HIGH SCHOOL STUDENTS’ SELF-REGULATED LEARNING
IN A VIRTUAL REALITY BASED LEARNING ENVIRONMENT

NAZMİ ERDOĞAN

BOĞAZİÇİ UNIVERSITY

2024

HIGH SCHOOL STUDENTS' SELF-REGULATED LEARNING IN A VIRTUAL REALITY BASED LEARNING ENVIRONMENT

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Learning Sciences

by

Nazmi Erdoğan

Boğaziçi University

2024

High School Students’ Self-Regulated Learning

in a Virtual Reality Based Learning Environment

This thesis of Nazmi Erdoğan

has been approved by:

Assoc. Prof. Engin Ader
(Thesis Advisor)

Prof. Emine Erktin

Prof. Diler Öner

Prof. Tova Michalsky
(External Member)

Prof. Şefika Feza Orhan
(External Member)

May 2024

DECLARATION OF ORIGINALITY

I, Nazmi Erdoğan, certify that.

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature…………………………………………….....

Date ……………………………………………...........

ABSTRACT

High School Students' Self-Regulated Learning

in a Virtual Reality Based Learning Environment

This instrumental case study aims to explore students' self-regulated learning (SRL) processes in a VR learning environment. In addition, a virtual reality (VR)-based learning environment was designed with combining traditional learning activities of mathematics education with the VR learning environment to facilitate students' SRL processes. Thus, this study also aims to explore the environmental features of the VR-based learning environment that are conducive to specific SRL processes. The participants were twenty eleventh grade students. The SRL processes of participants and the environmental features conducive to specific SRL processes were explored via using their think-aloud audio, screen recordings of their experiences in the VR learning environment, and semi-structured interviews. Qualitative data analysis was conducted through the coding of all these three data sources. The findings indicate that students engage in task analysis and monitoring processes and utilize a variety of self-control strategies in the VR learning environment. Furthermore, there is an interplay between the environmental features of the VR-based learning environment and SRL processes. The findings indicate that specific environmental features of the VR-based learning environment can facilitate students' specific SRL processes.

ÖZET

Lise Öğrencilerinin Sanal Gerçeklik Tabanlı Öğrenme Ortamındaki Özdüzenlemeli Öğrenmeleri

Bu araçsal durum çalışması, öğrencilerin sanal gerçeklik (VR) öğrenme ortamındaki özdüzenlemeli öğrenme (SRL) süreçlerini keşfetmeyi amaçlamaktadır. Ayrıca öğrencilerin SRL süreçlerini kolaylaştırmayı hedefleyen VR tabanlı bir öğrenme ortamı tasarlanmıştır. Bu çalışmanın bir diğer amacı, VR tabanlı öğrenme ortamının belirli SRL süreçlerine uygun çevresel özelliklerini de araştırmaktır. Katılımcılar yirmi on birinci sınıf öğrencisidir. Katılımcıların SRL süreçleri ve SRL süreçlerine yardımcı olan çevresel özellikler, katılımcıların sesli düşünme kayıtları, VR öğrenme ortamındaki deneyimlerinin ekran kayıtları ve yarı yapılandırılmış mülakatların nitel veri analizi ile araştırılmıştır. Çalışmanın bulguları, öğrencilerin görev analizi ve izleme süreçlerine katıldıklarını ve VR öğrenme ortamında çeşitli öz-kontrol stratejilerini kullandıklarını göstermektedir. Buna ek olarak, VR tabanlı öğrenme ortamının çevresel özellikleri ile SRL süreçleri arasında bir etkileşim bulunmaktadır. VR tabanlı öğrenme ortamının bazı özellikleri belirli SRL süreçleri için uygun zemin oluşturabilmektedir. Çalışmanın bulguları, VR tabanlı öğrenme ortamının çevresel özelliklerinin öğrencilerin SRL süreçlerini kolaylaştırabileceğini göstermektedir.

CURRICULUM VITAE

NAME: Nazmi Erdoğan

DEGREES AWARDED

MA in Primary Education, 2014, Boğaziçi University

BA in Mathematics Education, 2009, Boğaziçi University

AREAS OF SPECIAL INTEREST

Self-regulated learning, Computer-based learning environments

PROFESSIONAL EXPERIENCE

Mathematics Teacher, Şehit Öğretmen İzzet Yüksel Middle School - İstanbul, 2021-2024

Mathematics Teacher, Mehmet Akif Middle School – İstanbul, 2017-2021

Mathematics Teacher, Ziya Gökalp Middle School - Iğdır, 2015-2017

Mathematics Teacher, Cumhuriyet Middle School - Iğdır, 2014-2015

PUBLICATIONS

Conference Proceedings

Erdoğan, N., Ader, E. (2013). İlköğretim Matematik Öğretmen Adaylarının Bilgisayar Destekli Matematik Öğretimi Dersi Kapsamında Teknolojik Pedagojik Alan Bilgilerinin Gelişimi. *Karadeniz Teknik Üniversitesi Türk Bilgisayar ve Matematik Eğitimi Sempozyumu*, Karadeniz Teknik Üniversitesi, Trabzon.

Erdoğan, N., Ader, E. (2023). Lise Öğrencilerinin Sanal Gerçeklik Ortamındaki Özdüzenlemeli Öğrenmeleri, *15. Ulusal Matematik ve Fen Bilimleri Kongresi,* Kafkas Üniversitesi, Kars.

Article

Erktin, E., Aşık, G., Adagideli, F.G., Aşık, M., Erdoğan, N., Tekin, Ş. (2012). Matematik Eğitiminde Bilişsel ve Bilişüstü Yaklaşımlar: Bir Hizmetiçi Eğitim Semineri Örneği, *Matematik Eğitim Journal*, 1

ACKNOWLEDGMENTS

First and foremost, I would like to express my deepest gratitude to my doctoral thesis advisor, Assoc. Prof. Engin ADER, who has been by my side from the beginning to the end of my research, never withholding his support, knowledge, and time. I am truly grateful for his invaluable assistance in the successful progression and completion of this study.

I would also like to thank Prof. Dr. Diler ÖNER and Prof. Dr. Tova MICHALSKY, who have been members of my thesis monitoring committee from the very beginning. Their feedback throughout the process greatly contributed to my work's development and improvement.

I owe a debt of gratitude to Prof. Dr. Şefika Feza ORHAN and Prof. Dr. Emine ERKTİN, who kindly accepted to be part of my doctoral jury and contributed to the final form of my thesis with their valuable comments.

I would like to thank my dear friends from the Learning Sciences doctoral program at Boğaziçi University, Alev GÜNEŞ UZUN, Fetiye ERBİL, Nıvart Karin ATAOĞLU, and Melek PESEN, for their unwavering support throughout the courses, doctoral qualification, and thesis process. Additionally, I extend special thanks to my dear friend Zeynep KAYMAZ, whose friendship and academic support have always been by my side throughout this journey.

I also wish to express my gratitude to my dear friends Hakkı ÇAKIR, Selçuk DOĞAN, and Eyyüb Yunus KIBIŞ, who have provided their personal friendships during this process. I am grateful to have you all in my life.

Moreover, I would like to thank my colleagues, mathematics teachers Yakup ÇİÇEK, Tülin GÜMÜŞTEKİN ERTUGAY, Emine ARSLAN, Hilal GÜLER, and school administrators Kemal ALTUN and Bilal DİNÇER, for often supporting me by lightening my workload at the school where I work.

I extend my gratitude and love to my mother Şükran ERDOĞAN and my father Şahin ERDOĞAN, who raised me and enabled me to come to where I am today, never withholding their efforts.

Finally, I would like to thank my dear wife, Esra Nur ERDOĞAN, who has continuously supported and motivated me with patience. I am very fortunate to have you and our son, Kerem, in my life. Thank you for being part of my life.

To Hakan and grandmom,

we will always miss you

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 The problem

The aim of the learning sciences is to explore how people learn in specific contexts. Learning scientists investigate what is significant for people during learning and attempt to design and develop the contexts in which learning occurs (Fisher et al., 2018). But learning is a complicated process with cognitive, metacognitive, and motivational dimensions (Winne, 2017). The theory of self-regulated learning (SRL) has provided learning scientists with a useful framework for identifying crucial processes that promote learning (Jarvela et al., 2019). Zimmerman's cyclical phases model (2000) guided this study to explore students' SRL processes in a VR learning environment.

In the 21st century, people need to be lifelong learners, which means they need to take charge of their own learning (Jarvela et al., 2018; Sawyer, 2014). The capability to self-regulate one's own learning is crucial for success in the twenty-first century (Jarvela et al., 2019). This is due to the fact that self-regulated learners "have control over their cognition, behavior, emotions, and motivation by using personal strategies to achieve their goals" (Panadero & Alonso-Tapia, 2014, p. 450). Since people with low SRL skills may have many personal and academic problems (Zimmerman, 2000), learning environments should be set up so that people can engage in SRL processes in a productive way. Research on SRL can help learning scientists make various inferences for effective learning thanks to developments in methodological and analytical approaches (Hadwin, 2020). Various data collection and analysis methods in SRL studies provide valuable information for exploring students' learning processes that can contribute to learning environment designs (Winne & Azevedo, 2014). In brief, exploring individuals' learning processes in specific contexts under the guidance of SRL models can inform researchers to design learning environments that may provide individuals with effective learning experiences.

Computer-based learning environments are one of the focuses of learning sciences research because of their capacity to enhance deeper learning (Sawyer, 2014). Many computer-based learning environments, such as serious games, simulations, massive open online courses (Graesser et al., 2018), and virtual reality (Eisenberg & Pares, 2014; Graesser et al., 2018), are available for learners in this decade, and learning scientists investigate their potential for learning (Graesser et al., 2018; Kafai & Dede, 2014). Virtual reality (VR) environments, in particular, are being actively integrated into teaching and learning processes in a variety of domains (Radianti, 2020), including computer sciences, engineering, and social sciences (Freina & Ott, 2015). VR provides learners with realistic and situated learning contexts that are not easily accessible in the real world (Wu et al., 2020). For instance, making a journey into the blood vessels (Parong & Mayer, 2020), forensic analysis of a DNA sample (Makransky et al., 2020), or discovering an algebraic model for a global pandemic become possible for learners in a VR learning environment. However, most of the studies with VR in the field of education have either focused on learners' perceptions toward using VR instead of their performance (Radianti et al., 2020) or did not find any significant effect of VR on students' learning outcomes (Wu et al., 2020). Thus, there is a paucity of empirical evidence on the positive effect of VR on learners' performance (Wu et al., 2020). For instance, Makransky et al. (2020) compared two groups in their experimental study. Students were enrolled in either an immersive VR group or a video group. They conducted two experiments. In the first experiment, while the immersive VR group experienced the analysis of a DNA sample in a VR learning environment, the video group only watched the video of the same learning material. Even if the perceived enjoyment and presence of the immersive VR group were significantly higher than those of the video group, students' declarative and procedural knowledge were not significantly different from each other in the two groups. In the second experiment, they repeated the first experiment by adding a generative learning strategy (enactment) for half of the students in both the immersive VR and video groups. The implementation of the enactment activity resulted in significantly higher procedural knowledge and transfer only in the immersive VR group. Makransky et al. (2020) argued that the effectiveness of VR learning environments for learning depends on how the immersive lesson is designed and implemented.

Graesser et al. (2018) discussed "the risk of collecting dust without the human element" (Graesser et al., 2018, p. 251) in computer-based learning environments such as VR. Therefore, providing students with just an immersive VR game for learning may not result in an increase in their performance. Since some studies related students' poorer learning outcomes in VR environments to the higher cognitive load that learners experienced (Parong & Mayer, 2020; Makransky et al., 2017; Meyer et al., 2019), increased cognitive load may impede students' learning (Jong, 2010) in VR learning environments. Sweller et al. (1998) underlined the importance of instructional designs to reduce working memory load and maximize learners' intellectual performance in learning tasks. Similarly, Wu et al. (2020) and Makransky et al. (2020) suggested enhancing instructional design to increase the educational value of VR environments. For increasing the educational value of computer-based learning environments such as VR, human intervention is recommended (Means et al. 2014). In this way, students can be provided with a satisfactory technology integrated learning context, which may facilitate students' learning (Graesser et al., 2018). Therefore, the instructional design of the immersive lesson was taken into account in this study. Students were not just provided with a VR learning environment. Instead, some traditional learning materials were designed based on pre-training principle (Mayer & Pilegard, 2014) and generative learning strategies (Fiorella & Mayer, 2016), and they were integrated into the VR learning environment to support students' performance in virtual tasks.

Numerous VR studies have emphasized the importance of self-regulation as one of the key constructs for investigating learning in VR environments. For instance, Makransky and Petersen (2021) hypothesized that higher levels of presence and agency in VR have the potential to encourage students' SRL processes because they can engage in meaningful interactions with pedagogical agents. Due to the cognitively demanding nature of VR environments, they also emphasized that students' learning processes may suffer if they are unable to monitor and control their cognitive, metacognitive, emotional, and motivational processes. Providing appropriate support, such as pre-training (Meyer et al., 2019) or summarizing (Parong & Mayer, 2018), to students was suggested as a way of promoting students' SRL processes and deeper learning in VR (Makransky & Petersen, 2021).

This study focuses on how learning occurs in a specific setting by using Zimmerman's (2000) cyclical phases SRL model as a theoretical lens. The setting involved a virtual VR learning environment that was formed by merging traditional learning materials with an already existing VR application known as Pandemic by Prisms. The additional learning materials were designed based on the pre-training principle (Mayer & Pilegard, 2014) and generative learning strategies (Fiorella & Mayer, 2016). The focus of this study is to explore students' SRL processes in the VR application. In addition, many SRL models regard context as an important element of self-regulation. Context is crucial as it facilitates adaptation to task demands and is integrated into the feedback loops, where students receive information from the context and adjust their strategies accordingly (Panadero, 2017). Thus, this study also focuses on the contextual features of the VR-based learning environment and explores how these features are conducive to specific SRL processes.

