coursebook and supplemented any content missed during the teacher's explanations*." This reflects mature components of self-regulated learning.

Effective Planning

Effective planning is a key component of self-regulation. Sings of effective planning appeared clearly during the second week. Students started giving more attention to lesson objectives and asking clarifying questions before planning how to achieve them. Students' interviews provided many cases that reflect effective planning. Student A. M7 noted, "*the most important thing is to know your goals before entering the virtual world and to set a plan for how to achieve them*." FGs 1&2 most students agreed that "*you start by planning what you want to understand... and then you go to where you planned.*" This shows how students internalized the importance of precise planning before they start tasks.

Recognizing self-thinking

Students' ability to detail the sequence of their thoughts and analyze how awareness of their thinking improves performance was reflected during VRI. Students were asking themselves about whether their strategies were effective and useful to the task, and uttered phrases like "*let me check whether this approach helps.*" Awareness of metacognition was the most frequent subcategory (64 instances) in this study. A striking example mentioned by J.AD8,

"*VR taught me that focus is the key to understanding and reaching the right solutions, you start applying this in traditional classes as well. You remind yourself that if you concentrate, you can understand, and you push yourself to stay focused*."

FGs also provided numerous instances about this awareness of thinking. Most students in different FGs agreed that:

"*I started thinking about the function of the nucleus. Why is there a nucleolus? Why does it have this shape? I began asking myself questions about things: Why is this here? What is the purpose of this? Why does this have that shape*?"

This awareness of self-thinking helped students adjust their strategies and actions towards their goals and ensure enhanced engagement.

These enhanced self-regulatory skills during VRI improved students' performance and contributed to their overall learning process. Moreover, this enhanced form of SR is prepared for enhancing students' CRIT and CRET through strengthening the basis of these cognitive skills represented in effective planning, effective self-evaluation, sensitivity to feedback and effective management of resources.

3.2.4.2 Critical Thinking

The study revealed the development of students' CRIT through VRI. The category of CRIT included six deductive subcategories, namely, accuracy oriented, clarity driven, open-mindedness, impulsivity restrain, and sensitivity to other's feelings and knowledge. The emerging inductive subcategory of "exploratory oriented" represented the seventh subcategory.

Accuracy oriented

Paying attention to details, verifying key resources, and quickly correcting inaccuracies for clarity appeared clearly through students' continuous referencing to the book, the teacher and classmates during VR application. Precision was also observed through their participation during the discussion part: "*seeing something from all its angles, our understanding of it changes.*" E. Z2 noted, "*We saw each part. How it's formed, how it's structured, and how it interacts with the other parts*." During interviews A.K5 commented:

"*We saw the other organelles of the cell. This helps you understand the function of each part. Finally, we saw the cell as a unit, and this gave us a much deeper and more accurate understanding".*

During FGs discussions, many students noted that, VRI improved their accuracy through providing them with "*the details of the details*". These reflections demonstrate that VR not only deepened students' conceptual understanding but also significantly enhanced their attention to detail and scientific accuracy.

Clarity driven

Students' work and output gradually became clearer and free from confusing elements due to the precision they gained from VRI in biology classes. They were observed asking to clarify questions before handing out their final papers or before presenting their findings. MK3 noted, "*Today, I can answer questions clearly and in multiple ways from different perspectives, just like I learned from different angles*." FG3 students highlighted the insight that VRI deeply enhanced their understanding, and that receptive clarity generates productive clarity. Most students agreed that:

"*Studying the transmission of the nerve impulse from the textbook is a very difficult and exhausting process, because it involves many steps. However, seeing it through VR, the steps became neither complicated nor numerous, and could be explained simply and clearly*." This shows how VR transformed abstract and complex biological processes into clear, structured experiences.

Open-mindedness

Students' tolerance to consider, evaluate, and accept ideas different from their own was observed during the discussion part of the sessions. Students submitted new or contradicting views to investigations based on scientific facts from trusted references. Students' responses during interviews emphasized the same idea. SH. I4 for example, noted that "*I don't mind if my perspective differs from others'. In the end, it's evidence or proof that determines who is right or who is wrong. I can explain my point of view alongside the opposing one."* Discussions with different FGs showed that VR became a reliable source for the evaluation of correctness or wrongness of views or ideas: "*When someone says something incorrect, we take them to the VR, and there, they figure out truth, whether they are right or wrong.*" This shows the ability of VR to foster open-mindedness and encouraged evidence-based evaluation of ideas.

Impulsivity Restrain

Students' behaviors during VRI discussion parts, such as closing their eyes and raising their heads trying to recall VR happenings, and analyze it before talking to prove their points, were clearly observed. The same behavior was repeated during the interviews when they were asked to describe their feelings during VRI. Student A.H9 shared, "*I started double-checking my answers and verifying the accuracy of the information I have before responding in exams or in class.*" During FG2 Many students expressed, "*caring about the consequences of their decisions before they proceed*." Such insights highlight the growing sense of thoughtful reflection and responsibility in students' learning and decision-making processes.

Taking positions assertively

Maturity of students' SR enhanced their awareness of specific details about the content. This awareness improved their ability to take stands in discussions and support it logically based on facts and knowledge they acquired from interacting with the VR biology content. Having the freedom to interact freely, students were able to support their stands from different perspectives. Student A.K5 remarked: "*when you see something with your own eyes, you'll be able to discuss it confidently."* This clarifies the difference between knowledge gained and knowledge dictated.

Sensitivity to Others' feelings and knowledge

Students' empathy for others' feelings and knowledge was evident as students demonstrated empathy and respect while collaborating. They supported one another during the application. Competent students were patiently cooperating with weaker ones or those who were struggling with the VR tool. During interviews, A. H10 commented, "*I gained the ability to explain the lesson to my classmates in a simplified way, even better than the textbook*." During FG1 discussion, most students agreed that "*Some students feel shy about asking the teacher to explain again when they don't understand. But now, through VR, we can help them without embarrassing them. VR gives you the feeling that you're playing, not studying*. This shows how students cared about other's feelings and perspectives.

Exploration-oriented (Inductive)

This inductive category emerged during VRI sessions with many students uttering "*look what I found!*" or "*I am exploring the chloroplasts in the leaf.*" Interviews reflected students' desire to discover, gather evidence and construct their knowledge on their own. They saw VRI as the best environment for learning through exploration and discovering. M. A1 noted, "*Instead of the teacher giving us the rules and facts, we can deduce the rules ourselves through VR, verify their accuracy, and apply them as well.*" Exploration was heavily discussed with all FGs and most students agreed that exploration was part of their VRI session, and that it seemed more interesting to explore, discover and apply through VRI.

3.2.4.3 Creative Thinking

The study revealed that students' CRET was enhanced through interacting with VRI. Analysis of the data revealed four deductive subcategories and one inductive: Deductive Categories included: generation of new ways for viewing situations, generation of own standards for evaluation, pushing the limits of own knowledge and abilities and engagement in tasks with no clear solutions. Inductive analysis revealed the category '*Generation of Conceptual Visualization*'.

Generation of new ways for viewing

Students' hand movements during VRI showed that they were exploring the virtual objects with great attention. They were trying to zoom in and out and rotate the objects to check them from different angles, trying to arrive at new knowledge that was not required by the specific task they were expected to achieve. During the discussion part, students reflected on how VRI improved their perception of the objects. Interviews also revealed many instances that showed how students viewed things differently. For example, Sh. I4 noted, "*my previous understanding of DNA was that it was a stable organ used by the body. But through virtual reality, I learned that it keeps moving and exists in every cell of our body".* FGs with students provided numerous instances about students' innovative ways of viewing things. Most of the students agreed that "*The textbook images are interpretable in a limited way. However, with VR, you experience the process in a completely different manner.*" These examples clarify the power of VRI in enhancing students' abilities to generate new ways for viewing things.

Generation of own standards for evaluation

Observing students through VRI clearly reflected their new standards for evaluation. Creating new criteria for evaluating their own performance; their coursebooks; and their teachers. Phrases like "*this is exactly as the teachers explained*." Or "*This is missing in the book*" enabled students to make judgements based on their own experience. Interviewing students supported this when M. K3 said, "*I can now evaluate how accurate our coursebook is, especially in the topics related to the cell and the DNA."* Discussions with FGs revealed that most students can now easily evaluate their understanding. Hence, VRI empowered students to develop independent evaluative standards, enhancing their ability to critically assess content, instruction, and their own learning.

Pushing the limits of own knowledge and abilities

Students were observed to be persistent and insistent to complete the VRI tasks, and even eagerly asked for additional VRI time to allow them to try other approaches that might help complete the task successfully. During interviews, J. AD8 remarked, *"During VRI, I didn't feel that anything was impossible, especially that I could repeat the experiment* *and try again as many times as I wanted."* FG3 agreed with the student's comment, "*I've come to realize that I can overcome any obstacle successfully. Interacting with VR encourages you to repeat and try again without getting bored. In the end, you come away with more information than you initially aimed for."* These insights show that VRI enhanced students' enthusiasm and confidence, motivating them to keep trying until they succeeded.

Engagement in tasks with no clear solutions

Some of the tasks given to students during VRI needed problem solving skills. Students immediately immersed in the interactive VR scenes, stayed determined to find alternatives and came up with creative solutions. When the task was about "why do you think some trees has colors other than green? Student A. M7 answered,

"*I started trying to think about why trees are always green, but in autumn, they turn orange or other colors. Then I remembered that humans also need different kinds of food during the seasons, so I thought maybe plants have the same reason. Or maybe the amount of sunlight affects it as well."*

FG3 students supported the idea that VRI raised their curiosity and encouraged them to keep interacting until they arrive to a logical solution or a better understanding. These observations suggest that VRI stimulated students' curiosity and supported problem-solving by encouraging creative thinking and logical exploration.