1.2 Need for the study

Students' SRL processes have been identified in a variety of computer-based learning environments, such as hypermedia (e.g., Engelmann & Bannert, 2020; Moos & Azevedo, 2008; Taub et al., 2020), web-based learning environments (e.g., Joo et al., 2000), and simulations (e.g., De Jong et al., 2005). However, there is a paucity of research on self-regulation in VR learning environments. Chen and Hsu (2020) conducted one of the studies in a VR learning environment. They explored the effectiveness of students' learning, their engagement with educational games, and their SRL in a VR-based mobile English learning application. In their study, the apparatus was a smart mobile phone integrated into a head-mounted display (HMD). Radianti et al. (2020) classified phone-integrated HMDs as less immersive VR devices. In addition, Chen and Hsu (2020) measured the students' SRL by using a self-report questionnaire, and the content area was English in their study. An immersive VR learning environment may provide students with a highly engaging experience. However, an immersive VR learning environment can result in more presence, which can require the use of more cognitive resources while working on the virtual task (Makransky & Petersen, 2021). The cognitively demanding nature of highly immersive VR learning environments, according to Makransky and Petersen (2021), can affect students' SRL processes. Therefore, there is a need to explore students' SRL processes in a more immersive learning environment, such as Pandemic by Prisms. In addition, there is a need to measure students' SRL processes with more process-oriented methods such as think-alouds and screen recordings (Azevedo, 2020).

Recently, Sobocinsky et al. (2023) conducted a study in the same VR learning environment used in this study. They examined the metacognitive monitoring of pre-service teachers when they interact with exponential functions in the VR learning environment. Data sources included think-aloud protocols, bird's-eye view video recordings, and physiological measures. Think-aloud protocols were used to measure pre-service teachers' metacognitive monitoring. Bird's eye views video recordings served to analyze their movements. Additionally, cognitive load was measured using heart rate variability analysis. Their findings revealed a temporal relationship between metacognitive monitoring, motion, and cognitive load in the VR learning environment. The study highlights the capacity of VR learning environments to dynamically adjust to the particular needs of users, providing customized support as and when needed. In order to create successful adaptive learning scaffolds, it is crucial to have a thorough comprehension of the SRL processes that drive learning in immersive VR settings (Sobocinsky et al., 2023). Their results are critical in terms of the SRL processes they identified. Their study showed how pre-service teachers engaged in monitoring processes while working on virtual learning tasks about exponential functions. The mean of the participants' ages was 29. Given that "exponential functions" are part of the high school curriculum, it is necessary to investigate the SRL processes of high school students within the same VR learning environment. Sobocinsky et al. (2023) discussed detecting only monitoring processes in the VR learning environment and underlined the importance of a more detailed understanding of students' SRL processes in VR learning environments. It may be possible to detect other SRL processes, such as task analysis processes or self-control strategies, when conducting a study with participants whose age is suitable for the curricular level of the exponential functions.

Makransky and Petersen (2020) offered the cognitive affective model of immersive learning, which proposes a theoretical research-based framework for understanding learning processes within immersive virtual reality (VR) environments. This comprehensive model outlines six affective and cognitive factors (interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation) that can influence the outcomes of students in a VR learning environment. Self-regulation is one of those factors that has an impact on students' learning outcomes in a VR learning environment. Makransky and Petersen (2020) argued that students' self-regulation in an immersive VR learning environment is dependent on the instructional design of the immersive lesson. Students cannot successfully monitor and control their learning processes due to the highly engaging nature of the VR learning environment because they can be exposed to cognitive overload in a highly engaging environment (Makransky & Petersen, 2020). Providing students with some activities for reflecting on their learning in an immersive lesson may "prompt metacognition and deeper learning within or after" (Makransky & Petersen, 2020, p. 947).

In sum, self-regulation is one of the important factors that has an effect on students' overall learning processes in VR learning environments (Makransky & Petersen, 2020). Although many studies were conducted to explore students' SRL processes in other computer-based learning environments (e.g., De Jong et al., 2005; Engelmann & Bannert, 2020; Joo et al., 2000; Moos & Azevedo, 2008; Taub et al., 2020), the number of studies in VR learning environments is very low. Therefore, there is a need to explore students' SRL processes in VR learning environments, too.

Moreover, there is a need to measure students' SRL processes with multiple methods. In their study directly investigating students' SRL in a VR setting, Chen and Hsu (2020) used an HMD that provided a less immersive experience for the students. However, there is also a need to explore students' SRL processes in a highly immersive VR learning environment. Chen and Hsu (2020) also measured students' SRL processes by using a self-report questionnaire in an English learning context. It was suggested (Azevedo, 2020) that self-report measures of SRL processes should be combined with process-oriented methods like think-aloud and screen recordings. This study uses both self-report and process-oriented methods to measure students' SRL processes in a mathematics VR learning environment.

1.3 Aim and significance of the study

Recently, there has been an increasing integration of VR technology into education in several domains (Radianti et al., 2020). Therefore, it is important for educators to understand how learning occurs in VR learning environments. The SRL models provide learning scientists with a useful framework for identifying crucial processes in learning (Jarvela et al., 2019). SRL is a dynamic, complex, and multi-faceted process (Hadwin, 2020). Various assessment tools have been developed and utilized in order to gain a deeper understanding of this process (Azavedo, 2020). Therefore, the first aim of this study is to explore students' SRL processes in a VR learning environment.

By encouraging meaningful interactions with pedagogical agents and fostering a strong sense of social presence, VR learning environments can augment students' SRL (Makransky & Petersen, 2021). Students may encounter inadequate learning outcomes in such environments as a result of increased cognitive load (Parong & Mayer, 2020). They can also focus on hedonic VR features that may raise an individual's interest and pleasure, which can result in using superficial learning strategies (Makransky et al., 2020). The use of superficial learning strategies may ultimately hinder one's learning progress (Makransky et al., 2020) due to a decline in their self-regulation in the VR learning environments (Makransky et al., 2019). Therefore, it is advised to prioritize the instructional design of the lesson to facilitate students' SRL processes in VR learning environments (Makransky & Petersen, 2021; Wu et al., 2020). Thus, the second aim of this study is to construct an immersive lesson by combining traditional learning activities with an immersive VR application and to explore the features of the immersive lesson that are conducive to specific SRL processes.

The results of this study will be significant for teachers, researchers, and instructional designers. This study includes an immersive lesson that was constructed by integrating traditional learning activities with an immersive VR application. How the features of the immersive lesson are conducive to students' SRL processes will be explored in this study. Traditional learning activities will be investigated in terms of their impact on students' SRL processes. This may be important for teachers to enrich their instructions while integrating VR applications into their lessons.

This study is also significant for researchers because of their methodological choices about data collection. Three data sources are employed in order to explore students' SRL processes. Interviews are self-reported data sources that measure students' retrospective views about their learning in the immersive lesson. Interviews can be regarded as offline measurements of students' SRL processes. Think-alouds and screen recordings are process-oriented data sources (Azevedo, 2020) that are used to measure students' SRL processes as learning takes place in the VR learning environment. Therefore, think-alouds and screen recordings can be regarded as online measurements of students' SRL processes. Hence, this study can contribute to researchers' choices about selecting data sources for measuring students' SRL in VR settings.

Lastly, the findings of this study can be significant for instructional designers. This study not only investigates students' SRL processes in an immersive VR lesson but also explores the contextual features of the learning environment that are conducive to specific SRL processes. Therefore, this study can inform instructional designers about the features of the immersive VR lesson and their connections with students' SRL processes. Put simply, instructional designers can integrate those features that give rise to specific SRL processes into their immersive VR application designs to facilitate students' SRL processes.

1.4 Research questions

This instrumental case study was designed to explore high school students' SRL processes in the VR learning environment and the features of the VR-based learning environment that are conducive to those SRL processes. In line with these purposes, the following research questions guide the study:

1. What are high-school students' SRL processes in a VR learning environment?
2. How is the VR-based learning environment conducive to students' SRL processes?

1.5 Scope and limitations of the study

This study aims to explore both students' SRL processes in a VR learning environment and contextual features that give rise to specific SRL processes. Since the language of the VR learning environment was English, it was possible to conduct this study in any high school. Therefore, a high school was purposefully selected in terms of students' proficiency in English. The students at the selected high school were higher achievers who were enrolled in the high school with top grades in national exams. As a result, the findings of this study reveal which SRL processes higher achievers use in the VR learning environment.

This research study includes several limitations. First, the participants are twenty 11th grade students. In addition, the participants were purposefully selected among the higher achievers. Since the number of participants of this specific group of students is quite low, this group cannot represent other 11-grade high school students. The small sample size may be considered a limitation for this study. The second limitation has been the immersive VR application selected in this study. The VR learning environment utilized in this study is a previously designed VR application. The findings of this study demonstrate the utilization of several SRL processes by students in this immersive VR application. It is possible to investigate various SRL processes and the corresponding contextual features that contribute to these processes in different immersive VR lessons. While it is possible to anticipate similar results in comparable contexts, the findings of this study cannot be generalized to other VR applications. This has been another limitation of this study.

1.6 Key terms and definitions

Self-regulated learning : "An active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000, p. 453)

Self-regulation : "Self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals." (Zimmerman, 2000, p. 14)

SRL processes : "Specific processes that transform their preexisting abilities into task-related behavior in diverse areas of functioning." (Zimmerman, 2013, p. 137). SRL processes include "cognitive processes such as planning and goal setting, metacognitive processes, such as the use of task-related strategies, imagery, or verbal self-instruction, motivational variables, such as self-efficacy" (Zimmerman, 2013, p. 137).

Virtual reality: "a mosaic of technologies that support the creation of synthetic, highly interactive, three-dimensional (3D) spatial environments that represent real or non-real situations" (Mikropoulos & Natsis, 2011, p. 769).

The VR learning environment : The educational game called Pandemic by Prisms

The VR-based learning environment : The educational game called Pandemic by Prisms

CHAPTER 2

LITERATURE REVIEW

2.1 Self-regulated learning

The social cognitive theory of Bandura assumes that human learning occurs in a social environment by observing and modeling others (Schunk, 2012). Bandura (1986) focused on reciprocal relationships among people, their behaviors, and environments. Bandura (1986) asserts that individual (e.g., biological, behavioral, affective, and cognitive), behavioral, and environmental factors all contribute to human functioning. The social cognitive theory of learning has a direct focus on the role of self-regulation in controlling assumptions about the central role of self-regulation and triadic interactions among personal, behavioral, and environmental factors in learning.

Self-regulated learning (SRL) is "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000, p. 453). SRL provides a powerful framework to explore cognitive, metacognitive, motivational, and emotional aspects of learning (Panadero, 2017). From the perspective of learning sciences, the SRL framework elucidates how people learn, and this provides a guide for developing design principles for learning environments (Winne & Azevedo, 2014). Zimmerman's (2000) widely accepted and empirically validated model of SRL (Panadero, 2017) emphasizes learning processes, features of learning environments (Dignath & Büttner, 2018), and motivational and emotional aspects of SRL (Panadero, 2017), and this model will guide the current study.

2.2 Cyclical model of self-regulated learning

The social cognitive model of SRL proposed by Zimmerman (2000) emphasizes the interplay between personal, behavioral, and environmental processes. Zimmerman (2000, p. 14) highlighted that self-regulation is about “self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals." Self-regulation includes learners’ actions and covert processes that lead to those actions (Zimmerman, 2000). The approach of Zimmerman emphasizes SRL as a dynamic process that unfolds over time, phases, and tasks. The dynamic and temporal nature of SRL is a common conception of self-regulation in many SRL models (Hadwin, 2020). Temporal and dynamic conceptualizations of self-regulation differ from views that characterize it as a personal trait or an outcome (Hadwin, 2020; Zimmerman, 2000). This perspective focuses on the timing of a specific event (e.g., Jarvela et al., 2020). Researchers investigate when and how particular regulatory events occur as learners perform tasks (Hadwin, 2020).

Figure 1 depicts the three phases of the cyclical model of SRL proposed by Zimmerman and Moylan (2009): forethought, performance, and self-reflection. In the forethought phase, learners analyze the task, set their goals, plan how to engage in the task, select their strategies in accordance with their goals, and activate motivational beliefs (such as self-efficacy and intrinsic interest or value) towards the task. In the performance phase, learners monitor their progress and use self-control strategies to keep themselves cognitively and motivationally active to maintain the task. Learners also monitor and control their emotions in the performance phase. In the self-reflection phase, learners evaluate their performance and make self-judgments on their weaknesses and strengths. Thus, learners may generate self-reactions (e.g., self-satisfaction or affective reactions) that affect the forethought phases of future tasks - a strong indicator of the cyclical nature of the process.

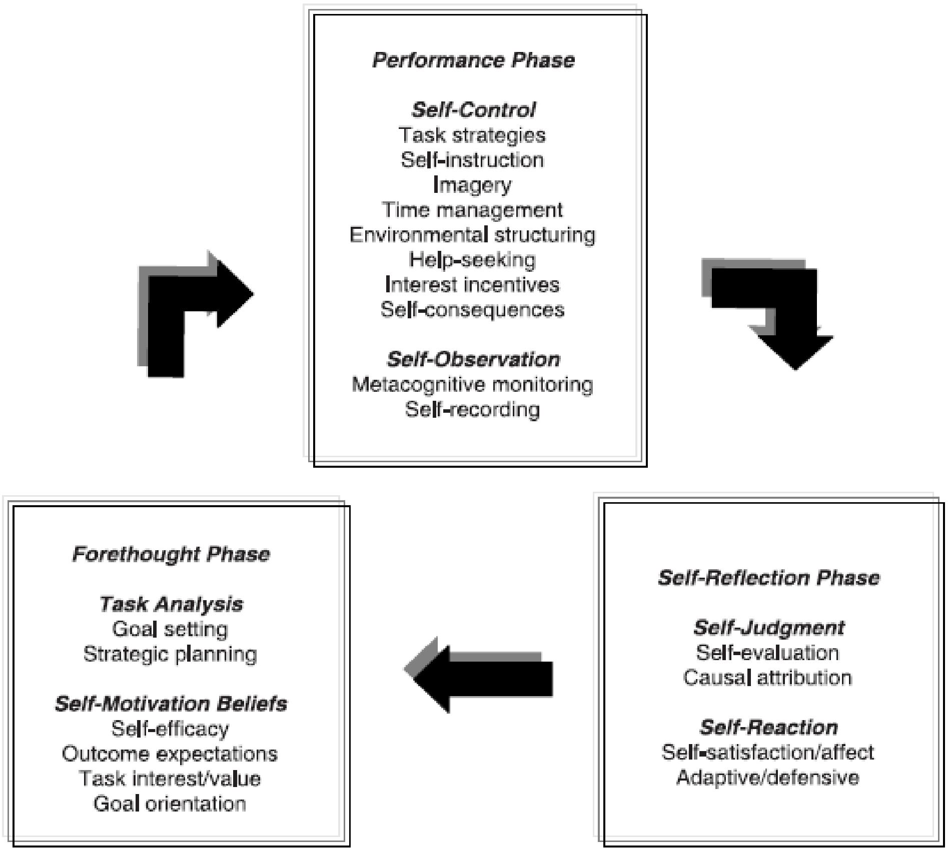


Figure 1. A cyclical model of self-regulation (Zimmerman & Moylan, 2009, p.300)

2.2.1 Forethought phase

The forethought phase includes processes that give rise to the learners' actions in the performance phase, where learning takes place, and it includes two processes: task analysis and self-motivation beliefs (Zimmerman, 2000).

2.2.1.1 Task analysis

In the forethought phase, learners decide what they expect from the task, shape their interest and confidence towards the task, set personal goals, and identify the ways of achieving those goals (Liu, 2012). The forethought phase includes task analysis processes and self-motivation beliefs. Goal-setting and strategic planning are two essential SRL processes of task analysis, according to Zimmerman (2008).

Goal setting is the first step of the SRL processes, where students set personally essential and meaningful self-goals (McCombs, 1989). Goal setting as a self-management technique is a purposeful action for students. Self-regulated learners volitionally set hierarchical goals and transform them into action (Latham & Locke, 1991; Zimmerman, 2000). A highly self-regulated student utilizes proximal process goals in order to achieve distal outcome goals (Zimmerman, 2000). For example, a distal goal of completing the entire task can be attained by breaking the task into a series of smaller tasks and establishing proximal goals for completing each smaller task (Schunk, 2012).

Strategic planning is the second subprocess of task analysis. Right after setting personal learning goals, students require strategies by which they can attain learning goals optimally. Developing suitable methods appropriate to both the task itself and the learning environment is a characteristic of self-regulated learners' goals (Zimmerman, 2000). For instance, a learner needs to select the most relevant solution strategy as a structured method in a problem-solving situation (Zimmerman & Campillo, 2003). It is important to underline that it is not possible for a learner to use a unique self-regulatory strategy for all tasks and events. Due to changes in personal, behavioral, and environmental factors, continuous adjustments are required in the planning and selection of strategies (Zimmerman, 2000). For instance, a student may benefit from a variety of problem-solving strategies. When the effectiveness of a strategy decreases, it is the learner's responsibility to select a more effective strategy in order to move closer to the solution (Zimmerman & Campillo, 2003). In conclusion, self-regulated learners are expected to "continuously adjust their goals and choice of strategies" (Zimmerman, 2000, p. 17) in order to adapt to ever-changing circumstances. Even if goal setting and strategic planning are important processes for self-regulation, their use relies on learners' motivation (Panadero & Alonso-Tapia, 2014; Zimmerman, 2000; Zimmerman & Campillo, 2003).

2.2.1.2 Self-motivation beliefs

Self-efficacy, outcome expectations, intrinsic interest or valuing, and goal orientation are self-motivational beliefs (Zimmerman, 2000) that give rise to carrying out strategic plans to reach established goals (Panadero & Alonso-Tapia, 2014). Self-efficacy refers to "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (Bandura, 1997, p. 3). Learners who possess high self-efficacy about their capabilities become more motivated to find and use different strategies (Panadero & Alonso-Tapia, 2014) and regulatory processes (Zimmerman, 2000) in case of difficulties while performing a task. In other words, highly self-efficacious learners are more persistent in performing difficult tasks, have more positive expectations, and regulate their learning in a better way when compared to those who have lower self-efficacy (Usher & Schunk, 2012).

Outcome expectations refer to beliefs about the product of a task (Bandura, 1997). Self-efficacy and outcome expectations are two closely related but frequently confused motivational beliefs (Panadero & Alonso-Tapia, 2014). Zimmerman (2000) gives an example to distinguish two concepts. For instance, a student believes that he can get a high grade in a course, and this shows his self-efficacy. He may expect that this high grade may help him find a good job, which is related to his outcome expectations.

Intrinsic interest and task value are individual variables that influence the initial motivation of learners toward a task. While intrinsic interest includes the personal value of the task due to its own characteristics, task value refers to the utility of the task for accomplishing learners' personal goals. A person, for instance, may not have an intrinsic interest in creating a CV. Thus, this task does not include an intrinsic value. However, this task includes an extrinsic value because a well-prepared CV increases the probability of finding a good job. Therefore, the task value of preparing a CV may be very high, and this maintains the individual's motivation towards the task beliefs (Panadero & Alonso-Tapia, 2014).

Learners' goal orientation is another variable that energizes their motivation and influences their self-regulation (Panadero & Alonso-Tapia, 2014; Zimmerman, 2000). A student with a performance goal orientation is more likely to compare his performance to that of others and to achieve success with less effort. A learner with a mastery goal orientation, on the other hand, strives to improve his skills and competence and attain mastery in an area of interest (Zimmerman & Campillo, 2003). According to Panadero and Alonso-Tapia (2014), learners' goal orientations influence their interest in the task, selection of strategies, focus on deeper learning, reflection on learning, and correction of errors. Learners' goal orientation is viewed as "an open-ended commitment" (Zimmerman & Moylan, 2009, p. 302) to completing learning tasks.

2.2.2 Performance phase

This is the phase in which students perform the task, and it requires maintaining concentration and employing appropriate learning strategies to maintain their motivation and track their learning progress by considering their learning goals

(Panadero & Alonso-Tapia, 2014). The performance phase includes two processes: self-control and self-observation (Zimmerman, 2000).

2.2.2.1 Self-control

Self-control refers to the process of sustaining concentration and interest by means of self-regulatory strategies. These strategies can be grouped as metacognitive strategies (task strategies, self-instruction, imagery, time management, environmental structuring, help-seeking) and motivational strategies (interest incentives and self-consequences) (Panadero & Alonso-Tapia, 2014).

Students develop and implement specific strategies for specific aspects of a task in order to promote their own learning (Zimmerman & Moylan, 2009). For example, reducing a task to its meaningful parts (Zimmerman, 2000) or identifying the underlying important parts of a text in order to focus on those sentences in subsequent readings of the same text (Panadero & Alonso-Tapia, 2014) are examples of SRL strategies that are task-specific.

Self-instruction is a self-control strategy that includes overt or covert orders about the ways of maintaining the task (Zimmerman, 2000). For instance, a student can ask herself questions about a text that she reads (Zimmerman & Moylan, 2009), or she can speak aloud the steps that she will follow in a mathematics problem-solving exercise (Zimmerman & Campillo, 2003). According to Schunk (1982), verbalizations can contribute to students' learning, but their effectiveness depends on their application and quality (Zimmerman & Moylan, 2009).

Imagery is the use of mental images, such as tree diagrams, concept maps, and flow charts, to facilitate learning and organize information in the learning task (Panadero & Alonso-Tapia, 2014; Zimmerman & Moylan, 2009). Consequently, students who use imagery as a self-control strategy to encode verbal or textual information into a non-verbal format can facilitate the retrieval of encoded information (Zimmerman & Moylan, 2009). According to Panadero and Alonso-Tapia (2014), this strategy also increases students' interest by enhancing their visual representation of the situation.

In order to complete the learning task within the allotted time, students must employ time management strategies while completing the task. A student can divide a task into smaller units and decide specific goals for each unit. Then, he schedules the necessary amount of time to complete each goal and monitors his progress towards these goals (Zimmerman & Moylan, 2009). For instance, in order to write a dissertation, a PhD candidate must identify a series of subgoals (Panadero & Alonso-Tapia, 2014).

Environmental structuring is a self-control technique for students that refers to the development of an efficient learning environment. For instance, writing an article on a computer instead of on paper provides the writer with a more powerful environment because of the computer’s function of automatic spelling and grammar checking (Zimmerman & Moylan, 2009). Creating an effective learning environment also maintains students’ concentration on the task. For example, a student can select a less talkative desk mate or prepare all the required learning materials before the lesson. These kinds of strategies prevent students' potential distractions from learning, so they can contribute to their performance on the task (Panadero & Alonso-Tapia, 2014).

Help seeking is a self-control strategy whereby students request assistance from others in order to complete a task (Zimmerman & Moylan, 2009). For instance, a student's request for the teacher's assistance in solving a math problem is an example of a help-seeking strategy to complete a task. The most important aspect of seeking assistance as a self-regulation strategy is its contribution to students' learning. If a student refrains from performing a task and asks another person to carry out the task instead of him, it cannot be claimed as a self-regulation strategy, as this behavior does not provide additional support to the student's performance and learning (Panadero & Alonso-Tapia, 2014). Since students interact with others to get their advice about how to proceed with the task, help seeking can be considered “a social form of information seeking” (Zimmerman & Moylan, 2009, p. 303).

Interest incentives and self-consequences are motivational self-control methods (Zimmerman & Moylan, 2009). Students use some incentives to encourage their interest in the task (Panadero & Alonso-Tapia, 2014). For instance, learning new words in a foreign language by competing with others can make the task more attractive and increase students’ interest (Zimmerman & Moylan, 2009). Students also use self-consequences as a strategy for self-control to advance in the task. The self-consequences strategy includes rewarding and praising oneself (Zimmerman & Moylan, 2009). For instance, responding to online messages after completing a portion of a learning task is an example of a self-consequences strategy that increases learner engagement and facilitates task progression (Panadero & Alonso-Tapia, 2014).

It is important to underline that “this list of self-control methods is illustrative rather than exhaustive” (Zimmerman & Moylan, 2009, p. 303). Thus, this list provides us with “the range of self-regulatory strategies that have been used to enhance students’ learning and performance of academic and non-academic skills” (Zimmerman & Moylan, 2009, p. 303).

2.2.2.2 Self-observation

Self-observation refers to a student's tracking of his or her own performance while completing a task (Zimmerman, 2000). Self-observation has a crucial role in students' effective use of self-control strategies because adaptation of those strategies depends on students' performance during the task (Zimmerman & Moylan, 2009). In the self-observation process, students gain insight into their performance and determine whether it is adequate or not. As a result, they decide whether to continue or alter the task process (Panadero & Alonso-Tapia, 2014). Metacognitive monitoring and self-recording are two key forms of self-observation (Zimmerman & Moylan, 2009).

Metacognitive monitoring (or self-monitoring) is an individual's monitoring of his or her own learning processes (Zimmerman & Moylan, 2009). According to Panadero and Alonso-Tapia's (2014) inference, metacognitive monitoring includes similar processes as self-assessment. Unlike self-assessment, which focuses on the outcome of a task, metacognitive monitoring assesses the process as it is being performed using previously established criteria.

The second form of self-observation is self-recording, in which students use formally produced records of their learning processes. A graph that represents a student's errors in his essay is an example of a self-record (Zimmerman & Moylan, 2009). Self-recording provides students with more accurate, structured, and longer evidence of their learning processes and outcomes without obtrusive rehearsal (Zimmerman, 2000).

2.2.3 Self-reflection phase

In the self-reflection phase, students judge their learning outcomes, decide their success or failure, attribute their success or failure to some reasons, and experience some emotions about their work (Panadero & Alonso-Tapia, 2014). The self-reflection phase includes two processes: self-judgment and self-reaction (Zimmerman, 2000).

2.2.3.1 Self-judgment

Self-judgment is the process of assessing one’s own performance. There are two forms of self-judgment. One of these is self-evaluation, which is the process of assessing one's own performance by comparing it to a standard or a previously established goal (Zimmerman, 2000). Students can evaluate their work using four types of criteria: mastery, previous performance, normative, and collaborative. Mastery criteria involve hierarchical and specific performance steps. Comparing a puzzle solution to an expert's solution (Zimmerman & Campillo, 2003), English workbooks that are coded by their level of difficulty, and the seven-point system used for grading tennis players (Zimmerman, 2000) are examples of mastery criteria that provide students with a precise criterion for mastery. The second criterion is previous performance, which involves comparing the current performance to that of the past. For example, a person who has a hazardous habit such as smoking and wants to overcome it can judge his performance by comparing the number of cigarettes that he consumes each day (Zimmerman, 2000). A shortcoming of using previous performance criteria for students is the difficulty of remembering previous performance in the absence of records (Zimmerman & Campillo, 2003). Using normative criteria for self-evaluation entails social performance comparison. For example, an athlete takes home a gold medal if he finishes first at the Olympics. The evaluation of his performance is dependent on others' performances. Thus, using normative criteria for self-evaluation is competitive in nature (Zimmerman, 2000). One of the two disadvantages of using normative criteria is that it places an emphasis on social factors, which may distract from the task. Secondly, social comparisons generally underline negative features of performance. For example, a student can get the second-best score in a competition, but he still loses the competition. This can result in a negative self-evaluation of his performance, even if he has improved over his previous performance (Zimmerman & Campillo, 2003). Lastly, a collaborative criterion is used to evaluate the work of a team. In a team, everyone has a unique role, and their success is evaluated by the degree to which they accomplish their own goals and by how well they cooperate with team members (Zimmerman, 2000).

The second form of self-judgment is causal attribution about the outcomes of the learning process. A poor performance can be attributed to either a lack of required ability or a lack of required effort (Zimmerman, 2000). Causal attributions are critiqued in the self-reflection process. A student can attribute her failure to uncontrollable (e.g., ability, talent) or controllable (e.g., effort, learning strategies) factors. Since uncontrollable factors are immutable, students who attribute their poor performance to their inability are less likely to exert effort to improve their performance. Students who believe that their poor performance is due to their use of ineffective strategies, on the other hand, attempt to improve their performance by testing additional strategies (Zimmerman, 2000; Zimmerman & Moylan, 2009). Zimmerman and Campillo (2003) emphasized that while the causal attributions of poorly self-regulated learners are oriented toward uncontrollable factors, those of highly self-regulated learners are oriented toward controllable factors.

2.2.3.2 Self-reaction

Students' self-evaluations and attributions are related to their self-reactions (Zimmerman, 2000). Students demonstrate emotional and cognitive responses to their attributions during the self-regulatory process of self-reaction (Panadero & Alonso-Tapia, 2014). Self-satisfaction and adaptive or defensive decisions are two forms of self-reaction (Zimmerman & Moylan, 2009). Self-satisfaction means being satisfied or dissatisfied with one's own performance (Zimmerman, 2000). The second form of self-reaction is making adaptive or defensive decisions (Zimmerman & Moylan, 2009). A student who makes adaptive decisions is more likely to engage in similar tasks, employ similar strategies, and enhance her performance. In contrast, if a student makes defensive decisions, she avoids similar tasks in order to avoid failing again. As a result of her defensive decisions, this student loses interest, experiences feelings of helplessness, and delays her responsibilities (Panadero & Alonso-Tapia, 2014; Zimmerman & Moylan, 2009).