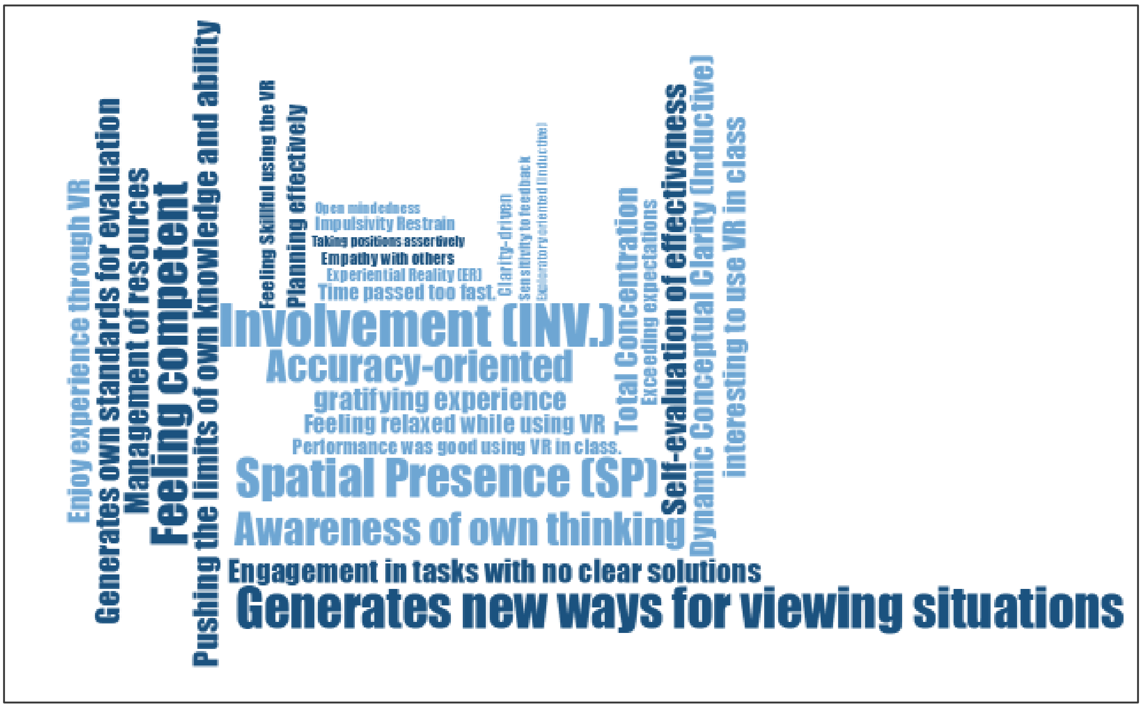
Generation of Conceptual Visualization (Inductive)

During the discussion part of the lesson, students used to close their eyes and move their hands trying to revisit the VR scene when they were trying to get an answer that needed critical or creative thinking. During interviews, J. AD7 noted, "*VRI videos rely on a detailed explanation of all the components of the organ, and in the end, you see them all working together. This way, you feel the connections between them, the picture becomes complete, and you never forget it".* The same idea of how VRI helped them visualize and understand, was highlighted through all FGs. For example, one student asserted, "*I still remember the shapes and sounds so vividly that I can draw them from multiple angels.*" These reflections show that VRI helped students remember and visualize complex ideas which enhanced deeper thinking.

To conclude, VRI enhanced HoM directly through its ability to provide students with clear, safe, attractive, and authentic experiences that helped them construct knowledge through exploration. It also impacted on their HoM, through FE which made them enjoy what they were doing and deeply focus on their tasks. The experience itself was autotelic, and it generated intrinsic motivation, allowing students to feel competent, comfortable, and skillful. This feeling generated self-efficacy which enhanced SR greatly. This enhanced SR doubled the effect of VRI on CRIT and CRET.

Figure 4

Code cloud frequency generated from MAXQDA



3.3 Integrating quantitative and qualitative results

Quantitative and qualitative results supported the hypothesized relations between VRI and HoM. While quantitative results detailed the enhanced magnitude of of VRI on students' HoM through the mediators FE, MT, and SR, qualitative findings provided specific insights and verbal explanations that supported these relations.

Figure 5

Transferring the effects of FE → MT → SR

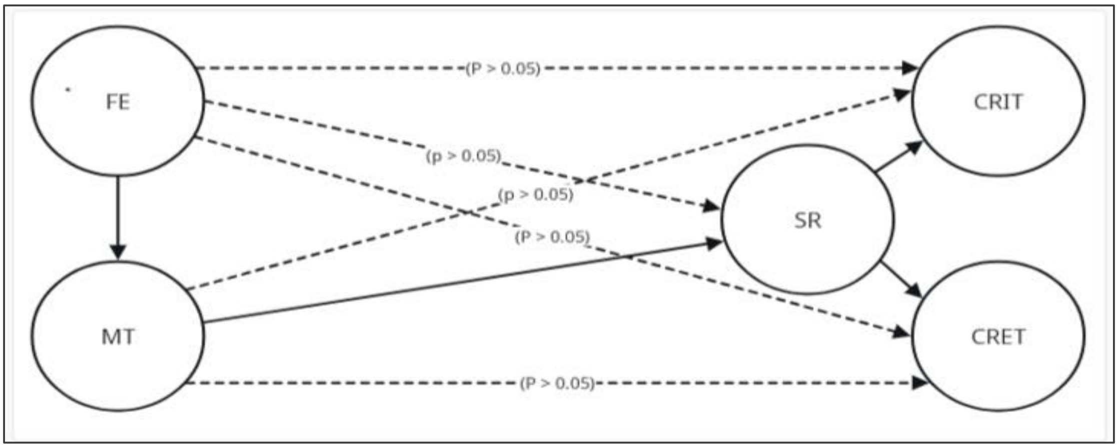


Figure 5 highlights the effect of sequential mediation in transferring the effect of FE and MT into SR as the final sequential mediator that transmits the effects into CRIT and CRET. The figure shows how FE has only one significant direct effect on MT. MT also has only one direct effect on SR. SR functions as the first output variable enhanced by the path FE → MT, then it enhances CRIT and CRET. Following is the significant findings of quantitative and qualitative analysis:

VRI → FE → MT → SR/CRIT/CRET

Quantitative results reflected moderate significant direct effects of VRI on SR ($\beta = 0.20$, $p < 0.05$), CRIT ($\beta = 0.27$, $p < 0.05$) and CRET ($\beta = 0.26$, $p < 0.05$). Total effects of VRI showed strong significant effects: SR ($\beta = 0.43$, $p < 0.05$), CRIT ($\beta = 0.52$, $p < 0.05$) and CRET ($\beta = 0.44$, $p < 0.05$). Highlighting the role of mediators FE, MT and SR in amplifying the effects.

Qualitative results manifested the sequential mechanism of mediators through students' insights about the way they were first highly engaged in VRI which enhanced their motivation. Higher levels of motivation developed their self-regulatory habits through the adjustment of their strategies to perform.

Enhanced CRIT was manifested in students' accuracy about the received and produced information 63 (27%), becoming clear 32 (14%); open-minded 27 (12%); being able to restrain their impulses 30 (13%); take positions assertively 26 (11%), and demonstrate empathy towards others' feelings and knowledge 29 (12%); and exploratory oriented, all ranging between (11% - 14%) of the total instances emphasizing the enhancement of students' CRIT.

Students' CRET also supported the quantitative analysis. Qualitative results showed 78 (28%) cases of the total codes reflecting students' generation of new ways for viewing situations. Interviews and focus groups reflected how VR-based biology classes helped students view knowledge from a broader perspective, allowing them to connect various elements and draw meaningful conclusions. An adjusted view based on students' prior knowledge and the VR content helped this enhancement. This led to students' generation of their own standards for evaluating knowledge 51 (18%) and encouraged them to engage in tasks with no clear-cut answers 49 (18%). This also encouraged them to seek and participate in highly challenging tasks and achieve them, 52 (19%). Finally, the inductive subcategory indicating students' ability to generate conceptual visualization recurred 49 (18%).

FE → [SR/CRIT/CRET]

Quantitative results revealed insignificant direct effects of FE on CRIT, CRET or on SR ($p > 0.05$). The only significant path through which FE affects CRIT and CRET was through its direct effect on MT ($\beta = 0.48$, $p < 0.05$).

Students' insights underscored the direct relationship between FE and MT. Deeper engagement and concentration resulted in sparking their motivation to comprehend.

MT → [SR/CRIT/CRET]

PLS-SEM results showed a significant direct effect of MT on SR ($\beta = 0.36$, $p < 0.05$). However, MT has insignificant direct effects on both CRIT and CRET ($p > 0.05$).

Many of the students' reflections about their increased motivation were related to the adjustment of their self-regulatory habits represented by their improved goal setting, effective planning, organization, self-monitoring and self-evaluation.

FE → MT → SR

There is a significant indirect effect of FE on SR mediated by MT ($\beta = 0.17$, $p < 0.05$). Quantitative results confirmed the insignificant direct effect between FE and SR indicating a case of full mediation of MT.

Qualitative results manifested the sequential mechanism of mediators through students' insights about the way they were first highly engaged in VRI which enhanced their motivation. Higher levels of motivation improved their feeling of competence and self-confidence affecting their self-regulatory habits through the adjustment of strategies to perform better.

FE → MT → SR → [CRIT/CRET]

Quantitative analysis found a weak significant indirect effect of FE on CRIT ($\beta = 0.07$, $p < 0.05$) and on CRET ($\beta = 0.05$, $p < 0.05$) through the indirect pathway FE → MT → SR → CRIT/CRET. PLS-SEM results showed that the direct effects of FE on SR and on CRIT/CRET were both insignificant ($p > 0.05$). Moreover, MT has an insignificant direct effect on CRIT/CRET ($p > 0.05$) suggesting the full mediation process involving MT and SR.

FE led to generating students' MT. Students stressed that VRI experience made them feel competent. Feeling competent was the most frequent subcategory 72 (32%) of the total instances. Other signs of motivation included students' self-evaluation of their performance as good 34 (15%) and feeling skillful 34 (15%) of the primary category MT. This justifies the strong significant direct effect of FE on MT ($\beta = 0.48$, $p < 0.05$). These positive attitudes improved students' self-confidence leading to enhance their SR and to explain the strong significant direct effect of MT on SR ($\beta = 0.36$, $p < 0.05$).

The central role of SR as both an outcome and as a final sequential mediator explains how the total effects of VRI on SR ($\beta = 0.43$, $p < 0.05$), CRIT ($\beta = 0.52$, $p < 0.05$) and CRET ($\beta = 0.44$, $p < 0.05$) were upgraded into strong significant effects through the chain mediation of FE, MT, and SR. Qualitative results also highlighted the role of chain mediation in enhancing CRIT and CRET.

MT → SR → [CRIT/CRET]

PLS-SEM results revealed a significant indirect effect of MT on CRIT ($\beta = 0.21$, $p < 0.05$) and on CRET ($\beta = 0.15$, $p < 0.05$). As MT has insignificant direct effects on either CRIT or CRET ($p > 0.05$), this indicates a full mediation case of SR in the pathway meaning that MT can affect students' CRIT and CRET when only when their SR is improved.

Qualitative results provided insights about this pathway. Although students' MT was enhanced through VRI and FE, it was not able to affect their CRIT and CRET unless SR was enhanced.