In summary, Zimmerman's (2000) social cognitive model of SRL is cyclical in nature. Thus, self-regulatory processes are interdependent with each other (Zimmerman & Moylan, 2009). For example, if a student is not satisfied with her performance but makes adaptive decisions such as trying new strategies, she will improve her motivational beliefs, set relevant goals, and select more effective strategies in the forethought phase of future tasks (Alonso-Tapia, 2005, as cited in Panadero & Alonso-Tapia, 2014).

2.3 Virtual reality

Virtual reality (VR) can be described as "a mosaic of technologies that support the creation of synthetic, highly interactive, three-dimensional (3D) spatial environments that represent real or non-real situations" (Mikropoulos & Natsis, 2011, p. 769). The main characteristics of VR environments are presence (Chen & Hsu, 2020; Witmer & Singer, 1998), interactivity (Makransky et al., 2020), and immersion (Buttussi & Chittaro, 2018; Chen & Hsu, 2020). Presence means “the subjective experience of being in one place or environment, even when one is physically situated in another” (Witmer & Singer, 1998, p. 225). Interactivity is a technical affordance of VR (Makransky et al., 2020) that fosters a sense of control and agency in users (Sawyer et al., 2017). Immersion (display fidelity) is an objective property of a virtual reality (VR) system that represents the realism provided by the VR system (Buttussi & Chittaro, 2018). Depending on the level of immersion offered to users, virtual reality environments can vary (Makransky & Petersen, 2021). Three displays offer a virtual reality (VR) experience: the head-mounted display (HMD), the cave automatic virtual environment (CAVE), and the desktop computer display (Makransky & Petersen, 2021). What distinguishes these environments are their immersive qualities, such as resolution of head tracing, the dimension of the vision, the level of users’ head rotation freedom, image quality, sound quality, and the capability of shutting out the external world (Cummings & Bailensoni, 2015; Parong & Mayer, 2020). HMDs and CAVEs are regarded as highly immersive environments when compared to desktop computers (Makransky & Petersen, 2021), and they reveal a greater sense of presence (Parong & Mayer, 2020). While Samsung Gear VR and Google Cardboard provide users the low-cost VR experience with their mobile devices, HTC Vive and Oculus Quest have become accessible for users in recent years as highly immersive latest VR HMDs (Radianti et al., 2020). The decreasing costs and increasing capabilities of VR technologies not only made them accessible for educational settings (Parong & Mayer, 2020; Radianti, 2020), but also increased educational researchers' interest in this area (Makransky & Petersen, 2021). While approximately 400 articles on VR in education were published in 2010 (Makransky & Petersen, 2021), this number has increased to over 1200 by 2020.

2.3.1 Virtual reality in education

Some previous studies (e.g., Makransky et al., 2020; Parong & Mayer, 2020) used the term "immersive virtual reality" to describe VR technology that is experienced through HMDs. However, other studies (e.g., Collins et al., 2019) preferred the term "VR" to describe the same experience. In this study, "VR" will refer to a virtual experience that is highly immersive. High immersion is the term used to describe the state in which the user is entirely immersed in the virtual environment and is unaffected by to external influences (Mills & Noyes 1999).

There are two recent comprehensive reviews of VR in the literature, conducted by Wu et al. (2020) and Radianti et al. (2020). In their meta-analysis, Wu et al. (2020) analyzed 35 experimental and quasi-experimental studies in education to explore the effect of VR on learning when compared to less immersive desktop VR and traditional instruction. Simulations, serious games, and representations were categorized as the fundamental types of VR applications in education. In terms of learning performance, their research demonstrated that learning with VR is superior to other methods. However, they reported a small effect size for this difference. Compared to lectures and real-world practices, virtual reality was found to have a greater impact. Another remarkable finding of the study was that VR and desktop VR showed similar effects on learning for both simulations and representations, but not for serious games. While serious games in desktop VR had a significant effect on learning, VR did not show the same impact. According to Wu et al. (2020), a possible explanation for this result was a dearth of serious games for HMDs.

Radianti et al. (2020) examined VR applications in higher education in a recent review. They provided several key points regarding the use of virtual reality in higher education. Initially, 76% of higher education institutions utilized HMDs as the most popular VR technology. Second, the majority of studies (68%) did not explicitly mention any learning theories that guided the development of their VR content. 11% of the studies identified experiential learning as their theoretical basis. The third significant finding of the review was the absence of evaluation of student learning in VR studies. While half of the studies did not specifically measure any learning outcome, others mostly used questionnaires (22 %) and students' activities logged in the VR system (12 %) to evaluate users' outcomes. In addition, most of the studies only focused on usability of VR application instead of learning outcome. Lastly, procedural knowledge (34 %) and declarative knowledge (26 %) were the most frequent learning contents that VR applications intended to teach users. This finding showed a very limited focus on learning processes in VR studies. Radianti et al. (2020) recommended a pedagogical standpoint for future studies in addition to technical feasibility of VR application. This requires well-evaluated works which focus both on students' knowledge and skills, and their experiences as they interact with VR applications (Radianti et al., 2020). Radianti et al. (2020) also suggested employing both quantitative and qualitative research methods for a complete understanding of learning in VR. Therefore, this study aims at deeper exploration of students' SRL processes and strategies in a VR learning environment by using strengths of both quantitative and qualitative research methods.

Parong and Mayer (2020) compared learning with VR and PowerPoint slide presentations as instructional media. They also examined affective and cognitive factors that foster learning in these learning environments. Affective processes included self-reported measures of presence, affective state, enjoyment, and motivation in addition to biometric measures of electrodermal activity (EDA), heart rate (HR), and heart rate variability (HRV). Cognitive processes were assessed based on self-reported cognitive load and electroencephalograms (EEG) measuring brain activity. Retention and transfer tests were used to assess learning outcomes. The main finding of the study was the poorer performance of the VR group when compared with the PowerPoint slide group. The VR group also showed less engagement, more cognitive load, and higher emotional arousal. For future research, they suggested comparing virtual reality environments with learning environments that are more comparable in terms of graphics and script. Another important point to consider in designing a study with VR is the novelty effect, which indicates that using new technological equipment like HMDs and controllers may lead to poorer performance (Parong & Mayer, 2020). Thus, this study aims at introducing students to a VR environment that includes two modules. The aim of the first module will be to make students familiar with the VR environment and VR equipment; in this way, it is expected to decrease students' novelty towards VR and its equipment before the second module, where actual learning and data collection will take place.

Makransky and Petersen (2019) highlighted the significance of extending a study beyond simply measuring learning outcomes, and they investigated why and how users learn in a VR environment. Using structural equation modeling, they focused on desktop VR simulation and investigated affective and cognitive processes that play a role in learning. Cognitive variables were cognitive benefits and reflective thinking, while affective variables were presence, enjoyment, control, and active learning. Outcome measures were motivation, self-efficacy, and learning (i.e., knowledge about genetics). Makransky and Petersen (2019) discovered affective and cognitive learning pathways in desktop VR. The affective path revealed that VR characteristics contributed to a sense of presence, which increased the outcome measures (i.e., motivation, self-efficacy, and learning). In addition, the cognitive path included VR features that contributed to usability and cognitive benefits, which led to self-efficacy and learning. The most significant limitation of Makransky and Petersen's (2019) research was that they utilized a less immersive virtual reality (VR) environment. That's why they recommended different versions of VR environments for future studies. In addition, they suggested using other instructional materials and combining self-report measures with objective measures (such as log files, EDA, eye tracking, and EEG) for a better understanding of learning in VR environments. Based on these suggestions, combining self-reported, observational, and physiological data sources is the objective of this study to investigate students' SRL processes and strategies in a VR environment.

Makransky et al. (2020) compared VR and video recording for an optimal use of VR. Their study with two experiments showed the importance of ways to integrate VR into regular classroom activities. In the first experiment, although the VR group demonstrated significantly greater presence and enjoyment than the video group, their knowledge scores did not differ significantly from those of the video group. However, when enactment (an activity with tangible objects) was added to experiment 2 as a generative learning strategy, the VR and enactment group performed better than the other groups on the procedural knowledge and transfer test. Makransky et al. (2020) stated that learning with VR may be difficult for users due to increased extraneous processing due to sounds and visual objects, as well as increased student agency. When utilizing VR to learn, students may have trouble selecting and organizing pertinent information. Thus, learners may not easily monitor and regulate their learning in a VR environment. Therefore, Makransky et al. (2020) suggested encouraging learners to reflect on their learning with some strategies such as summarizing and enactment. Consequently, users were able to regulate their affective, cognitive, and metacognitive processes while learning in a VR environment. In addition, they suggested using log files and psychophysiological measures in future research to gain a deeper understanding of how users learn in VR and video.

The cognitive affective model of immersive learning (CAMIL) framework was developed by Makransky and Petersen (2021) to describe how people learn in a virtual reality (VR) environment based on existing research on immersive learning. Their framework is shown in Figure 2. Presence and agency are two VR affordances that influence six cognitive and affective processes that play a role in learning with VR. Interest, intrinsic motivation, self-efficacy, embodiment, cognitive load, and self-regulation are significant determinants of learning outcomes in VR environments. CAMIL hypothesizes all relationships in the model clearly except paths 15 and 16, which are related to self-regulation. These paths are dependent on the instructional design of VR lessons. These paths may be negative in two situations. Initially, the presence and agency affordances of virtual reality require learners to engage in cognitively demanding tasks. In VR environments, students may experience higher cognitive load because of the higher amounts of sensory information (Makransky et al., 2021). If learners are not supported in a VR learning environment, it is more challenging to monitor their affective, cognitive, metacognitive, and motivational learning processes. Secondly, learners may focus on the fun aspects of VR. Even if this results in increased interest and enjoyment, learners may not employ appropriate learning strategies in the VR environment. On the contrary, paths 15 and 16 may be positive (Makransky & Petersen, 2021). For instance, VR learning environments provide a high level of social presence, which may enable learners to increase their SRL processes by interacting with pedagogical agents or avatars. Additionally, more agencies may present an opportunity for facilitating SRL processes as learners assume responsibility for their own education.

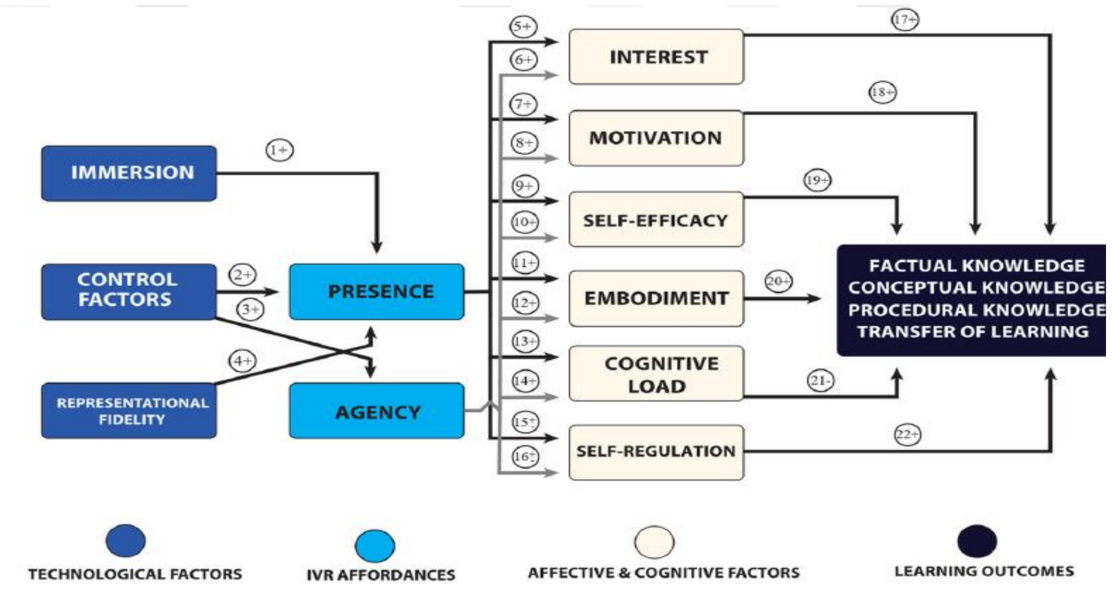


Figure 2. CAMIL framework

Adding some reflection activities (e.g., explaining learning tasks to an avatar or a real peer and summarizing what is learned) is one way of prompting learners to activate their SRL processes and strategies. In VR environments, learners' deeper processing should be supported by various interventions (Klingenberg et al., 2020; Makransky & Petersen, 2021; Parong & Mayer, 2018). Due to the potential of SRL activities to promote essential processing in immersive learning (Makransky & Petersen, 2021), it is crucial to investigate the ways in which VR environments can support students' SRL processes and strategies.

2.3.2 Virtual reality and self-regulated learning

The number of studies focused on students’ self-regulation in immersive VR learning environments is quite low. One of them was conducted by Chen and Hsu (2020) in an English learning context. Chen and Hsu (2020) examined the effectiveness of a mobile game-based VR application for English learning by focusing on students' engagement and SRL. Their research revealed not only a significant increase in students' English proficiency but also an effect of mobile VR games on students' game engagement and SRL. Students' game engagement was enhanced by self-efficacy, intrinsic value, and test anxiety. Students were motivated to learn English and enjoyed engaging in VR activities, but they also encountered obstacles and negative emotions. Additionally, the VR environment had a moderate influence on students' SRL. VR characteristics such as immersion and presence affected students’ self-efficacy positively which increased their motivation to endeavor on difficulties and manage their learning in the VR environment. Students who reported higher self-efficacy were more inclined to use cognitive and metacognitive strategies as they dealt with English learning tasks in the VR environment. One of the key contentions of Chen and Hsu (2020) is the critical role of metacognitive strategies in students’ self-regulation of their English learning in game-based VR environments.

In another study, Sobocinski et al. (2023) explored pre-service teachers’ SRL processes in VR. They focused on metacognitive monitoring processes of pre-service teachers’ while learning exponential functions in a VR game called Pandemic by Prisms. Namely, Sobocinski et al. (2023) employed the same VR learning environment with this study. They measured pre-service teachers’ SRL processes with think-aloud protocols. They also utilized bird’s eye view video recordings to measure pre-service teachers’ movements and heart rate variability records to measure their cognitive load. Their findings showed that pre-service teachers' physical actions align with their pre-service teachers' monitoring processes. Specifically, changes in cognitive load predicted instances of metacognitive monitoring, and monitoring processes predicted pre-service teachers' physical actions within the VR environment. In sum, their study showed the interaction between how cognitive load, metacognitive monitoring, and physical movements within VR learning environments.

CHAPTER 3

METHODOLOGY

3.1 Research design

This study employed a qualitative case study design in an effort to better comprehend the SRL processes of high school students in a VR-based mathematics learning environment. Case study can be defined as “a qualitative approach in which the investigator explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audiovisual material, documents, and reports) and reports a case description and case themes” (Creswell, 2013, p. 97). In general, case studies offer researchers a deeper understanding of complex issues in their authentic context (Crowe et al., 2011); thus, researchers may investigate and portray a specific setting in order to enhance their comprehension of it (Cousin, 2005).

According to Yin (2018), the selection of a research method is contingent on three criteria: the nature of the research questions, the degree of control the researcher has over the behavioral events of individuals, and whether the research focuses on contemporary or historical events. Firstly, if researchers are interested in "how" or "why" questions, have little control over the behavioral events of individuals, and are focusing on a contemporary event, the case study method is an ideal choice (Yin, 2018). From this perspective, the case study approach was an appropriate choice for this study. One of the research questions that guided this study was a "how" question. The second research question is concerned with the environmental features that facilitate students’ SRL. It focuses on how the features of

VR-based learning environment give rise to specific SRL processes while students are working on the virtual tasks. In addition to “how” or “why” questions, open-ended “what” questions may be beneficial for case studies to explore the case in a more exhaustive way (Yıldırım & Şimşek, 2016). To answer the second “how” question, two “what” questions were needed to be answered. The goals of the “what” questions were to investigate the SRL processes that student employed in the VR learning environment. Thus, before exploring the environmental features that are conducive to the SRL processes, it was a requirement to detect the students’ SRL processes in this learning environment. In sum, the research questions that guided this study were appropriate for a case study design. Secondly, students were expected to complete a series of traditional learning tasks and VR tasks using a HMD in this study. The researcher could not manipulate participants’ behaviors, especially during their experiences in the VR learning environment. In other words, the researcher’s control over students’ actions was very limited in this learning environment. Lastly, this study focused on a a current issue in education. In mathematics education, learning a mathematical topic in a VR-based learning environment is an up to date question that will be investigated in a real-school context through the lens of Zimmerman’s (2000) SRL model. This is also suitable for the contemporary nature of the case study. In sum, this study focused on a contemporary educational issue by asking “how” and “what” questions about students’ SRL processes in a VR-based learning environment where the researcher’s control was very limited, and these characteristics made this study fit the case study design.

Researchers describe and analyze a bounded system (a single case) or multiple bounded systems (multiple cases) in detail in the case study (Cresswell, 2013; Merriam & Tisdell, 2015). Miles et al. (2014, p. 44) defined the case as “a phenomenon of some sort occurring in a bounded context." The case functions as an "integrated system" (Stake, 1995, p. 2). While individuals and programs are obviously potential case examples, events and processes are not (Stake, 1995). A researcher may decide an individual, a small group, an organization, a project, etc. to be the case (Yin, 2018). Namely, various "integrated systems" (Stake, 1995, p. 2) can be selected as cases in different disciplines. For instance, in medicine, a patient may be the case; in business research, a workshop may be the case; and a program, a school, a module, or a specific innovation may be selected as a case in education research (Cousin, 2005). An immersive lesson, which is a specific innovative learning environment (a VR-based learning environment), was selected as the case for this study.

It is important to describe the case and its boundaries by stating specific parameters such as time and place (Creswell, 2013); physical borders; population; range of activities; and time span (Cousin, 2009). Figure 3 is the graphical representation of Miles et al.'s (2014) definition of the case, where the heart symbolizes the focus of the study and dashed lines show the limits of the case. The phenomenon of a case study may be an individual described with contextual boundaries in some situations. For instance, a teacher may be the heart of a case study that is bound to her students, school setting, and time (Miles et al., 2014). Given the purpose of the study, the research question that guided this study, and the research site, the heart of this study is the immersive lesson. I set the boundaries of the case in terms of the following dimensions: activities included in the immersive lesson, the population that the case pertained to, and the time period during which the immersive lesson was applied. Firstly, this case was bounded by a variety of activities. The immersive lesson included a set of traditional learning activities that were designed to facilitate students’ self-regulation and a VR learning environment that is composed of a set of virtual learning tasks. Students were expected to complete these traditional and virtual learning activities in this study. This case was bounded by the learning activities incorporated into the immersive lesson. Secondly, this case was bounded by the population who are concerned about the case. The population is the possible users of the case due to the suitability of the subject matter presented in the case. The immersive lesson was designed by considering curricular objectives related to exponential functions. The curricular objectives are suitable for acquisition by high school students in the 11th and 12th grades. Therefore, the population that can be concerned about the case is 11th and 12th graders. Lastly, this case was also bounded by the time span. Students’ SRL processes in the VR environment and how the features of the immersive lesson give rise to students’ SRL processes were explored in this study. The implementation of the immersive lesson in the selected high school took one semester, and it took approximately two hours for each participant. As a result, the case had a time boundary that was the second semester of the academic year 2022–2023 for the entire group and two hours on average for each participant.

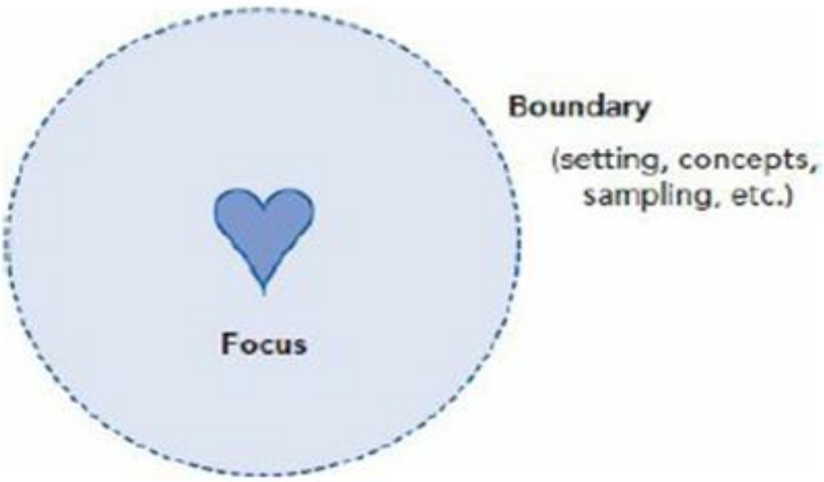


Figure 3. The case and its boundary (Miles et al., 2014, p.28)

According to Baxter and Jack (2008), a researcher must decide what type of case study best fits the research's purpose. Stake (2005) identified three types of case studies: intrinsic, instrumental, and collective. The basic intent of a researcher in an intrinsic case study is to gain a deeper understanding of a specific case, such as a specific child, curriculum, program, etc. In an intrinsic case study, the researcher is not primarily interested in developing a theory or investigating a general phenomenon. The case is dominant in an intrinsic case study, and the researcher gives the utmost significance to the case itself (Stake, 1995). To thoroughly comprehend a particular issue or phenomenon, Stake (2005) suggests conducting an instrumental case study. If the researcher has a research question and wants to build up an understanding of the question, he/she may expect to answer the question by focusing on a specific case. In this situation, the primary purpose of the researcher is not to understand this specific case; it is to understand something else (Stake, 1995). "Case study here is instrumental to accomplishing something other than understanding the particular case" (Stake, 1995, p. 3). Stake (1995) underlined the importance of issues in instrumental case studies. Issues are dominant, and the researcher begins and finishes his/her study with the issues. The researcher chooses a case as an instance in action to explore selected issues (Bassey, 1999). Even if issues are not easy to define due to their "complexity and contextuality" (Stake, 1995, p. 16), they "can be good research questions for organizing a case study" (Stake, 1995, p. 17). Although the case is of secondary interest and has a supportive role in an instrumental case study, researchers are required to examine the case's context and activities involved in it in a detailed way to trace the main interest. Researchers may gain insight into a specific phenomenon or contribute to a theory by means of an instrumental case study. Researchers can extend an instrumental case study to a few cases; Stake (2005) identifies this approach as a collective (multiple) case study, which is also used for detailed investigation of a particular phenomenon. The reason why a few cases are preferred instead of one is for a better understanding of the phenomenon of interest or a better contribution to the theory by comparing findings with cases.

The starting point of this study is the educational issue of students' learning in VR learning environments in general. Related studies did not report the positive effect of VR on learners' performance (Wu et al., 2020) when compared to other multimedia instructions such as video (Makransky et al., 2020) or PowerPoint (Parong and Mayer, 2020). Even if students' use of self-regulation may facilitate students' learning in VR, this depends on the design and implementation of the immersive lesson. Therefore, as a complicated framework, more research on SRL is recommended to understand the learning mechanisms of students in VR learning environments (Makransky & Petersen, 2021). Thus, the focus of this study was sharpened based on the related studies about students' learning in VR. The issues that guided the onset of this study were understanding the learning mechanisms of students in a VR learning environment from the perspective of the SRL framework and supporting students' SRL through a set of instructional activities. "Issue questions or issue statements provide a powerful conceptual structure for organizing the study of a case" (Stake, 1995, p. 17). This study investigated high school students' SRL processes in a VR learning environment through the lens of Zimmerman's (2000) social cognitive model of SRL and explored how the design of the immersive lesson (the case) supported students' SRL processes. In sum, the issues were dominant in this study, and the selected case served to comprehend the issues rather than the case itself. Since this feature is proper to Stake's (1995) classification, this study can be classified as an instrumental case study.

3.2 Research site

The research site in this study was selected purposefully, which is a common practice in case studies (Baxter & Jack, 2010; Hancock & Algozzetti, 2006). Three criteria were determined before deciding on the research site. Firstly, the case in this study is an immersive lesson about exponential functions. Since the language of the VR learning environment was English, accessing a high school that has students with adequate English language skills was a necessity in order to collect meaningful data from participants. Therefore, selecting an Anatolian high school was a suitable choice because of the number of English courses in their programs. Secondly, the physical location of the research site was an important criterion for this study. For this research, a pilot study was conducted before the data collection to make decisions about the design of the immersive lesson and the suitability of the students at the selected high school. In the pilot study, students were invited to Boğaziçi University's VR laboratory. Thus, the research site, whose location was closer to the university, would make access easier for the participants to the VR laboratory. In addition, selecting a high school that was close to the university enabled me to easily carry VR equipment to the high school while carrying out the main study. Thirdly, Stake (1995, p. 57) pointed out that "almost always, data gathering is done on somebody's home grounds," and people may not be so willing to permit a researcher to be present in their own environment. Thus, the last criterion was securing a collaborator on the research site to be able to access participants easily throughout the study.

A high school with a strong EFL program was selected as the research site based on the criteria as stated in the previous paragraph. I first contacted one of the teachers (the contact person) in the school. The contact person was the school counselor, and she was my friend's colleague. Then, I met with the school principal. In line with Stake's (1995) suggestions, I shared the legal permissions for the study (from the provincial directorate for national education and the university's ethical committee), my plans for the study, and the learning materials for the immersive lesson. They informed me about the school and the students. The school principal approved my collaboration with the school counselor during the study.

Due to the language requirements of the chosen virtual reality environment, which could have a direct impact on data quality, I informed the school counselor and principal of my intention to conduct a pilot study prior to commencing data collection. Upon their approval, I worked with five participants in the pilot study in the first semester of the 2022-2023 academic year. My pilot study demonstrated that this school and its students were appropriate for my intended purpose of collecting data from a suitable group of individuals. They could manage their work in the VR learning environment without major difficulties. Language did not seem to be an obstacle for them. They were able to carry out the virtual tasks effortlessly, unaffected by any language barriers within the game.

3.3 Participants

The study included 11^{th} grade students from a high school in Istanbul as participants. The choice of 11^{th} graders as participants in this study arises from two motives. The first one is about the curricular objectives of the Turkish curriculum. "Exponential functions" is the mathematical focus of this study, and it is the initial topic of the 12^{th}

grade curriculum. This means that students are knowledgeable about exponential functions after the first week of the 12th grade. Since I intend to examine students' SRL in a VR environment as they learn a new topic, the highest possible grade level for target students could be 11th grade. The second reason relates to the intent to be practical. In Turkey, high school seniors are required to prepare for university entrance examinations. Therefore, it would be challenging to find willing participants at this grade level. In light of these considerations, selecting participants among 11th graders seemed both expedient and practical.

Participants in this study were selected based on the purposeful sampling method (Creswell, 2012; Fraenkel et al., 2012). In purposeful sampling, researchers intentionally select participants (Creswell, 2012). Utilizing a method of purposeful sampling to select participants is a common practice in case studies (Baxter & Jack, 2010; Hancock & Algozzetti, 2006). The objective of purposefully selecting participants was to conduct my study with a sample that had the potential to provide more pertinent data (Fraenkel et al., 2012) that I required to investigate my research questions.

The researchers are expected to make three decisions, which are about the participants, the sampling strategy, and the size of the sample (Creswell, 2013). The initial consideration of the researcher in the purposeful sampling approach is participant selection. Patton (2014) contends that the primary objective of all purposeful sampling strategies is to collect data from individuals who can offer valuable insights on the study's focus. In this study, two criteria guided the selection of participants. Since motivated participants are more inclined to share their experiences (Patton, 2014), the first criterion was studying with willing students. Thus, instead of studying with one of the classroom’s students from the high school, I tried to reach students from all classrooms who had an intrinsic interest in participating in this study. The second criterion was the students' proficiency in English. Even though a high school with an EFL program was selected as the research site, some students might not have been confident in their English listening or reading skills. The traditional learning materials were in Turkish, but the language of the VR learning environment was in English, necessitating an intermediate level of English proficiency to complete tasks comfortably. The participants were selected based on their willingness and proficiency in English.