To conclude, the qualitative results of the study aligned with the quantitative ones about the significant effects of VRI-based biology classes on students HoM through a sequence of mediators FE → MT → SR. Both quantitative and qualitative findings confirmed:

VRI enhances FE.
FE generates MT.
MT enhances SR.
SR significantly fosters both CRIT and CRET.

Chapter Four
Discussions and Conclusions

The chapter discusses the implications of the study findings regarding VRI impact on students' SR, CRIT and CRET through the sequential mediation of FE, MT, and SR. Quantitative and qualitative data are integrated, situating the results within the framework of the Cognitive Affective Model of Immersive Learning (CAMIL) and existing literature.

4.1 Quantitative Discussions

Learning is an active process through which students construct their own knowledge through their engagement in actual experiences. CAMIL provides an explanation of how cognitive immersion through VR affects the final desired outcomes through the provision of interaction and participatory experiences. This encourages learners to engage in learning responsively and develop self-regulatory habits that can finally affect critical and creative thinking by providing chances to solve problems and make decisions according to Tang (2024). This study examined the impact of VRI on desired scientific habits of mind, namely, self-regulation, critical and creative thinking through a sequence of mediators: Self-regulation, flow experience, and motivation. Results of analysis provided valuable insights about the mechanisms through which VRI can strongly enhance higher cognitive skills in education.

4.1.1 Direct effects of VRI

Direct effect results confirmed that VRI-based biology classes have a moderate direct significant impact on students' self-regulation, critical and creative thinking: VRI on SR ($\beta = 0.2$ $p < 0.05$), CRIT ($\beta = 0.27$, $p < 0.05$) and on CRET ($\beta = 0.26$ $p < 0.05$). VRI-based biology classes helped overcome the barriers of the traditional teacher-centred classroom environment represented in time, space, danger, cost or accessibility as noted by Rojas-Sánchez et al. (2023), and provided practical experiences for students. Thus, immersion in the virtual environment allowed students to actively interact with new fundamental biology concepts enhancing learners' behavioral and cognitive skills. This idea of how immersion helps students deeply understand the content and promote critical and creative thinking aligns with Solmaz et al. (2024) and (Prawat, 1991).

However, PLS-SEM results reflected strong total effects of VRI on SR, CRIT and CRET resulting from mediators' intervention.

4.1.2 Mediation effects

Results of indirect and specific indirect effect analysis revealed the significant indirect enhancement caused by mediators FE, MT, and SR. The absence of direct significant effects of either FE or MT on CRIT or on CRET made the final sequential mediator SR function as a harbor through which the effects of FE and MT are significantly transferred to CRIT and CRET. This asserts the findings of Hyytinen et al. (2021) about SR being crucial for fostering CRIT and Ghbari and Harahsheh (2024) about SR as a predictor for CRET, reinforcing the idea that students' ability to regulate their learning plays a crucial role in fostering higher order thinking skills.

4.1.2.1 The role of FE in fostering MT through VRI

VRI has a strong direct effect on FE ($\beta = 0.61$, $p < 0.05$). VRI biology classes caused students to be fully absorbed in the virtual environment of the biology content, (the cell, the DNA, the nerve impulse, or in photosynthesis), enhancing high levels of engagement, and deep concentration corroborating with Mahnke et al. (2012). VRI instruction provided students with immersion and higher levels of engagement which facilitated perception of complex biology concepts constructively supporting the ideas and findings of Marougkas et al. (2023) about immersive learning. Educators can use VRI to introduce complex biology contents to students, to make sure they develop a sense of self-competence about them. This mirrors Thompson et al. (2022), about students highly valuing VRI as an effective instructional method that improved their attitudes towards learning.

Furthermore, FE has a strong direct effect on MT ($\beta = 0.47$, $p < 0.05$). Being completely engaged in the virtual environment, students became inherently satisfied and enjoyed interacting with the simulated scenes. This created a type of intrinsic motivation that was caused by the force of flow experience. An improved self-regulation resulted in the form of students' goal-setting skills, persistence to complete the tasks in hand, and resistance to failure. This corroborates with Thompson et al. (2022) view of VRI as positively associated with students' positive attitudes towards learning.

4.1.2.2 The role of MT in enhancing SR

Findings also confirmed the strong impact of VRI on MT ($\beta = 0.32$, $p < 0.05$) caused by students' satisfaction or enjoyment for the sake of the activity itself or for the enjoyment and satisfaction gained from it. This aligns with Zeng et al. (2022) and implies that VRI can generate high levels of MT which enhance SR, and subsequently CRIT and CRET. Educators can plan and implement interactive classes to generate higher levels of motivation that can finally impact their higher order thinking skills.

MT functioned as an intermediary variable in the relationship between VRI and SR which accounted for 53% of the total effect. FE, as PLS-SEM result confirmed, does not significantly affect HoM in a direct path which underscores the role of MT as an intermediary variable. This emphasized the role of VRI in inducing intrinsic motivation either directly or through FE which, in turn, sparks motivation as inherently enjoyable which directly relates to extrinsic motivation according to Mills and Fullagar (2008) and finally enhances students' SR.

This final effect of motivation gained directly from both VRI and FE directly affects SR enhancing students' ability to plan, monitor, and evaluate their own behavior. This echoes De La Fuente et al. (2022) view about SR as positively related to personal adjustment factors, diligence, and well-adjusted academic behavior. Students then, redirect themselves according to their self-evaluation and as part of adaptation of their learning strategies confirming (Baranovskaya, 2015; Mitsea et al., 2023; Zimmerman, 2002) ideas about SR as judging consistency of actions which enables the learner to adaptively redirect him or herself. This enhanced form of student's SR directly affects their critical and creative thinking.

It is important to note that previous studies about the effects of MT on CRIT and CRET reflected significant results (Fahim & Hajimaghsoodi, 2014; Munahefi et al., 2018; Valenzuela et al., 2017). However, the current study revealed insignificant effects. This might be attributed to the inclusion of SR items such as self-monitoring and self-evaluation, as well as goal-directed strategies as belonging directly to critical and creative thinking. This negligence of SR as a step preceding the enhancement of CRIT and CRET might explain the significant results of MT on CRIT and CRET in previous studies. It is important therefore to distinguish between dispositions (self-regulation) and cognitive skills of critical and creative thinking.

4.1.2.3 The role of SR as a mediator in enhancing CRIT and CRET

Analysis showed that SR is the final sequential mediator only through which variables like FE and MT can foster CRIT and CRET. In other words, SR is enhanced directly through VRI ($\beta = 0.20$, $p < 0.05$) and indirectly through the sequence of FE and MT ($\beta = 0.106$, $p < 0.05$), before it finally transmits the effect into CRIT and CRET. This implies that educators can arrange immersive learning experiences through VRI to generate an enhanced FE, which intrinsically enhances MT. Effects of FE and MT amplify the direct effect of VRI on SR which transfers the amplified total effects to higher order thinking skills. SR, as a cognitive skill that is based on meta skills which enable awareness of one's thinking, monitoring, and adaptation of learning strategies through cognitive and metacognitive processes Zimmerman (2002), is moderately impacted by VRI through a direct pathway. However, it functions as both: an endogenous variable and as a mediator that transfers the effects of other mediators into critical and creative thinking. This aligns with Zimmerman (2002) view of SR as a self-directed process that enables learners to transform their mental abilities into academic skills. The role of SR as a mediator, predictor, precursor to critical and creative thinking was highlighted in the findings of many recent studies (Akcaoğlu et al., 2023; Ariyati & Fitriyah, 2024; Hyytinen et al., 2021; S. Lee, 2009) confirming the role of SR as a precursor to critical and creative thinking. In addition, according to Costa and Kallick (2000) creating self-directed learners is the goal for teaching HoM. Therefore, educators can employ VRI to enhance SR skills, which significantly predicts the enhancement of higher order thinking skills.

To conclude, analysis reflected that VRI can significantly enhance SR, CRIT and CRET directly and indirectly. While direct effects showed how VRI can moderately impact HoM, total effects reflected a strong impact through the sequence of mediators FE, MT, and SR with SR having the most critical mediating role. This supports that VRI, as grounded in CAMIL theory, helps students gain knowledge constructively through active and interactive methods (Kavanagh et al., 2017) and improve cognitive outcomes.

4.2 Qualitative Discussions

To show how VRI positively affected HoM (SR, CRIT and CRET), qualitative analysis provides numerous insights generated from observations, semi-structured interviews and focus groups, about the mechanisms through which VRI enhances cognitive outcomes. Results are contextualized in existing literature, emphasizing how VRI affects SR, CRIT and CRET, including insights into how mediation contributed to the effects of VRI on the final cognitive outcomes.

4.2.1 The effect of VRI on HoM (SR, CRIT and CRET)

Qualitative research findings confirmed the positive impact of VRI on Students' HoM (SR, CRIT and CRET). VRI-based biology sessions enabled students to engage with diverse perspectives, solve problems and participate with analytical activities that fostered their SR, CRIT and CRET:

4.2.1.1 Effects of VRI on SR (as an outcome)

Qualitative findings highlighted the effects of VRI on improving students' SR as a healthy habit of mind responsible for critical and creative thinking. This aligns with Marzano et al. (1993) who emphasized the development of SR as a life-long habit of mind that can create self-directed learners. SR enhancement was manifested during VRI discussion parts which reflected a maturity form of SR through students' ability to plan and set achievable goals effectively and continuously. This corroborates with (Abdalkader (2022) definition of SR as the ability to choose a goal and try to achieve it by specifying the 'how and what to do' to achieve it. Students reflected their matured metacognition skill through their awareness of their thinking and self-evaluation of their performance, while assuming responsibility on their performance mirroring (Marzano et al. (1993) first desired learning outcome, namely 'a self-directed learner'. Students' awareness of their own thinking was reflected through their critical evaluative inquiries during discussion parts or during VRI application attempting to adapt their strategies to effectively achieve their goals. A common perception of students during interviews and focus groups was about how VRI changed their strategy for learning biology from raw memorization into comprehension. This echoes Mitsea et al. (2023) and Baranovskaya (2015) definition of SR as an adaptive habit that enables the learner to redirect or change his or her strategies based on new findings. Sensitivity to feedback was another common feature in VR-based biology classes. Students remarked that they continuously sought feedback from different sources such as textbooks, teachers, peers, VR content, or from the internet to evaluate their performance and make adjustments to improve it. This is caused by high levels of intrinsic motivation or by self-determined extrinsic motivation which echoes De La Fuente et al. (2022) definition of SR as related to personal adjustment factors, diligence, and well-adjusted academic behavior which cannot be achieved without sensitivity to feedback. Metacognition was exhibited through students' ability to express their thoughts clearly and unambiguously. VRI helped students notice how to arrange a flow of thoughts in a clear and logical way which was later reflected on their own flow of thoughts and resulted in an improved performance. During interviews and focus groups, students took time to think about the questions before they provided a detailed well-organized answer reflecting metacognitive processes such as planning, monitoring and evaluation. This aligns with (Baranovskaya, 2015; Mitsea et al., 2023; Zimmerman, 2002) view of SR as the ability to employ a set of meta skills to enable awareness, monitoring, and adaptation of learning strategies.