Another consideration for the researcher in the purposeful sampling approach is the sampling strategy. Creswell (2013) described sixteen types of sampling strategies in qualitative research. Merriam (2009) outlined five common strategies used by qualitative researchers to select their sample: typical, unique, maximum variation, convenience, and snowball. Among these, snowball sampling was identified as the most prevalent type of purposeful sampling. In this study, snowball sampling was used to find “information-rich key informants” (Patton, 2014, p. 451). At the beginning of this study, I conducted a pilot study with five students. These initial five students were chosen in collaboration with the school counselor. The collaboration with the school counselor enabled me to reach participants appropriate to the criteria that were decided before starting the study because of the position of the school counselor. She was knowledgeable about all 11th graders since she had organized many activities such as workshops, training, and school trips for students. Thus, based on her suggestions, I contacted five students for the pilot study. These five students’ levels of English were above the intermediate level, and they shared their interest in new technological innovations such as VR. These students were key participants who were suitable for the participant selection criteria. I asked their opinions about reaching potential students who could provide rich information for this study after the interviews. I wanted to identify their friends who could proficiently complete the VR tasks without any language barriers. Thus, I had three names who could potentially participate in the study at the beginning of the main study. I shared these names with the school counselor. We talked to these students and informed them about the study. Subsequently, in the second semester, data collection commenced. Afterwards, the snowball got bigger as the participants offered their friends' names.

The third consideration for the researcher in the purposeful sampling approach is the size of the sample. Patton (2014) argues that there are no specific guidelines on the appropriate sample size to use in qualitative research. The sample size depends on a number of issues, such as the purpose of the study, the available resources, time constraints, credibility, etc. "With the same fixed resources and limited time, a researcher could study a specific set of experiences for a larger number of people (seeking breadth) or a more open range of experiences for a smaller number of people (seeking depth)" (Patton, 2014, p. 470). In this study, students experienced an immersive lesson. Their SRL processes and how this VR-based learning environment gave rise to SRL processes were explored. I focused on "a specific set of experiences" (Patton, 2014, p. 470), and it would be meaningful to increase the number of participants to get rich information about the research issues. Patton (2014) argued that advancements in qualitative data analysis software enabled researchers to manage the data of a larger number of participants in case studies and capture overall patterns in participants' experiences. In this study, MAXQDA was used as the qualitative data analysis software to organize, manage, and analyze the data. This software also made it possible for me to increase the sample size. Patton

(2014) discussed the emergent nature of qualitative studies. A qualitative researcher decides the number of minimum participants before starting the study, but she or he must be flexible about the actual sample size. If the collected data reaches saturation, the actual sample size can be smaller than the initial plan. If the amount of collected data per participant seems to be small, the actual sample size can be larger than the initial plan. In this study, the initial plan for the sample size was 10 because of the time constraints to collect data. The high school's administration let me collect data just on Fridays. Initially, my plan was to gather data from one or two students per day. Once data collection started, I discovered that I could increase number of participants per day. In addition, I also realized that some interviewees concluded semi-structured interviews that were shorter than I expected. Additionally, Mason (2010) reported that the mean sample size in qualitative case study dissertations was 36. In other words, researchers can prefer to increase the sample size in dissertations that use the case study approach. Thus, I decided to increase the number of participants from 10 to 20 as the study unfolded.

3.4 The immersive lesson (The VR-based learning environment)

The immersive lesson was the case in this instrumental case study. Figure 4 illustrates the immersive lesson. The immersive lesson was composed of four parts. While two of them offered students a VR experience, others were designed to support students' SRL in this immersive lesson.

VR Module 1 is the first part of the immersive lesson in which students were expected to perform a reasoning task. This module included a task describing how the virus spreads in various situations. Figure 5 represents an instance of VR Module 1, where the student observes the spread speeds of the virus in three different containment protocols. In addition, this module included a drag and drop type of question that focused on the spread of viruses in three distinct situations (see Appendix A).

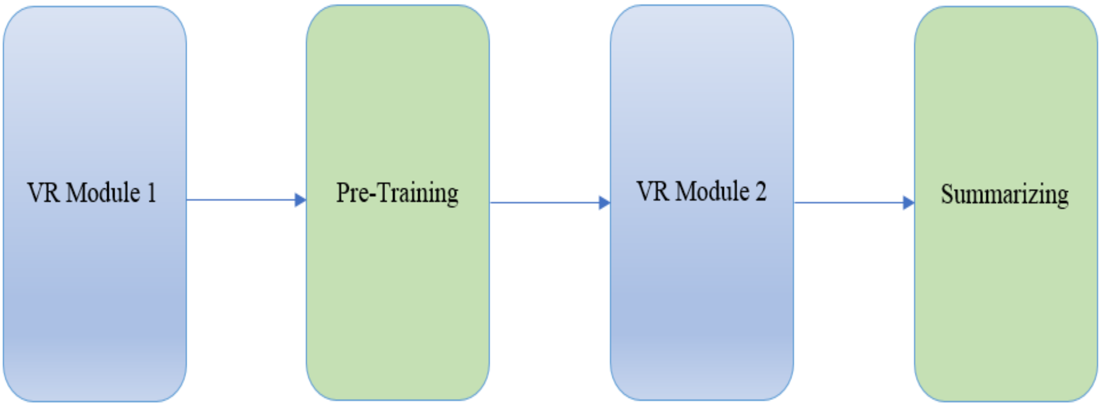


Figure 4. The flow of the immersive lesson

Figure 5. A screenshot of VR module 1

Pre-training is the second part of the immersive lesson. This part included three paper-based learning materials. The first one was prior knowledge activation material, which included brief descriptions of exponential numbers, linear functions, and the graph of a linear function. In a VR learning environment, students are expected to take control of their own learning. Students who possess adequate prior knowledge about the subject can guide their own learning (Kirschner et al., 2006). Thus, this learning material was designed to activate students' prior knowledge regarding exponential functions. The details of prior knowledge activation material are portrayed in Appendix C. The second and third pre-training materials were designed based on the pre-training principle, which asserts that students can learn deeply if they know the names and some features of the crucial concepts in a multimedia learning environment (Mayer & Pilegard, 2014). While the second learning material represented the Turkish translations of some significant concepts, the third learning material summarized the definition of the exponential function, the graph of an exponential function, and some graph types shown in VR Module 2.

The third part of the immersive lesson is VR Module 2, which is composed of four connected tasks. The first task was about a graphical representation of exponential growth. Students were expected to fill a table by considering an interactive bar graph and to solve a multiple-choice question in this task. The second task's focus was making a connection between exponential growth and exponential numbers. Students' duty was to fill a new table by using exponential numbers. Figure 6 represents an instance of this task where the student filled the table. The next task's goal was to write the exponential function based on the numbers in the filled table. Students were instructed to explore the difference between a linear function and an exponential function, and they were responsible for solving two multiple-choice questions to finish the third task. In the last task, students were requested to conduct a series of calculations and fill out a table. The aim of this task was to construct a new exponential relationship by using an existing one. A multiple-choice question was posed to students at the end of the last task.

The last part of the immersive lesson was summarizing, which was included in the immersive lesson as a generative learning strategy (Fiorella & Mayer, 2016). Students' reflection on their learning by summarizing can support deeper learning and promote students' self-regulation (Parong & Mayer, 2018). Thus, the summarizing material was designed based on what students experienced in VR Module 2. This learning material provided a step-by-step guide for the students. Students were able to summarize what they learned about exponential functions in VR Module 2. Appendix E represents a detailed description of the summarizing material.

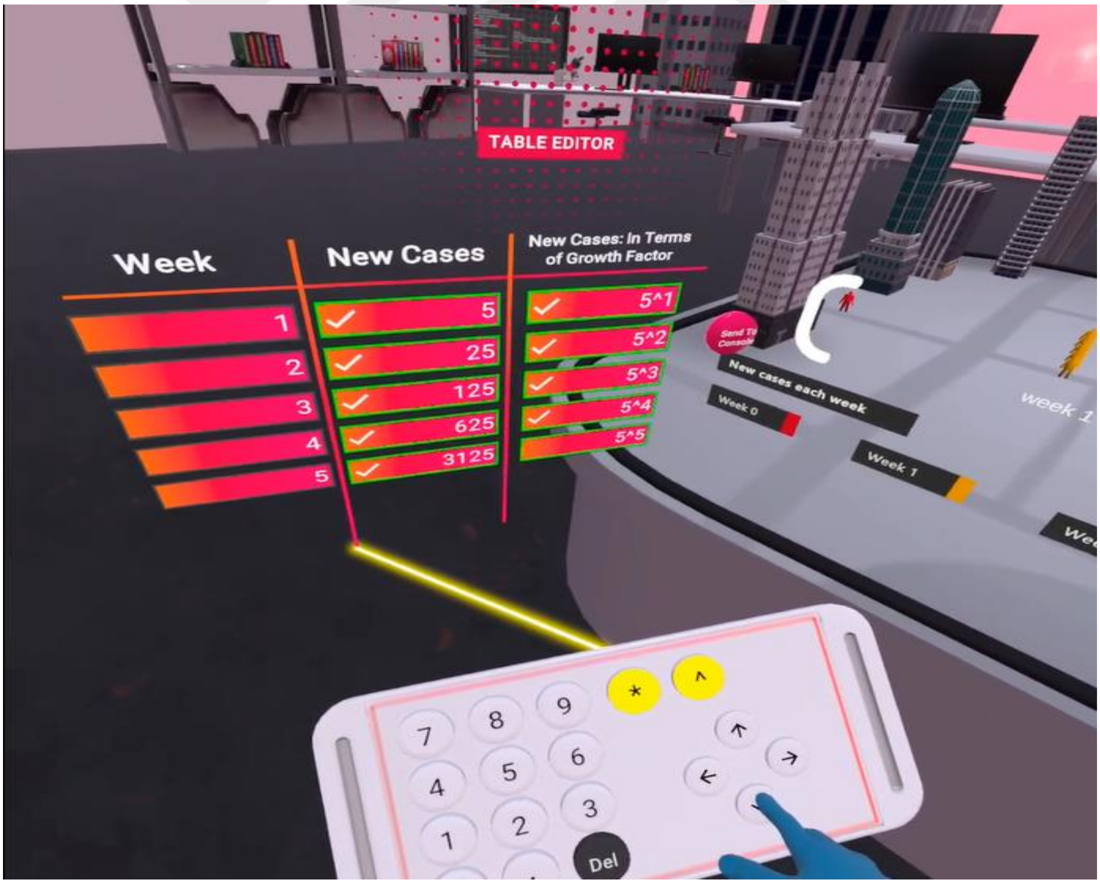


Figure 6. A screenshot of VR module 2

3.5 Instrumentation

One of the characteristics of case study research is using multiple data sources, such as interviews, audiovisual materials, and observations, to investigate the phenomenon holistically (Baxter & Jack, 2008; Creswell, 2007). Synchronizing and triangulating multiple data sources enables researchers to explore “the situated nature of regulation as it unfolds in response to challenging situations" (Hadwin, 2020, p. 3). Self-reported and observational data sources were used in this instrumental case study for a comprehensive understanding of the issue. Self-reported data were collected by verbal think-aloud protocols and stimulated recall interviews. Screen recordings of participants served as the source of observational data.

3.5.1 Think-aloud protocols

Students’ SRL processes in the VR learning environment were captured using think-aloud protocols in this study. Veenman (2005) classified think-aloud protocols as an online method by which researchers can measure students’ SRL processes concurrently with learning. Participants are requested to talk continuously as learning takes place in the think-aloud method (Bannert & Mengelkamp, 2008). Measuring participants’ SRL by means of think-aloud protocols is one of the process-oriented methods (Azevedo, 2020). Zimmerman’s (2000) approach describes SRL as a dynamic process that unfolds over time, stages, and tasks, and this approach guided this study. The dynamic processing of SRL can be captured moment by moment as it occurs in learning by means of think aloud protocols (Greene et al., 2018). Consequently, the use of the think-aloud protocols as a data collection method was appropriate in light of the theoretical model of SRL chosen for this study. The purpose of the think-aloud protocols was to capture the SRL processing of the participants as they completed the VR learning task.

Greene et al. (2018) suggested three methods to the researchers that can be used in data gathering with think-aloud protocols. The first one is about the design of the research environment and instructing the participants to think-aloud. The research environment should be free of distractions, allowing participants to complete learning tasks without interaction with researchers. In line with Greene et al.'s (2018) recommendations, the research environment was set up in an empty classroom at the high school for this study. There were only the researcher and one participant in the room during the data collection process. Participants were also able to complete VR learning tasks without any need to interact with the researcher, since the VR learning environment could provide support when it was required. Based on Greene et al. 's (2018) suggestions, clear instructions were given to the participants before the data collection. The participants were instructed to verbalize their thoughts and actions as if they were conversing with themselves. They were instructed to avoid pausing their conversation for longer than five seconds, as they would be warned to continue talking. Greene et al. (2018) also recommend that participants practice how to verbalize their thoughts. They contend that participants require practice to become acquainted with not only verbalizing their thoughts but also contextual factors like tools and the learning setting. Thus, this study implemented think-aloud training. Participants were provided with a good example of thinking aloud. Participants viewed a two-minute video of a student engaging in thinking aloud within the VR learning environment at the start of the study. Then, the participants practiced thinking aloud in Module 1 of the Pandemic by Prisms. This practice also ensured gaining experience with the VR tools, such as controllers, and the VR learning environment itself. Greene et al. (2018) proposed prompting students during learning tasks when they cease speaking. As a result, if they did not express their thoughts verbally for more than five seconds, the participants heard the phrase "keep talking."

3.5.2 Screen-recordings

Observation is one of the crucial tools for gathering data in qualitative research (Creswell, 2013). Observation of students during the learning process is a way of identifying students’ SRL processes (Schunk & Greene, 2018). Observation methods enable researchers to accurately depict students’ environments and behaviors within those environments. Specifically, students' involvement in learning activities can be examined through detailed descriptions of the context. These contextually rich data can enable researchers to explore students’ SRL processes in a detailed way (Patrick & Middleton, 2002). In this study, the source of observational data is screen recordings of participants in the VR environment. Hadwin (2020) identified screen recordings as an observational data channel source for SRL research. For instance, Engelmann and Bannert (2020) combined screen recordings with think-aloud data to conduct a comprehensive analysis of SRL processes in a hypermedia learning environment. Moreover, triangulating different types of data improves the accuracy of qualitative research studies (Creswell, 2012). The study collected screen-recordings to capture participants' naturalistic engagement with the task and analyzed them along with think-aloud data to gain a comprehensive understanding of participants' SRL processes during VR learning tasks. Creswell (2013) emphasized the significance of research questions in determining what to observe. Patrick and Middleton (2002) argued that researchers can answer what and how questions by using rich and contextual observation data. One what type of and one how type of research questions guided this study. Screen recordings were recorded as video files. These video files provided not only students’ actions in the VR environment but also rich information about the contextual elements of the VR environment.