4.2.1.2 Effects of VRI on Critical Thinking

Qualitative findings confirmed VRI's ability to influence the different aspects of CRIT. Students' accuracy and clarity were manifested during VRI applications when students started to listen attentively to the teachers' instructions before hastily interacting. They asked clarifying questions about the details of the content and finally revisited their textbooks to compare with what they have learnt and made final decisions. This finds resonance in Paul and Elder (2019) about critical thinking including, among other characteristics, self-corrective thinking as essential for critical thinking. Open-mindedness was also reflected through group discussions after VRI application. Students embraced different or opposing views and submitted them to discussions in which each student was trying to prove his or her own views based on persuasion and reliable sources which bolstered Campo et al. (2023) view of CRIT as a skill directed towards understanding and solving problems through evaluating alternatives and making decisions. When students' competence and self-confidence were enhanced, they fostered their assertiveness which appeared through the way they expressed their opinions, ideas, and beliefs confidently and respectfully during discussions and interviews. This aligns with Paul and Elder (2019) view of a critical thinker as self-directed and self-disciplined.

In addition, hybrid analysis revealed the inductive ‘exploratory oriented learning’ as a probable subcategory for CRIT that can be generated through VRI. The idea of exploring knowledge rather than receiving it was highly emphasized through VRI-based biology interaction. Students enthusiastically reflected on the pleasures of discovering related and unrelated facts or exploring “*the details of the details*” as FG2 noted, that are usually ignored by their textbooks or their teachers. Exploration can enhance comprehension, analysis, evaluation, problem solving, and decision making which demonstrates consistency with (Campo et al., 2023; Dwyer et al., 2014; Jamaludin et al., 2022; Kusmaryono, 2023; Paul & Elder, 2019; Utomo et al., 2023) who highlighted exploratory learning as a catalyst for CRIT.

4.2.1.3 Effects of VRI on Creative Thinking

Qualitative findings also revealed the benefits of VRI-based biology classes on the different dimensions of students’ CRET. Students’ intense engagement in tasks with no clear solutions as a cognitive habit generated from improved self-regulation was clearly observed during discussions following VRI application. Parts of the discussions included issues with a problem-solving nature in which students showed active engagement reflecting on their experience through the VRI journey, rearranging their ideas in a different new spectrum through analysis, and came up with creative ideas such as “*viewing our bodies from inside the cells might help preventing or curing cancer*”. This underscores Sternberg and Lubart (1998) definition of creative thinking as coming up with a new design through rearrangement of existing ideas. In addition, students pushed the limits of their own knowledge and abilities driven by VRI’s motivating force and demonstrated willingness to participate in challenging tasks and work on them with persistence and insistence to improve performance until they were completed. This finds resonance in Behmanesh et al. (2022) about how increased interaction and levels of engagement lead to better outcomes. Students reflected their ability to define the problem, verify its validity based on scientific reasoning generated from VRI which mirrors (Usha (2009) view about validating innovative ideas with scientific reasoning. Generating new ways for viewing things was reflected during and after VRI application through students’ evaluation of the available alternatives. Gradually, their recklessness decreased and was replaced by a composed behavior in which they effectively defined their goals, explored alternatives, sought feedback from other students or from the teacher, then made decisions based on the data available to come up with the best outcomes. This mirrors what (Lindberg et al. (2017) assigned to produce creative work. In addition, generating, trusting, and maintaining own standards of evaluation was conveyed by students through completing the VRI tasks based on their own standards of quality. Although students were engaged in the same virtual environment, and interacted with the same 3D scenes, their presentations differed greatly in terms of creativity, language and knowledge based on their own different criteria for a good performance which echoed (Karunarathne & Calma, 2024) three themes for creativity. Finally, the inductive subcategory (Generating dynamic conceptual visualization) gained much weight through students' verbatims reflecting on the VRI experience. Students transformed this useful VRI experience of dynamic visualization of complex content in biology into other subject areas like chemistry or physics trying to generate a visual representation for chemical reactions or for physical concepts for example. This improved their understanding and memorization.

To sum up, VRI-based biology classes reflected gradual improvement on students' scientific habits of mind (SR, CRIT, and CRET). The immersion approach helped students deeply understand the content and therefore promote higher-order thinking.

4.2.2 Effects of VRI on (HoM) through Mediators

4.2.2.1 Effects of VRI on FE

Insights generated from observations, interviews and focus groups about VRI-based biology classes confirmed how VRI created conditions conducive to FE (Kim & Biocca, 2018). Numerous reflections highlighted students' presence in the virtual reality characterized by higher levels of engagement, loss of track of time, and greater concentration. Students reflected that they felt they were part of the biology content they were exploring. This aligns with Schubert et al. (2001). They also commented about losing track of time and place and everything else except for the task in hand, according to (E. Lee, 2005). The above elements of flow echoes Guerra-Tamez (2023) criteria for flow experience.

4.2.2.2 Effects of VRI on MT

When students were highly engaged and deeply focused through VRI, they became intrinsically motivated to master the biology content according to Mazllami (2020). MT, directly generated from VRI and enhanced by FE, was manifested through observations and interviews. Students reflected their satisfaction about their improved performance during VRI activities. Relaxation while performing interestingly was clearly witnessed. Interviews revealed students' feeling of competence about the subject matter and skilfulness in using VR as a tool for learning. This echoes Guerra-Tamez (2023) criteria for MT where students show persistence to master the content.

4.2.3 Mechanism of Mediators in the relationship between VRI and CRIT/CRET

FE, generated directly from VRI, played a crucial role in leveraging the levels of students' motivation by functioning as a sub-sequential mediator of VRI on HoM. Quantitative analysis reflected greater engagement of students leading to increased levels of motivation, causing a greater impact on HoM through fostering SR. Analysis revealed that 'enjoyment' as a key dimension of FE according to Lee et al. (2022) and Guerra-Tamez et al. (2021) was manifested during VRI application through students' smiles, laughter, and interaction, featuring intrinsic enjoyment during application which echoed Nakamura and Csikszentmihalyi (2001) who considered FE as a product of intrinsically rewarding experiences. This also highlights the view of Kavanagh et al. (2017) and Jackson et al. (2008) about the autotelic dimension of flow experience, which is directly related to students' motivation and performance according to Mirvis and Csikszentmihalyi (1991). Although insights explained how FE fostered students' motivation, there was no evidence whether FE alone can enhance SR, CRIT or CRET.

MT was nurtured by FE. Students were observed to be totally engrossed by the experience as an autotelic enjoyable one. This echo (Csikszentmihalyi, 2000) view of FE as directly related to intrinsic motivation. Filgona et al. (2020) highlighted the effects of motivation on the level of engagement, the amount of learning, and the level of cognitive processes employed. Study findings supported this through the employment of VRI which resulted in affecting levels of engagement. VR as a novel device that is usually connected with games and entertainment was interesting and engaging for students. This shows how VRI was intrinsically motivating and was manifest in students' responses reflecting on their satisfaction and enjoyment while performing the activities: "*as if* *playing a game*" which aligns with Zeng et al. (2022) vision of intrinsic motivation. Feeling of skillfulness generated by familiarity with the device as a tool for games created a feeling of mastery over, not only the controllers, but also the biology content they were handling, through fostering their motivation, affirming Tyrrell et al. (2018) of self-directed learning.

SR as an outcome of VRI according to Marzano et al. (1993) also functioned as part of the mediation mechanism that fosters critical and creative thinking through the transformational role it has in delivering the effects of FE and MT into CRIT and CRET (Akcaoğlu et al., 2023). Qualitative findings revealed that SR functions as a predominant habitual component of HoM preceding critical and creative thinking. This aligns with Ariyati and Fitriyah (2024). Students reflected how VRI fostered their self-awareness, goal-setting precision, planning effectiveness, metacognitive skills and sensitivity to feedback which resulted in cognitive control that finally contributed to critical and creative thinking processes.

To conclude: VRI in biology classes promoted students' critical and creative thinking through a straight-line of relations VRI → FE → MT → SR → CRIT/CRET.

VRI sparks FE through spatial presence, involvement and experiential reality. FE generates MT through providing an enjoyable and gratifying experience that exceeds expectations resulting in capturing students' concentration. FE fosters students' MT by making them feel skilful and competent, while performing in a relaxed manner. MT enhances SR as the first cognitive outcome which increases their awareness of their own thinking, improves their planning, raise their attention to the importance of feedback for quality performance and improves their self-evaluation of their effectiveness. Then, SR functions as the final sequential mediator that enhances further outcomes: critical and creative thinking.

4.3 Integration of Quantitative and Qualitative Findings

Quantitative results statistically highlighted the difference between the moderate direct effects of VRI on SR ($\beta = 0.20$, $p < 0.05$), CRIT ($\beta = 0.27$, $p < 0.05$) and CRET ($\beta = 0.26$, $p < 0.05$) compared with the strong total effects on SR ($\beta = 0.43$, $p < 0.05$), on CRIT ($\beta = 0.52$, $p < 0.05$) and on CRET ($\beta = 0.44$, $p < 0.05$) caused by the intervention of mediators, qualitative results supported this through students' insights and reflections about the experiment. Qualitative results supported the mediation effects of FE, MT and SR in transferring the effects of virtual reality immersion as a transformational instructional method of teaching biology on enhancing high school students' self-regulation, critical and creative thinking. Quantitative results underscored the effects of sequential mediation in amplifying the direct effects. Qualitative results, on the other hand, provided insights on the mechanisms through which sequential mediation functions to transfer the effects of VRI on CRIT and CRET via SR. There were no signs of direct effects of VRI on the outputs of the study revealed by students' insights.

Both quantitative and qualitative results highlighted the role of SR as an output and as a mediator. Quantitative results statistically confirmed the insignificant direct effects of FE and MT on CRIT and CRET ($p > 0.05$), However, FE and MT can significantly intensify the direct moderate magnitude of VRI on CRIT and CRET into a significant strong one through enhancing SR as an output. When SR is significantly enhanced, it functions as the final sequential mediator that finally fosters students' CRIT and CRET.

VRI as a novel tool usually connected with enjoyment through its ability to immerse students in games, encouraged them to use it in biology classes as an extension to that feeling of enjoyment. VR's ability to immerse students enjoyably "as if playing a game" increased their engagement with the biology content sparking their motivation to accomplish biology tasks and activities as if winning a game. This also resulted in persistence and resistance to failure. Therefore, students reconsidered their strategies for studying biology in the same manner of employing strategies to win a game. Choosing achievable goals and effectively planning to achieve it during biology classes was derived from their strategies for winning a game. Deeper comprehension of the subject matter was equivalent to the pleasure gained by overcoming challenges of a game through VRI and winning it.

Quantitative results statistically evidenced the absence of significant direct effects of FE on SR/CRIT and CRET and MT on CRIT and CRET ($p > 0.05$), qualitative analysis resulted in the absence of insights supporting these direct relations. Although some quantitative studies found significant effects of MT on CRIT and CRET (Fahim & Hajimaghsoodi, 2014; Munahefi et al., 2018; Valenzuela et al., 2017), this might be attributed to imprecision of the difference between dispositions and cognitive skills resulting in the inclusion of SR elements as directly belonging to CRIT or CRET.

4.4 Study Limitations

Though the study highlighted important and generalizable insights about the effects of VRI on habits of mind, it faced many challenges related to time, place, the nature of the final dependent variables (SR, CRIT and CRET).

This study took place in East Jerusalem Municipal High Schools where VR is still in its infancy as an educational tool. Many schools still lack labs designed for VR applications and teachers who are qualified to integrate it professionally into their subject matter. Furthermore, lack of educational applications that suit different grade levels to meet different curriculum designs represented some of the limitations of the study. 3D biology contents had to be chosen carefully before application. In addition, training the participating teachers on how to integrate VR effectively in their classes represented another limitation for the study. The researcher had to provide schools with VR sets, videos and scenes related to the content of the subject matter. In addition, technical support had to be available consistently.

This study was conducted in three secondary schools located in East Jerusalem, a context with unique cultural, political, and educational characteristics. The findings of the study provide important insights into the role of virtual reality immersion, flow, motivation, and self-regulation in enhancing students' habits of mind; however, the results may not be directly generalized to other regions or educational systems. Therefore, future research is encouraged to replicate this model in diverse cultural and institutional contexts to test its applicability and strengthen its external validity.

Another limitation was the full reliance on self-reported questionnaire data to assess the different constructs of the study. While the instrument is validated and widely used, it does not measure students' observable learning gains such as achievement. To enhance construct validity, future studies are advised to integrate subjective and objective measures.

The restricted time and number of VR sets also made it difficult to apply VRI on other scientific subjects such as chemistry, physics and mathematics, which would have enabled more noticeable generalizable results.

Moreover, fostering habits of mind needs a long time to be realized, achieved and internalized as healthy habits of the learners. The experiment lasted for one semester which might not clearly reveal the effects of VRI on students' self-regulation, critical and creative thinking.

Future research should take these notes into consideration in terms of time, place, applications such as the adoption of longitudinal methodology and the inclusion of other scientific subjects to allow for more generalization of their results. Furthermore, the study's findings cannot be extrapolated to other fields or subjects because they only examine the use of VRI in biology lessons. A more comprehensive study that includes other subjects like physics, mathematics and chemistry can provide a more thorough knowledge of the role of VRI on students' self-regulation, critical and creative thinking.

4.5 Conclusion

This mixed-methods study aimed to explore the effects of VRI-based biology classes on high school students HoM, considering the role of FE, MT, and SR as mediators between VRI and HoM, complying with CAMIL. Findings confirmed the positive effects of VRI on enhancing critical and creative thinking through enhancing students' self-regulatory habits. PLS-SEM statistics, observations, semi-structured interviews and focus groups with participating students reflected the usefulness of VRI in fostering students HoM in biology. A higher level of students' engagement in virtual biology environments resulted in deeper understanding of complex contents which motivated students to regulate themselves and fostered their critical and creative thinking abilities.

VRI represented a transformative potential of traditional education by creating a student-centered classroom in which students engage actively, enjoyably and responsively in the construction of knowledge. Higher engagement generated higher levels of intrinsic motivation and self-determined extrinsic motivation driving students to persist in their tasks and resist failing. Engagement through VR during biology classes created students who are reflective to their thoughts and performance and flexible about adapting their strategies to meet their goals creatively. Clarity and accuracy gained from VR experiences affected students' clarity and accuracy and encouraged analysis of complex concepts assertively and confidently. Higher engagement and better comprehension encouraged students to go beyond their abilities trying to think divergently by examining different alternatives to come up with creative results.

The study complied with the constructivist principles, especially CAMIL which emphasizes the critical role of learners as being active in constructing their own knowledge. However, VRI proved not only to enhance students' knowledge, but also to foster their critical and creative thinking through fostering their self-regulatory thinking and learning habits.

4.6 Recommendations

The findings of the study reflect VR as a promising tool for educational out-comes; however, practical implementation must consider the varying contexts of school environments. Resource constraints might limit the full adoption of the VR tool especially with under-funded schools. Our recommendations should be seen as flexible and adaptable. Under-funded schools can start with more affordable alternatives such as computer simulations, mobile-based VR, or even cheaper sets of VR tools. Such schools can find creative ways to introduce the tool based on their context.

The following recommendations stem from the findings of the study aiming to enhance the educational impact and sustainable use of VRI in biology classrooms:

1. Future cross-cultural research should be conducted to help validate and expand the model of the study into broader cultural contexts.
2. Biology teachers are advised to integrate VRI in biology classes, especially when introducing complex foundational concepts to ensure students' effective and constructive perception to foster students' habits of mind.
3. Biology teachers should structure sessions around inquiry-based learning cycles to enable students to predict, explore, discuss and reflect. Teachers should encourage students to explore and ask questions during VR sessions.
4. Teachers should encourage students to reflect, solve problems, and think creatively. They should also be asked to: reflect on the content of the VRI-based biology session, solve problems that need critical and creative thinking and think about new idea.
5. Teachers should encourage students to work independently and in groups during VRI-based biology sessions to support students with low academic achievement.

6. Teachers should include self-evaluation prompts that enhance students' self-regulation habits which are basic for enhancing their critical and creative thinking.
7. School administrations should work on establishing and furnishing VR labs with a full-time technician and include VR as a fixed session included in the weekly schedule of all grades. Students should be given free access to use the labs at any time for repeating the VRI session or exploring other aspects of the topic as much as possible.
8. Curriculum designers should reconsider the designation of the curriculum based on the principles of CAMIL. Moreover, program engineers should provide suitable VR applications that meet the content of different school subjects for all grades. They should focus on biological contents that show how systems work together.
9. Curriculum designers should include activities that allow critical and creative thinking.

List of Abbreviations

Abbreviation	Meaning
VRI	Virtual Reality Immersion
HoM	Habits of Mind
MT	Motivation
FE	Flow Experience
VR	Virtual Reality
MR	Mixed Reality
AR	Augmented Reality
CRIT	Critical Thinking
CRET	Creative Thinking
SR	Self-regulation
SP	Spatial Presence
INV	Involvement
ER	Experiential Reality
IMT	Intrinsic Motivation
EMT	Extrinsic Motivation
AMT	Amotivation
ILO’s	Intended Learning Outcomes
SEM	Structural Equation Modeling
PLS	Partial Least Squares
PLS-SEM	Partial least squares structural equation modeling
AVE	Average Variance Extracted
CAMIL	Cognitive Affective Model of Immersive Learning
FGs	Focus Groups

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Appendices

Appendix A

Supplementary Tables

Table A1

Demographic information of the sample (initials are fictitious)

School	Grade	School Gender	# of Students	# of Groups
Shu'fat Comprehensive School	10th	M	72	2
	11th		50	2
	12th		67	2
Beit Hanina Secondary School	10th	F	30	1
	11th		30	1
	12th		30	1
Al Mutanabbi Comprehensive School	10th	M	32	1
	11th		22	1
	12th		16	1
Total			349	12

Table A2

Demographic information of interviewees and focus groups (initials are fictitious)

Student / Group	School	Class	Gender	Topic
M. Ah1	Shu'fat	10th	M	The Cell / DNA
E. Z2	Shu'fat	10th	M	The Cell / DNA
M.Kh3	Shu'fat	10th	M	The Cell / DNA
Sh. I4	Beit Hanina	10th	F	The Cell / DNA
A. K5	Al-Mutanabi	10th	M	The Cell / DNA
K. Ah6	Al-Mutanabi	12th	M	Photosynthesis
A. M7	Shu'fat	12th	M	Photosynthesis
J. Ad8	Beit-Hanina	12th	F	Photosynthesis
O. As9	Shu'fat	11th	M	Nerve Impulse
A. H10	Shu'fat	11th	M	Nerve Impulse
FG1	Shufat	10th	M	The Cell / DNA
FG2	Al-Mutanabi	11th	M	Nerve Impulse
FG3	Beit-Hanina	12th	F	Photosynthesis

Table A3

Model of good fit

	Saturated model	Estimated model
SRMR	0.06	0.07
d_ULS	1.57	1.92
d_G	0.52	0.57
Chi-square	1032.11	1086.11
NFI	0.75	0.74

Table A4

Direct Effects

Path	H	β	*t*	*p*
VRI → CRIT	H1a	0.27	7.07	0.00
VRI → SR	H1b	0.20	3.55	0.00
VRI → CRET	H1c	0.26	5.11	0.00
VRI → FE	H1d	0.61	13.77	0.00
VRI → MT	H1e	0.32	6	0.00
FE → MT	H2	0.48	8.56	0.00
MT → SR	H4	0.36	6.61	0.00
SR → CRIT	H5a	0.58	14.11	0.00
SR → CRET	H5b	0.42	8.33	0.00

Table A5

Primary indirect effect hypotheses

Path	H	β	*t*	*p*
VRI → MT → SR	H9	0.12	4.74	0.00
VRI → SR → CRIT	H12	0.12	3.49	0.00
VRI → SR → CRET	H13	0.09	3.37	0.00
VRI → FE → MT	H14	0.29	7.22	0.00
FE → MT → SR	H15	0.17	4.96	0.00
MT → SR → CRIT	H18	0.21	5.62	0.00
MT → SR → CRET	H19	0.15	5.03	0.00

Table A6

Secondary indirect effects (Two mediators)

Path	H	β	*t*	*p*
VRI → MT → SR → CRIT	H22	0.07	4.416	0.00
VRI → MT → SR → CRET	H23	0.05	4.275	0.00
VRI → FE → MT → SR	H24	0.11	4.567	0.00
FE → MT → SR → CRIT	H25	0.10	4.425	0.00
FE → MT → SR → CRET	H26	0.07	3.983	0.00

Table A7

Tertiary indirect effects (Three mediators)

Path	H	β	*t*	*p*
VRI → FE → MT → SR → CRET	H27	0.05	3.778	0.00
VRI → FE → MT → SR → CRIT	H28	0.06	4.139	0.00

Table A8

Total Effects

Path	β	*t*	*p*
VRI → CRET	0.44	9.588	0.00
VRI → CRIT	0.52	12.713	0.00
VRI → SR	0.43	9.571	0.00

Appendix B

Images of participants during application

Figure B1

10th grade students interacting with cells using VR Software in Meta Quest 3.