In sum, observation data were used to capture both students’ SRL processes and the contextual elements that give rise to those SRL processes.

3.5.3 Semi-structured interviews

Even though observations provide valuable information about students’ actions and context, they provide little understanding of how students interpret events in the learning environment. Interviews can enhance observations by enabling students to elucidate events and experiences using their own viewpoints (Patrick & Middleton, 2002). As one of the fundamental methods of data collection in qualitative research, interviews provide valuable information about the participants' experiences relating to the phenomenon under investigation (Creswell, 2013).

In this study, semi-structured interviews, which included a stimulated recall part, were used to gain insight into the participants' learning experiences. Initially, the participants were asked seven semi-structured interview questions, as outlined in Table 1. The purpose of a semi-structured interview is “obtaining descriptions of the life world of the interviewee in order to interpret the meaning of the described phenomena” (Kvale & Brinkmann, 2015, p. 6). The interviewer has a chance to develop a dialogue with the interviewee by focusing on important issues for the study (Kvale & Brinkmann, 2015). Participants' use of SRL processes while learning in a VR environment was this study's main concern. The purpose of the first five questions was to find out how participants perceived their use of SRL processes. These interview questions were developed in conjunction with the phases of

Zimmerman's (2000) cyclical model of SRL. While the sixth question focused on the participants' general perceptions of VR, the final question sought to ascertain their perspectives on the immersive lesson as a whole, which included both traditional learning materials and the VR tasks. Following the semi-structured interview questions, a stimulated recall interview was carried out with each participant.

Table 1. The Focus of Interview Questions

Interview Questions	Focus
1) What have you enjoyed the most and least about the VR task?	Task Interest/Value (Forethought Phase)
2) What goals did you set for yourself at the onset of this task?	Goal Setting (Forethought Phase)
3) Have you used any particular strategy to enhance your learning during the task? Can you give an example?	Self-Control Strategies (Performance Phase)
4) Did you check your progress while you were working on the VR task? How?	Monitoring (Performance Phase)
5) How did you help yourself learn or understand during the task?	Evaluation (Self-reflection Phase)
6) What aspects of VR did you find challenging, and why?	General VR Perception
7) What do you think about the tasks that you completed before and after the VR task? Did they contribute to your learning? If so, how?	Support Materials Value

Stimulated recall is one of the introspective research methods that enables the examination of learning processes by asking people to remember and describe their thoughts during a specific event shown in a video (Lyle, 2003). In the stimulated recall part, critical moments of learning in the VR environment were shown to the students, and they were requested to explain their thinking at those moments. I chose critical moments based on the challenging situations students faced in the VR environment. Challenging situations such as obstacles, complexities, or uncertainties refer to circumstances that require students to apply significant cognitive effort and persistence to progress in the virtual tasks. The reason why challenging situations were used for stimulated recall is their potential to induce students to engage in SRL processes (Hadwin et al., 2018).

3.6 Research flow and data collection

Table 2 summarizes the research questions, data collection, and analysis methods, while Figure 7 shows the research flow. The study included twenty-two 11th-grade students from a high school in Istanbul. Table 3 displays pseudonyms of students, the dates of data collection for each student, along with the durations of their VR task performance and interviews. Two students' data, however, was omitted from this study. While one of the students could not finish the VR task due to a problem with her contact lens, the other student restarted VR Module 2 because of some technical problems. Consequently, the data of twenty students was included in this study.

The data collection process was completed at the site of the high school. One of the classrooms was re-designed in a way that students could easily experience the immersive lesson. Students could safely move around in the room during the learning in the VR environment because of the empty space arranged in the classroom. In addition, they could complete traditional learning materials on a desk prepared for their use. Before participating in the study, students were informed about the research, its purpose, and its context through direct contact with the students. In addition, a parental consent form was requested before students' involvement in the study.

Each participant participated in the study one-by-one. As it was shown in Figure 7, students were expected to complete six steps in this study, and data were collected at two of them (i.e., VR Module 2 and interview steps). Initially, participants were informed about the study through an informed consent form. They read and signed the consent form at the beginning of the study. As discussed before, it was expected that some participants might need some practice on how to think aloud (Greene et al., 2018). In the pilot study of this research, this requirement was also noticed. Some participants had difficulty sustaining verbalization as they were occupied with completing the VR learning tasks. Therefore, after signing the informed consent form, participants watched a two-minute video segment, which was chosen as a good example of thinking aloud. This video segment was recorded in Module 1 of the Pandemic by Prisms during a pre-service teacher's experience, and it was shown to the participants as a think-aloud training.

At the second step, participants experienced the VR environment with Module 1 of Pandemic by Prism. Since this step was used for making participants familiar with the VR equipment (novelty training) and verbalizing their thinking (think aloud training), data were not to be collected at this stage of the study. This step was used to help participants become acquainted with the VR environment, head-mounted display (HMD), and equipment. Becoming familiar with these tools is important, as being new to the VR environment and its tools can lead to increased extraneous load, reducing cognitive resources available for essential learning tasks, and potentially hindering student learning processes (Makransky et al., 2017; Parong & Mayer, 2020). Due to the possible novelty effect on learning in VR environments, participants were familiarized with the VR environment and equipment prior to the data collection. In this manner, I intended to standardize each student's exposure to virtual reality, and I considered eliminating all participant novelty with regard to the VR environment and tools. Following Greene et al.'s (2018) recommendation to collect detailed data, think-aloud practice was implemented using VR Module 1. Participants learned to articulate their thoughts while engaging in a learning activity using VR Module 1. The detailed description of VR Module 1 is given in the next section.

Table 2. Summary of Research Questions, Data Collection and Analysis Methods

Research Questions	Data Collection Method	Data Analysis
1. What are high-school students' SRL processes in a VR learning environment?	• Think-Aloud Protocol • Screen-Recordings • Interview	• Content Analysis
2. How is the VR-based learning environment conducive to students' SRL processes?	• Think-Aloud Protocol • Screen-Recordings • Interview	• Content Analysis

Table 3. Dates of Data Collection and Durations

Student	Date	VR_Module 1	VR_Module 2	Interview	Interview
Eray	17.03.2023	12	21	17.03.2023	16
Aylin	17.03.2023	3	30	17.03.2023	20
Erden	24.03.2023	12	25	24.03.2023	15
Yakup	24.03.2023	11	21	24.03.2023	15
Metin	24.03.2023	15	34	24.03.2023	23
Banu	07.04.2023	12	32	07.04.2023	22
Ezgi	07.04.2023	11	21	07.04.2023	12
Fatih	07.04.2023	15	28	07.04.2023	28
Demet	07.04.2023	12	32	07.04.2023	18
Aziz	28.04.2023	10	19	28.04.2023	15
Itır	28.04.2023	15	26	28.04.2023	17
Esra	05.05.2023	15	41	05.05.2023	19
Zerrin	05.05.2023	11	21	06.05.2023	15
Gülden	05.05.2023	14	30	05.05.2023	20
Didem	12.05.2023	14	24	12.05.2023	17
Bartu	26.05.2023	11	19	26.05.2023	16
Sude	26.05.2023	14	21	26.05.2023	19
Damla	26.05.2023	10	22	27.05.2023	11
Hakkı	02.06.2023	11	19	02.06.2023	16
Engin	02.06.2023	11	17	02.06.2023	10

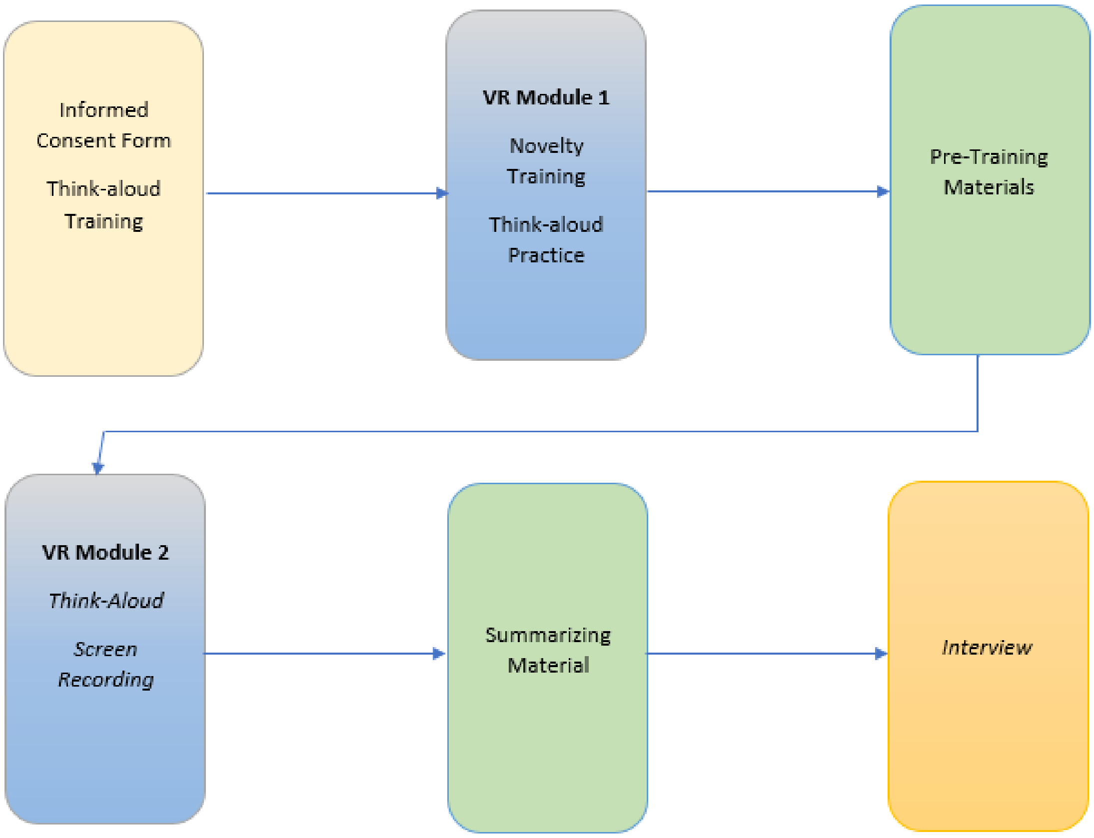


Figure 7. Research procedure and data collection process

At the third step of the study, participants engaged in a series of activities with pre-training materials. These activities contained three printed educational materials. One of them was prior knowledge activation material. The intent of this material was to activate students' prior knowledge about exponential functions. The aim of adding prior knowledge activation material was to support students' SRL processes. Self-regulated learners successfully search their memory for relevant prior knowledge in the planning phase of SRL (Pintrich, 2000). However, humans have limited capacity for working memory (Sweller et al., 2011). If students cannot reach relevant prior knowledge for engaging in a task, they cannot use most of the SRL processes because of their limited working memory capacity (Moos & Azevedo, 2008). Moos and Azevedo (2008) showed that students' prior knowledge is positively associated with their self-regulatory behaviors in a hypermedia learning environment. They argued that students' prior knowledge of the hypermedia is related to planning, monitoring, and strategy use. Given that the objective of VR Module 2 was to teach exponential functions, this material was designed to equip students with the prior knowledge required to learn exponential functions. Appendix C presents prior knowledge activation material. The second and third pre-training materials (see Appendix D) were designed based on the pre-training principle (Mayer & Pilegard, 2014). The primary concepts and terms related to exponential functions, as well as their characteristics, were included in the pre-training materials. The language of the VR environment is English. Although participants were selected by considering their proficiency in English, some of the participants did not know expressions such as steeper curve, shallower curve, etc. In fact, in the pilot study of this research, some students asked for help from me with the translation of some key concepts. This interaction with the researcher could disrupt their thinking aloud (Greene et al., 2018). Hence, participants in this study were given the Turkish translation of certain words through this second supplementary learning material. The third learning material included the definition of an exponential function and a visual representation of its graphs. These two materials were created to lessen the cognitive load for learners in the VR environment by introducing them to new concepts and terms prior to their VR experience.

After completing the pre-training materials, participants engaged in the fourth step of the study, which was VR Module 2 of Pandemic by Prism. VR module 2 included a series of tasks that aimed to teach exponential growth in a pandemic case. This was the part where exponential functions and their graphical representations were introduced, and two joint data collection tools were used. Data were collected through think-aloud protocols and screen recordings. In other words, both self-reported and observational data were collected simultaneously in VR Module 2. Students' verbalizations of their thinking while they were completing VR learning tasks were recorded at this step. Participants were requested to think aloud throughout VR Module 2. Their screens in the VR environment were also recorded as synchronous to the think-aloud data. This enabled me to establish a match between the verbal declarations of students and their corresponding actions within the VR environment. In other words, screen recordings recorded what a student did, while the think-aloud protocol captured what she or he thought. These two concurrent data sources enriched and supported the collected data.

Students were requested to make a summary of what they learned in VR Module 2 in the fifth step of the research. A summarizing material (see Appendix E) was designed to assist students in summarizing what they experienced in VR Module 2 by performing a variety of learning tasks. The aim was to provide students with opportunities to reflect on what they learned in the VR environment. Instructing students to generate explanations and articulate their ideas about what they study is one way to transform learning tasks by incorporating support mechanisms (Reiser & Tabak, 2014). Summarizing as a generative learning strategy (Fiorella & Mayer, 2016) provides students with opportunities to reflect on their learning and can facilitate their learning in VR (Parong & Mayer, 2018).

In the last stage of the research, interview data was collected on an online platform (Zoom). The reason for using an online platform for interviewing was to make use of the stimulated recall method "to relive an original situation with vividness and accuracy" (Bloom, 1953, p. 161) by means of cues from the original situation (Bloom, 1953, p. 161). After the first five steps of the research, I uploaded think-aloud and screen recording data to my computer. Then, I watched them by taking notes about the instances of challenging situations and the moments that the participants solved them. Thus, I determined timestamps that I would show students in the stimulated recall part of the interview. I utilized these video segments to prompt the participants to recall their experiences in the VR environment. Initially, a semi-structured interview was conducted with each participant to gain a deeper understanding of their VR experiences. I posed seven previously determined questions to the participants (see Table 1), but I also directed new questions based on the answers of the participants to understand their points of view in a more detailed way. Then, I shared my computer screen for the stimulated recall part of the interview. Participants' think-aloud data and screen recordings were used as stimuli to remind them of some prominent cases. Throughout the interview, video and audio recordings of participants were documented for analysis.