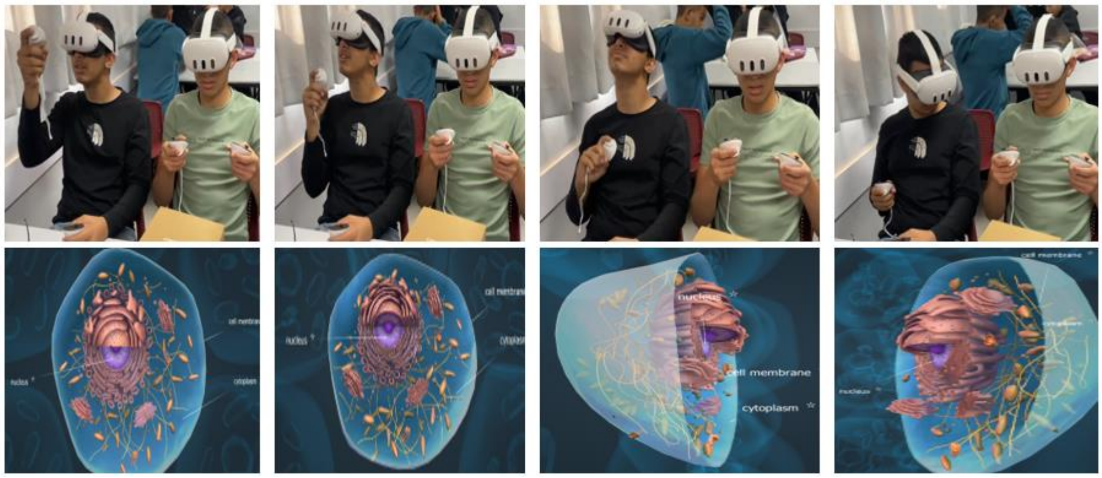

Figure B2

11th grade students immersed

Appendix C
Institutional Review Board (IRB)

جــامـعـة النجــاح الـوطـنـيـة
An-Najah National University

مكتب مجلس المراجعة المؤسسية
Office of Institutional Review Board (IRB)

Dear Dr. Abdulkarim Ayoub,

We are pleased to inform you that your research proposal titled:

"The Impact of Virtual Reality in Biology on Habits of Mind Self-Regulation, Critical Thinking, and Creative Thinking) through the Mediating Variables: Flow Experience, Motivation, and Self-Regulation in Secondary Schools in East Jerusalem"

has been approved by the **Institutional Review Board (IRB)** at **An-Najah National University**.

Please note that the approval has been granted on the condition that you obtain permission from the **Ministry of Education and the school administration** where the study will be conducted.

Here are the approval details:

Submitted by:	Abdulkarim Ayoub, Nader Beroch
Approval Date:	26th February. 2025
IRB Protocol Number:	Fgs/Hum. Feb. 2025/70

Kindly inform the **IRB** of any modifications to the study protocol for proper review. If you have any inquiries or require further information, please do not hesitate to contact us at **.irb@najah.edu**

.Thank you for your commitment to ethical standards in scientific research

Best regards,

Naim Kittana, Dr.

Najm

IRB, Chairperson

IRB
Institutional Review Board
An-Najah National University

Appendix D

A general framework for planning VR-Based biology lessons

Part	Minutes	Procedure
1	10 -12	The teacher introduces the topic; highlights the most important issues; frames the learning experience with an open-ended question or challenge related to the 3D scene, encouraging students to explore and uncover learning ILOs through their interaction and inquiry.
2	8 - 12	Students watch an explanatory 3D video about the topic.
3	8 - 12	Students interacted directly with a 3D scene or watched an additional interactive video related to the topic. My classroom observations revealed that this part was crucial for activating constructivist learning processes. Students worked collaboratively in groups, manipulating virtual objects, discussing potential interpretations, and debating alternative explanations based on what they observed. For example, in the session on cell division, students paused the simulation at key points, identified structures, and predicted the next stages of mitosis before verifying their hypotheses through further exploration. This interaction was observed to support behaviors such as hypothesis testing, perspective sharing, and inquiry, all of which are principles of constructivist pedagogy. Students became active co-constructors of meaning through dialogue, comparison, and reflection. Moreover, as I observed, students often asked spontaneous questions, adjusted their reasoning in response to group input, and referred to prior knowledge. These behaviors indicated SR, CRIT and CRET.
4	10	Students discuss results, discoveries, or solutions with the teacher who provides feedback to the findings and wraps them up for the whole class.
5	3 - 5	Students reflect on the experiment.

Appendix E

Questionnaire

Dear student, thank you for taking the time to participate in this study.

This questionnaire is part of a research study for my PhD dissertation titled 'The Impact of VRI in Biology classes on the Habits of Mind of East Jerusalem Municipality High School Students: Examining the Mediating Roles of Motivation and Flow Experience.' The aim of this study is to understand how virtual reality (VR) can enhance students' learning experiences, specifically in biology, and how it influences their thinking habits, motivation, and engagement.

Your responses are crucial for this research as they will provide valuable insights into the effectiveness of VR in educational settings. By participating, you will help me identify potential benefits and areas for improvement in using VR for teaching biology and other subjects.

Please be assured that all the information you provide will be kept confidential and will only be used for the purposes of this research. Your responses will be anonymized to protect your privacy.

Your participation in this questionnaire is entirely voluntary. You have the right to withdraw at any time without any negative consequences. If you choose to continue, your input will be greatly appreciated.

The questionnaire is divided into two sections and should take no more than 10 minutes to complete. Please answer each question as honestly and accurately as possible.

Thank you very much for your time and contribution to this important research. Your participation is highly valued.

Section 1: Personal Information:

1. Name (Optional)

2. Class (10^{th}, 11^{th}, 12^{th})

3. Name of School:

4. Gender: M / F

5. Subject:

6. Topic:

7. Is this your first time using the VR?

Yes / No

Section 2: Questionnaire:

Dear student: based on your experience with Virtual Reality Immersion during your biology classes, would you kindly complete the following questionnaire from 1 – 5:

1 = strongly disagree 2 = disagree 3 = doubt 4 = agree 5 = strongly agree

Construct	Abb	#	Item	1	2	3	4	5
Immersion VR	IVR	1	I felt that I had a sense of being there. (SP)					
		2	I felt that VR world surrounded me. (SP)					
		3	I was completely captivated by the virtual world. (INV)					
		4	I was aware of my real environment during the experience. (INV)					
		5	The virtual world seemed very realistic to me. (ER)					
		6	I felt the objects in the virtual world looked realistic. (ER)					
Flow Experience	FE	7	I enjoyed the experience through VR technology.					
		8	I found VR experience gratifying.					
		9	I felt in total concentration during the experience.					
		10	I felt that time passed too fast.					
		11	This class through VR technology exceeds my expectations.					
Motivation	MT	12	It is interesting to use VR technology in class.					
		13	My performance was good using VR technology in class.					
		14	After using VR technology for a while, I felt competent.					
		15	I was very relaxed while using VR technology in class.					
		16	I am skilled when I use VR technology in class.					
Self-Regulation	SR	17	Recognizing self-thinking					
		18	Making effective plans					
		19	Understanding and using the needed information					
		20	Becoming sensitive toward feedback					
		21	Evaluating the effectiveness of acts					
Critical Thinking	CRIT	22	Being accurate and able to look for accuracy					
		23	Being clear and able to look for clarity					
		24	Being open					
		25	Being able to position oneself when there is a guarantee					
		26	Being sensitive and able to recognize friends' abilities					
Creative Thinking	CRET	27	Being able to involve oneself in tasks although the answer and solution has not yet to be found					
		28	Trying hard to expand skills and knowledge					
		29	Creating new ways or point of view outside the common knowledge					

Would you like to add anything related to your experience with the virtual reality?

Thank You

الاستبيان باللغة العربية:

عزيزي الطالب: شكرا لك على تخصيص الوقت للمشاركة في هذه الاستبانة:

هذه الاستبانة جزء من دراسة بحثية لأطروحة الدكتوراه الخاصة بي بعنوان "أثر الانغماس في الواقع الافتراضي في مادة الأحياء على عادات العقل لدى طلاب المدارس الثانوية التابعة لبلدية القدس الشرقية: الأدوار الوسيطة للدافعية وتجربة التدفق." تهدف هذه الدراسة إلى فهم كيفية تعزيز الواقع الافتراضي (VR) لتجارب التعلم لدى الطلاب، خصوصاً في مادة الأحياء، وكيفية تأثيره على عادات التفكير والدافعية والانغماس.

إجاباتكم مهمة لهذه الدراسة حيث ستقدم رؤى قيمة حول فعالية الواقع الافتراضي في البيئات التعليمية. من خلال المشاركة، ستساعدوننا في تحديد الفوائد المحتملة ومجالات التحسين في استخدام الواقع الافتراضي لتدريس مادة الأحياء.

جميع المعلومات التي تقدمونها ستكون سرية وستستخدم فقط لأغراض البحث. ستتم معالجة إجاباتكم بشكل مجهول لحماية خصوصيتكم.

مشاركتكم في هذه الاستبانة طوعية تماماً. لكم الحق في الانسحاب في أي وقت دون أي عواقب سلبية. إذا اخترتم الاستمرار، فسيكون لمساهمتكم قيمة كبيرة.

تتكون الاستبانة من قسمين ويستغرق إكماله ما لا يزيد عن 10 دقائق. يرجى الإجابة على كل سؤال بأمانة ودقة قدر الإمكان.

شكراً جزيلاً على وقتكم ومساهمتكم في هذا البحث الهام. مشاركتكم لها قيمة عالية.

القسم الأول: المعلومات الشخصية

1. الاسم (اختياري) 2. الصف: 3. المدرسة: 4. الجنس: 5. المادة: 6. موضوع الدرس:

القسم الثاني: الاستبانة:

عزيزي الطالب، من خلال مشاركتك بدروس مادة الأحياء بواسطة الانغماس في الواقع الافتراضي، الرجاء الإجابة على الأسئلة التالية من 1 – 5. حيث:

1 = لا أوافق بشدة 2 = لا أوافق 3 = لست متأكدا 4 = أوافق 5 = أوافق بشدة

البناء	الرقم	الفقرة	1	2	3	4	5
الانغماس في العالم الافتراضي	1	شعرت بأنني كنت هناك (جزءا من الواقع الافتراضي)					
	2	شعرت بأنني كنت محاطا بالعالم الافتراضي.					
	3	كنت مأسورا بشكل كامل بالعالم الافتراضي.					
	4	كنت مدركا لما يدور حولي خلال التجربة.					
	5	بدا لي العالم الافتراضي واقعيا للغاية.					
	6	شعرت بأن الاجسام بالواقع الافتراضي بدت واقعية.					
الخبرة المتدفقة	7	أحسست بمتعة كبيرة خلال استخدام تقنية الواقع الافتراضي في دروس الأحياء.					
	8	وجدت تجربة الواقع الافتراضي مرضية.					
	9	شعرت بتركيز كبير خلال خبرة الواقع الافتراضي.					
	10	شعرت بأن الوقت يمر بسرعة كبيرة خلال استخدام تقنية الواقع الافتراضي.					
	11	الدروس خلال الواقع الافتراضي فاقت توقعاتي.					
الدافعية	12	من الممتع استخدام تقنية الواقع الافتراضي في الصفوف التعليمية					
	13	كان أدائي جيدا باستخدام تقنية الواقع الافتراضي داخل الصفوف.					
	14	شعرت بالكفاءة بعد استخدام التقنية بفترة وجيزة					
	15	شعرت بالارتياح خلال استخدام تقنية الواقع الافتراضي.					
	16	أكون ماهرا عندما استخدم تقنية الواقع الافتراضي في الصف.					
التنظيم الذاتي	17	الواقع الافتراضي ساعدني على ملاحظة ومراقبة تفكيري وتسلسله في حل المشاكل.					
	18	الواقع الافتراضي جعلني قادرا على وضع خطط فعالة تجاه أهداف أقوم بتحديدها بدقة.					
	19	الواقع الافتراضي جعلني أفهم واستخدم مصادر المعلومات المطلوبة للمهمات بشكل محدد.					
	20	الانغماس في الواقع الافتراضي جعلني أهتم أكثر بالتغذية الراجعة.					
	21	الانغماس في الواقع الافتراضي مكنني من تقييم أدائي بشكل أفضل.					
	22	الانغماس في الواقع الافتراضي زاد من دقتي وبحثي عن الدقة من خلال الاهتمام بأدق التفاصيل اللازمة.					
	23	الانغماس في الواقع الافتراضي جعلني أكثر بحثا عن الوضوح وتجنب التضارب					

					الانغماس في الواقع الافتراضي جعلني أكثر انفتاحا على الأفكار والمفاهيم المختلفة، والتفكير بها بشكل موضوعي.	24	التفكير الناقد
					الانغماس في الواقع الافتراضي شجعني على أخذ مواقف محددة ودعمها بالأدلة والبراهين.	25	
					الانغماس في الواقع الافتراضي جعلني أعرض أفكاري مراعيا لمستويات المعرفة لزملائي ومشاعرهم.	26	
					الانغماس في الواقع الافتراضي أندمج في مهمات ليس لها إجابات أو حلول جاهزة.	27	التفكير الابداعي
					الانغماس في الواقع الافتراضي جعلني أجتهد لتحسين مهاراتي ومعارفي.	28	
					الانغماس في الواقع الافتراضي جعلني أبتدع طرقا جديدة أو أفكار خارج الصندوق.	29	

هل هنالك ما ترغب بإضافته فيما يتعلق بخبرتك بالواقع الافتراضي؟

شكرا لك

Appendix F
Interview Guide

Research Title:

The Impact of (VRI) in Biology classes on the Habits of Mind (HoM) of East Jerusalem Municipality High School Students: Examining the Mediating Roles (SR), (MT), and (FE).

Target Groups:

Municipal secondary school students.

Goal: To explore secondary students' experiences and perceptions of VRI in biology classes, and the effects it has on their HoM through the mediation of MT and FE.

Interview Questions:

This semi-structured interview consists of questions that are derived from the study. The interview included different types of questions (introducing, follow up, probing, specifying, direct, indirect, and interpreting questions) recommended by (Dumay and Qu, 2011) to get comprehensive answers to the questions of the study in a systematic way. The questions allow the interviewee the freedom to answer, and the flexibility to add insights and reactions according to his / her experience.

Each interview starts with acknowledging the interviewee for his / her cooperation, explaining the goal of the interview, asserting their freedom to participate and ensuring the secrecy of the data. The interview is closed after asking the interviewee if he would like to add anything and thanking him / her for his/her cooperation with the interviewer.

A guide for Semi-structured interviews and Focus Groups:

Section One:

1. Greetings and introduction:

- Greet the interviewee and introduce myself, explaining the purpose of the interview.
- Emphasize the confidentiality of the data and the interviewee's freedom to participate.
- Request permission to record the session.

2. Information about the Interviewee:

- Ask the interviewee to introduce themselves, including their name, age, grade, school, and gender.

Section Two: Immersion in Virtual Reality

1. Can you generally describe your learning experience with virtual reality?
2. Do you have a specific example of how virtual reality helped you understand the subject better?
3. How do you think learning through virtual reality differs from other learning methods?

4. How has the immersive virtual reality method in biology classes affected your learning process?

Section Three: Habits of Mind

A. Critical Thinking:

1. Have you noticed any changes in your thinking style with the use of virtual reality in biology lessons?
2. How has immersion in virtual reality affected your analytical ability?
3. How has immersion in virtual reality affected your problem-solving ability?
4. How has virtual reality affected your ability to evaluate?
5. Can you provide an example of a situation where virtual reality helped you solve a specific problem or make a difficult decision?
6. How has immersion helped you synthesize and integrate parts of information to reach a comprehensive understanding of the subject?
7. Has immersion helped you evaluate the credibility of information and its sources?

B. Creative Thinking:

1. How has virtual reality influenced the generation of new ideas or creative thinking?
2. Can you provide an example where virtual reality helped you think outside the box?
3. How has virtual reality stimulated your imagination and visualization compared to other teaching methods?
4. Do you feel that virtual reality enhances your ability to connect different concepts? How?
5. Has virtual reality encouraged you to engage in creative tasks with challenges? How?
6. Has virtual reality helped you focus more during creative activities? How?

C. Self-Regulation:

1. How has immersion in virtual reality affected your ability to plan for learning?
2. Has the learning experience through virtual reality influenced your self-monitoring of thinking? How?
3. How has virtual reality affected your way of evaluating your personal learning?
4. Do you find a difference in your engagement and reflection process when learning with virtual reality compared to regular classes? How?
5. How has immersion affected your learning behavior in general?
6. How has immersion helped you achieve your goals effectively?
7. How has virtual reality affected your self-discipline compared to other teaching methods?

Section Four: Mediating Variables

D. Motivation:

1. How do you feel about learning biology through virtual reality compared to other teaching methods?
2. Which specific aspect of virtual reality increases your motivation for learning (e.g., visualization, interaction)?
3. Has the use of virtual reality increased your interest in biology? How?
4. What features motivate you to learn biology through virtual reality?

E. Flow Experience:

1. How would you describe the experience of immersion in virtual reality?
2. Have you encountered immersive experiences in other situations? When?
3. Do you feel that virtual reality balances the challenges with your skills? How?

F. General Habits of Mind:

1. How has the use of virtual reality affected your learning habits?
2. How has virtual reality influenced your attitudes towards learning in general?

Section Five: Closing the Interview

- Ask if the interviewee wants to add anything else.
- Thank the interviewee for their cooperation.

Appendix G

Focus Group Discussion Guide

Target Groups:

Municipal secondary school students.

Goal: To explore secondary students' shared experiences and perceptions of VRI in biology classes, and the effects it has on their HoM through the mediation of FE, MT and SR.

A guide for Semi-structured interviews and Focus Groups:

Section One: Greetings and introduction:

- Greet the group members and introduce myself, explaining the purpose of the interview.
- Emphasize the confidentiality of the data and the interviewee's freedom to participate.
- Request permission to record the session.

Information about the Interviewee:

- Ask the group to introduce themselves, including their name (optional), age, grade, school, and gender.

Section Two: Immersion in Virtual Reality

1. Can you generally describe your learning experience with virtual reality?
2. Do you have a specific example of how virtual reality helped you understand the subject better?
3. How do you think learning through virtual reality differs from other learning methods?
4. What challenges faced you during the experiment?

Section Three: Habits of Mind

A. Self-Regulation:

1. Did learning through VRI help you better organize your time and plan for your learning? How?
2. Did learning through VRI help you evaluate your self-performance effectively? How?
3. Did you notice any improvement on your concentration as a result of VRI learning experience?
4. Did you note any change on your habits of learning after the experience?

B. Critical Thinking:

1. How did VRI enhance your analysis and problem-solving skills?
2. Do you think virtual reality affected your ability to evaluate your performance? How?
3. Can you provide an example of a situation where virtual reality helped you solve a specific problem or make a difficult decision?

B. Creative Thinking:

1. How has virtual reality influenced the generation of new ideas or creative thinking?
2. Can you provide an example where virtual reality helped you think outside the box?
3. How has virtual reality stimulated your imagination and visualization compared to other teaching methods?

Section Four: Mediating Variables

D. Motivation:

1. What do you think caused your high level of interaction with the biology content during VRI?
2. Has VR-based virtual reality classes increased your interest in biology How?
3. What features motivate you to learn biology through virtual reality?

E. Flow Experience:

1. How would you describe the experience of immersion in virtual reality?
2. Did you lose track of time and place during VRI? Describe?
3. Do you feel that virtual reality balances the challenges with your skills? How?

F. General Habits of Mind:

1. How has the use of virtual reality affected your learning habits?
2. How has virtual reality influenced your attitudes towards learning in general?

Section Five: Closing the Interview

- Ask if the group members want to add anything else.
- Thank the group for their cooperation

Appendix H

Observation Checklist

Category	Indicators	Notes
VRI	Spatial Presence: Having a sense of being there.	
	Spatial Presence: Feeling surrounded by VR environment.	
	INVolvement: A sense of captivation	
	INVolvement: Unawarenese of the real world.	
	Experinced Realism: The virtual world seems very realistic.	
	Experienced Realism: Objects in the virtual world looked realistic.	
FE	Enjoying the experience.	
	Feeling gratified by the experience. Showing persistence.	
	Deep concentration. Staying focused.	
	Feeling that time passes quickly.	
	Feeling satisfied about the experience.	
MT	An interesting experience. (Enthusiasm).	
	A feeling of good performance during VR.	
	Feeling of competence with VR. (Exploring areas beyond the required).	
	Feeling relaxed during VR application.	
	Feeling of skillfulness while using VR.	
SR	Recognizing self-thinking	
	Making effective plans	
	Understanding and using the needed information	
	Becoming sensitive toward feedback	
	Evaluating the effectiveness of acts	
CRIT	Being accurate and able to look for accuracy	
	Being clear and able to look for clarity	
	Being open: able to identify problems and challenges and come up with decisions based on critical evaluation.	
	Being able to position oneself when there is a guarantee	
	Being sensitive and able to recognize friends' abilities	
CRET	Being able to involve oneself in tasks although the answer and solution has not yet to be found	
	Trying hard to expand skills and knowledge to face challenges.	
	Creating new ways or point of view outside the common knowledge	

Other observations: --

Appendix I
Code Book

Primary Categories	Sub-categories	Description	Example codes
1. Virtual Reality Immersion	Spatial Presence	The level to which students feel physically present in the virtual environment.	“I felt I was diving inside the cell.”
	Involvement	The level of engagement and attention of students within the VR environment.	"When I followed the neural impulse, I understood how chemicals transform and turn into electrical transmission. VR simplifies the picture significantly."
	Experiential Reality	How realistic and believable the virtual environment seems to students.	"The entire virtual environment feels real — the organelles, movements, images, and colors."
2. Flow Experience	Enjoying experience	- The intrinsic pleasure and satisfaction derived from engaging in VR sessions.	"I felt great enjoyment in learning the intricate details about the subject, which increased my love for it."
	Gratifying experience.	- Satisfaction gained from achieving a meaningful task in VR sessions.	"VR activities are not boring; They are both enjoyable and beneficial."
	Total concentration	A state of deep focus and immersion in the task at hand, where attention is fully directed toward the activity.	"...and nothing distracts me from it."
	Time passing fast	Time distortion, where time seems to fly due to deep engagement and absorption in an activity.	"Time seemed to fly during VR sessions.”
	Experience exceeding expectations.	Realization that the outcomes of an activity surpass initial assumptions.	"VR sessions exceeded my expectations."
3. Motivation	Interesting to use	VR is an engaging and captivating tool, which drives the desire to further explorations.	"The VR tool is novel, engaging, and enjoyable to use."
	Self-performance satisfaction	The feeling of contentment about own’s performance during or after the VR activity.	"Having the VR tool, I feel that we can learn without anyone helping us."
	Feeling competent	A sense of mastery or confidence in one’s ability to perform the activity effectively.	"Now, I can confidently excel in my biology test on the cell, as my understanding improves my answers."
	Feeling relaxed	The sense of calm and ease experienced while engaging in VR activities.	"I learnt more about DNA while feeling comfortable."
	Feeling skillful	Recognition of one’s abilities and proficiency while engaging in a task.	"In virtual reality, I felt skilled as I found solutions to questions much more easily than in traditional classes."
4. Self-Regulation	Self-thinking awareness	- Students’ ability to detail the sequence of their thoughts and analyze how awareness of their thinking improves performance.	"I started paying more attention to the way I think and analyze topics."
	Effective planning	- Students’ ability to set precise goals, execute necessary sub-goals, and follow a detailed outline.	"You start by planning what you want to understand at the beginning... and then you follow the plan during the VR experience to achieve your goals easily."
			"...I used to rely solely on the book and the teacher to know whether I

	Resources-management	- Students' ability to carefully assess resource needs, review available options, and anticipate potential demands before starting a task.	understood. I couldn't tell if the information I had was correct or incorrect. But now, I can assess how much I understand or don't understand through VR."
	Self-evaluative effectiveness	- Be sensitive to diverse feedback, adapt promptly to ineffective approaches, and seek advice from knowledgeable sources.	"I compare what I saw in virtual reality with what the teacher said, and I identify where my inaccuracies were, which improves my understanding and learning."
	Sensitivity to feedback	- Students' thoroughly review actions from multiple perspectives, consider short- and long-term effects, and value lessons from both success and failure.	"If I faced difficulties, I would ask the teacher or the students, listen to their guidance, and find the solution after trying."
5. Critical Thinking	Accuracy oriented	- Students Pay attention to details, verify with key resources, and quickly correct inaccuracies for clarity.	"So, I started to understand how accuracy in information works and when the information is not very accurate. I compare between different sources and know what to do."
	Clarity driven	- Students' whole work is free of confusing parts or elements.	"Today, I am able to answer questions with clarity, using multiple approaches and from various perspectives, just as I learned from diverse viewpoints."
	Open-mindedness	- Students seek and evaluate diverse perspectives impartially and rationally.	"VR helped me understand more than just memorize, to be clear in my answers, and to express them with clarity and detail."
	Impulsivity Restrain	- Students carefully evaluate situations and investigate thoroughly before taking action.	"Before answering, I recall the information I got from the teacher, the virtual reality experience, and also from the book. Then I answer, feeling confident in my response."
	Taking position assertively	- Students take appropriate positions and introduce valuable perspective. They provide strong supporting evidence for the position.	"VRI helped understand faster and deeper... I can now provide supporting evidence to my answers."
	Sensitivity to Others' feelings and knowledge.	Students demonstrate empathy for others' feelings and knowledge while fostering respect for differences and sensitivities.	"I don't get upset by an opinion that disagrees with mine. Everyone has their own perspective based on their understanding and sources of information."
	Exploration oriented.	Self-directed exploration with structured guidance to deepen understanding and adaptability.	It is imprinted in my brain in a motor way because I saw it, analysed it, and understood why it happens.
6. Creative Thinking	Engagement in tasks with no clear solutions.	- Students show determination in solving problems, monitor involvement, and use strategies to stay on task.	"When I am familiar with the materials and understand them through VR, I feel confident about my knowledge. This encourages me to engage in challenging activities."
	Exceeding limits of knowledge and abilities	- Seek out highly challenging tasks and work on it until completed or understood.	"When I made mistakes during VR sessions, like going to other places and see things that weren't exactly required, however they were part of the DNA, or the cell. So, I was happy that I was learning more things, even while I was lost."

	Generation of self-evaluative standards	- Generate personal standards for completion of the task that significantly raise the quality level of the task. - Incorporate those standards into the final product.	"I understood much better through VR and learned how to create an accurate mental image of these things based on multiple sources, not just the book or the teacher."
	Generation of new ways for viewing situations.	- Explore as many alternatives as possible. - Analyse how alternatives will affect the outcome of the task.	"Having prior knowledge about the topic and watching the VR video helped me view it from a broader, more interconnected perspective, allowing me to connect various elements and draw meaningful conclusions."
	Generation of Conceptual Visualization	Students' ability to transform abstract ideas into visual representations to enhance understanding and communication.	"You deduce and see how the movement happens, and you see all the information on your own without anyone having to explain it to you exactly, or tell you all the information, or forget a detail.

Appendix J

Certificate of Research Acceptance Derived from Dissertation

Research title: Impact of Virtual Reality Immersion in Biology Classes on Habits of Mind of East Jerusalem Municipality High School Students: Examining Mediating Roles of Self-Regulation, Flow Experience, and Motivation.

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CERTIFICATE OF ACCEPTANCE

The certificate of acceptance for the manuscript (**education-3548529**) titled:

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كلية الدراسات العليا

أثر الواقع الافتراضي على عادات العقل في حصص الأحياء من خلال المتغيرات الوسطية: خبرة التدفق، الدافعية، والتنظيم الذاتي في مدارس شرقي القدس

إعداد

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إشراف

د. عبد الكريم أيوب

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الدكتوراه في التعليم والتعلم، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس–فلسطين.

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الملخص

في عالمنا الرقمي، أصبحت التكنولوجيا تحتل مكانة أساسية، حيث أصبحت مهارات التفكير الناقد والتفكير الإبداعي ضرورة ملحة. وقد أصبحت مخرجات التعليم تتطلب من المتعلم معالجة الأمور بدلا من حفظها، والتفكير بطريقة إبداعية بدلا من الطرق التقليدية. تهدف هذه الدراسة (المختلطة) الكمية والنوعية إلى استقصاء تأثير الانغماس في الواقع الافتراضي على تعزيز عادات العقل العلمية كتنظيم الذات والتفكير الناقد والتفكير الإبداعي من خلال المتغيرات الوسطية لخبرة التدفق، والدافعية، وتنظيم الذات في دروس الأحياء لدى طلاب المدارس الثانوية في شرقي القدس. تألفت العينة العشوائية الطبقية من (347) طالبا من المرحلة الثانوية في ثلاث مدارس قامت بتعليم مفاهيم الأحياء بطريقة بنائية بواسطة الواقع الافتراضي بما يتوافق مع النموذج المعرفي العاطفي للتعلم الغامر (CAMIL). وقد كشفت نتائج التحليل المعتمدة على (PLS–SEM) أن الانغماس في الواقع الافتراضي قد أثر بشكل ملاحظ على تنظيم الذات، والتفكير الناقد، والإبداعي بشكل مباشر وغير مباشر. وقد ظهرت حالات وسطية كاملة وجزئية، مما أظهر تأثير المتغيرات الوسطية في تعزيز عادات العقل من خلال تسلسل المتغيرات الوسطية بدءا من الخبرة المتدفقة، مرورا بالدافعية إلى تنظيم الذات، والذي عمل كعامل أساسي في العلاقة ما بين الانغماس في الواقع الافتراضي وعادات العقل. استنادا إلى نتائج الدراسة، فإن البنية المعقدة لهذا النموذج تتطلب المزيد من البحث المستقبلي. حيث أشارت النتائج إلى أن تأثير الانغماس في الواقع الافتراضي على عادات العقل يزداد قوة بفضل تأثيرات المتغيرات الوسطية. إضافة لذلك، أكدت النتائج أن تجربة التدفق والدافعية يلعبان دورا أساسيا

في تعزيز بيئة تعليمية ملائمة وداعمة لتطوير المهارات المعرفية. كما أظهرت نتائج النموذج المقترح مؤشرات ملاءمة جيدة (SRMR = 0.064) ودلالة تنبؤية مقبولة. كما أبرزت نتائج الدراسة أن تعزيز تنظيم الذات، باعتباره المتغير الوسطي النهائي في سلسلة المتغيرات الوسطية يشكل خطوة مهمة تسبق تعزيز مهارات التفكير الناقد والتفكير الإبداعي.

الكلمات المفتاحية: الواقع الافتراضي، الانغماس في الواقع الافتراضي، الدافعية، تجربة التدفق، تنظيم الذات، عادات العقل، التفكير النقدي، التفكير الإبداعي.