3.7 Data analysis

"The processes of data collection, data analysis, and report writing are not distinct steps in the process—they are interrelated and often go on simultaneously" (Creswell, 2013, p. 182). In this study, the data collection and analysis processes were intertwined, and they were carried out concurrently.

In this study, I investigated two research questions. While the first research question is about students' SRL processes in a VR learning environment, how the VR-based learning environment (VR tasks and traditional learning activities) gives rise to those SRL processes. Think-aloud protocols, screen recordings, and interviews were three data sources that were analyzed to answer research questions. To address each research question, two interrelated analyses were conducted through the application of content analysis (Patton, 2015). Patton (2015, p. 790) described content analysis as “any qualitative data reduction and sense-making effort that takes a volume of qualitative material and attempts to identify core consistencies and meanings. Case studies, for example, can be content analyzed.” Thus, in this instrumental case study, I used content analysis to systematically analyze self-reported (think aloud and interview) and observational (screen recording) data to identify patterns and themes.

Data analysis involved the application of both deductive and inductive approaches. The deductive approach involves the researcher having pre-established guiding constructions and propositions to investigate. The researcher assesses the extent to which the data corresponds with established findings and theories (Miles et al., 2015; Patton, 2015). The inductive approach involves segmenting data, classifying it with codes, checking for overlap or duplication, and then condensing these codes into overarching themes. This method allows researchers to develop new conceptualizations and explanations directly from the data (Patton, 2015).

The objective of the first research question is to explore which SRL processes students employ in the VR learning environment. An analysis of interview data, think-aloud data, and screen recording data has commenced by using a deductive approach. The process followed a coding scheme established in the EFG study, incorporating the social cognitive model of self-regulation (Zimmerman & Moylan, 2009), and relevant studies such as Azevedo et al. (2004) and Sonnenberg & Bannert (2015). In this study, data collection and analysis were conducted as a simultaneous process. Throughout the study, I imported all data into MAXQDA for analysis. In fact, the analysis of the data for this study commenced prior to the collection of the data from the main sample. As previously mentioned, this research study included a pilot study. I collected data from five students in the pilot study and analyzed their data. Therefore, at the beginning of the study, I had a code book that was constructed in the pilot study. “After or alongside this deductive phase of analysis, the researcher strives to look at the data afresh for undiscovered patterns and emergent understandings (inductive analysis)” (Patton, 2014, ğ. 793). Based on Patton’s (2014) suggestions, I looked and relooked at the data to see new emerging codes. When new codes emerged, I revisited the data to explore whether these new codes were apparent in the previous data. Thus, I revised the code book again and again as the new data came from the actual study. For instance, “observation-emulation” was a SRL process that students use in the VR environment. Students observed the pedagogical agent’s behaviors and imitated them for their own learning. This code emerged in the middle of the data analysis (the tenth student’s data), and I reanalyzed previous students’ data to see whether this SRL process existed in their learning too.

The second research question concerns the manner in which a VR-based learning environment (VR game and traditional learning activities) facilitates the SRL processes of students. Thus, I needed to answer the first research question to answer the second research question. Without identifying the instances when students engaged in SRL processes, it was not reasonable to identify the underlying mechanisms that gave rise to students’ SRL processes. Thus, data analysis for RQ 2 was started after reaching a certain maturity in answering RQ 1. More clearly, in the middle of the study (after collecting and analyzing the data of the tenth student), data analysis for RQ 2 started. The second research question was examined through an inductive approach, following Creswell's (2012) proposal. The six steps outlined below guided the data analysis:

- The interview data captured on audio was transcribed. For a comprehensive understanding of the data, I watched and listened to screen recording and thinking aloud data, read transcriptions of interview data, and took notes that represented my initial thoughts regarding the data.

- For preliminary analysis, four of the participants were chosen. I studied them while asking myself, “What are the mechanisms that give rise to SRL processes?”
- I commenced the process of data analysis by identifying and assigning unique codes to voice and screen segments (think aloud and screen recording data) and text segments (interview data).
- Upon completing the coding process for the entire dataset, an attempt was made to reduce the number of codes by grouping together those that were similar and excluding any that were deemed unnecessary.
- An initial codebook was organized. I revisited the complete dataset to apply the initial codebook to it. Based on the remaining sixteen participants' data, I attempted to ascertain whether any new codes had emerged.
- During this stage, the codes were classified into six categories. For categorizing data, codes that exhibited similar characteristics were chosen from among those that occurred most frequently.

3.8 Trustworthiness of the study

Trustworthiness in qualitative research is dependent on four criteria which are credibility, dependability, confirmability, and transferability of the research (Lincoln & Guba, 1985). Credibility means building “confidence in the truth of the findings of a particular inquiry for the subjects (respondents) with which and the context in which the inquiry was carried out” (Lincoln & Guba, 1985, p. 290). A qualitative study requires the research process and results to be transparent, coherent, and replicable by other researchers. The researcher needs to present evidence regarding the validity of the findings, their validity in similar contexts, the consistency of processes, and the objectivity of data collection and analysis (Yıldırım & Şimşek, 2016). I considered the credibility of this study in the following ways, prolonged engagement, peer debriefing, and triangulation (Lincoln & Guba, 1985). Prolonged engagement means having a long-term interaction with data sources. In this way, the researcher has the opportunity to confirm whether the collected data is periodic or not. Interaction time may vary depending on the nature of the research and the characteristics of the data sources (Yıldırım & Şimşek, 2016). Even if the nature of this study and types of data sources did not allow me to increase the amount of time for data collection for individual participants, I met with each participant one week before the data collection and conducted an informal conversation about their interests in innovative technologies and the study. The aim of this conversation was to create an environment of trust (Yıldırım & Şimşek, 2016). In addition, I extended the study over three months, which expanded my interaction with people on the research site. This enabled me to spontaneously get in touch with eleventh graders about my study. Some of them became participants in this study afterwards. These communications made students familiar with me before their participation in the study. Peer debriefing was the second technique that was used to facilitate credibility in this study. Peer debriefing means asking people who have general knowledge about the research topic and who are specialized in qualitative research methods to examine the research from various dimensions (Yıldırım & Şimşek, 2016). For this study, peer review was conducted through review meetings with an expert. In these meetings, raw data, analysis processes, and results were discussed. Expert feedback was taken into account when shaping the study. Triangulation was another method used to establish credibility in this study. Triangulation can be achieved through various sources, methods, researchers, and theories (Lincoln & Guba, 1985). To achieve triangulation, I used multiple modes of data collection. Self-reported data was collected through think-aloud protocols and semi-structured interviews. Observational data was collected through screen recordings. By using different data sources, I tried to confirm results coming from one data source by using other data sources.

Dependability is the second criterion for establishing trustworthiness in a qualitative study. Lincoln and Guba (1985) preferred the concept of dependability in qualitative research to the concept of reliability. There is an approach that accepts variability and can reflect this variability in research in a consistent manner in qualitative research for dependability. Dependability audit is the technique proposed by Erlandson et al. (1993). The aim of this technique is to examine the research from an outside perspective. I have prepared an audit trail file in MAXQDA that includes my personal notes that I used in data analysis. Thus, an external person may audit the data analysis process for dependability.

Confirmability is about constantly confirming the results reached with the data and offering a logical explanation to the reader (Yıldırım & Şimşek, 2016). An audit trail was suggested for establishing confirmability in qualitative research (Erlandson et al., 1993). In this study for the audit trail, raw data from interviews, think-aloud and screen recording data, the researcher's memos, and initial code books were stored.

Transferability is the last criterion for ensuring trustworthiness in qualitative research. Transferability refers to “determine the extent to which the findings of a particular inquiry have applicability in other contexts or with other subjects (respondents)?" (Lincoln & Guba, 1985, 290). As stated by Erlandson et al. (1993), a researcher is obliged to illustrate the applicability of the findings to analogous circumstances. Purposive sampling and detailed descriptions were proposed as means to enhance the transferability of the research to different contexts. I utilized both methods in this study to ensure transferability. Initially, this chapter provided a detailed description of the research site, participants, and case. Furthermore, the research site and participants were intentionally chosen, as detailed in the relevant sections.

CHAPTER 4

RESULTS

Two research questions guided this study. The initial research question focused on identifying SRL processes employed by high school students when studying a mathematics topic in a VR learning environment. The second question relates to the factors in the VR-based learning environment that are conducive to the emergence of those SRL processes. Results regarding these two research questions will be presented in this chapter.

4.1 Students' SRL processes in VR learning environment

The first research question that guided this study was "What are high school students' SRL processes in a VR learning environment?". To address this question, think-aloud, screen recording, and interview data were jointly analyzed by using content analysis with a deductive approach (Miles et al., 2015; Patton, 2015). Students used three main SRL processes in the VR learning environment (VR Module 2) as they were learning exponential functions, according to the findings of this instrumental case study. Task analysis, monitoring, and self-control strategies were categories that specified high-school students' SRL processes in the VR learning environment. Table 4 displays definitions of categories of SRL processes, and Table 5 shows minimum and maximum values, absolute frequencies, means and standard deviations of all coded SRL processes.

Table 4. Categories for SRL Processes

Category	Definition
Task Analysis	Breaking down a learning task into basic components, then creating an individualized plan based on the prior knowledge of these components (Winne & Hadwin, 1998)
Monitoring	"Informal mental tracking of one's performance processes and outcomes, such as one's learning processes and their effectiveness in producing learning" (Zimmerman & Moylan, 2009, p. 303)
Self-Control Strategies	Process of maintaining concentration and interest through strategies (Panadero & Alonso-Tapia, 2014)

4.1.1 Task analysis

Task analysis is an SRL process in the forethought phase of the social cognitive model of SRL (Zimmerman & Moylan, 2009), and it means breaking down a learning task and its context into individual components and formulating a personal approach based on prior knowledge about these components (Winne & Hadwin, 1998). Students engaged in task analysis processes in two ways, orientation and strategic planning, according to the results of this study. Table 6 demonstrates these sub-categories, their definitions and examples about task analysis processes. Findings about these sub-categories are presented in the following subsections.

Table 5. Absolute Frequencies and Means of all Coded SRL Processes

	Min	Max	Absolute Frequency	*M*	*SD*
Task Analysis	2	19	145	7.25	4.34
Orientation	2	18	126	6.30	4.18
Strategic Planning	0	5	19	0.95	1.32
Monitoring	3	31	265	13.25	7.14
Content Understanding	0	6	26	1.30	2.15
System and Task Understanding	0	17	99	4.95	4.21
Monitoring of Progress	0	9	54	2.70	2.47
Relying on System Feedback	0	9	65	3.25	2.57
Recognizing Errors	0	7	21	1.05	1.61
Self-Control Strategies	23	76	766	38.30	11.39
Elaboration	0	12	80	4.00	3.34
Reading	0	3	18	0.90	1.02
Environmental Structuring	0	7	57	2.85	2.16
Calculation	0	5	28	1.40	1.50
Mental Operation	0	7	59	2.95	1.47
Task Solution	0	8	96	4.80	1.88
Searching	0	7	46	2.30	1.81
Self-instruction	0	12	80	4.00	3.40
Help-seeking	0	6	49	2.45	1.76
Interacting with Tables and Graphs	1	19	111	5.55	3.87
Drawing	0	7	53	2.65	1.95
Trial-Error	0	8	56	2.80	2.84
Observation-Emulation	0	4	33	1.65	1.31
Sum all Coded SRL Processes	30	116	1176	58.80	18.26

Table 6. Task Analysis Processes: Their Descriptions and Examples

Sub-Category	Definition	Example
Orientation	Task clarification and overview of material (Sonnenberg & Bannert, 2015)	Twenty percent of infected people are hospitalized. Then it asks us week by week. (Think-
Strategic Planning	Planning how to proceed by selecting an action plan and choosing the strategies that are needed (Panadero & Alonso-Tapia, 2014; Sonnenberg & Bannert, 2015)	Then I start again by writing down the first week's things (number of cases). (Think-aloud, Aylin)

4.1.1.1 Orientation

Orientation refers to an SRL process by which participants clarify the learning tasks and review the materials in the VR environment (Sonnenberg & Bannert, 2015). Orientation was one of the most frequently employed SRL processes in the VR learning environment.

The findings regarding orientation were rooted in participants’ think-aloud data collected while they were performing four interrelated virtual learning tasks. Students mostly utilized orientation at the beginning of each VR task to be clear about the tasks’ givens, to clarify task requirements, to gain a general outlook on the virtual materials provided to them, and to comprehend the multiple-choice questions before starting the solution. These three uses of orientation by high school students in the VR learning environment will be mentioned one by one.

Firstly, at the beginning of each VR task, students predominantly employed orientation to ensure clarity regarding the tasks' givens. For instance, at the beginning of VR Module 2, an interactive bar graph represented the spread of viruses over four weeks. Students were able to observe and manipulate that graph, and afterwards they were responsible for filling out a table and calculating the number of new infections in the fifth week. Some students used orientation to understand what the graph showed them. As an example, Sude utilized orientation while she was examining changes in the graph. Without Sude's intervention, the VR system generated those changes.

> “Now, it shows how many people are infected from week to week.” (Think-aloud, Sude)

In another example, Esra engaged in orientation while manipulating the graph to make sense of the givens. She clarified what the virtual learning material showed her by means of the orientation process.

> "Week to week, I'm back to the beginning now. Now, I am in the second week. Third week. Fourth week. It shows all of the weeks." (Think-aloud, Esra)

In the fourth task, for instance, Gülden clarified what was given to her at the beginning of the task. She explained the information provided to her about the task by engaging in the orientation process.

> "Only twenty percent of cases require hospitalization. And we have 3000 available beds in total." (Think-aloud, Gülden)

Secondly, students utilized orientation process to clarify the task requirements. For instance, two excerpts below show Zerrin and Eray's use of the orientation process in the second task, which was about re-expressing case numbers by means of exponents.

> "Now it wants me to write these in a different way, as exponents." (Think-aloud, Zerrin)
> "Now, she is asking me how to write the case numbers I just found by multiplying as exponents." (Think-aloud, Eray)

They clarified themselves about the requirements of the second task. Most of the students engaged in the orientation process in the third task, which was about writing an exponential function. Itır's expert below illustrates participants' common use of the orientation process to clarify the task's requirements in the third task.

> "It asks me to create the graph and its equation." (Think-aloud, Itır)

Some students also utilized orientation as an SRL process at the onset of the last task. which was about calculating 20% of each number in the table. Eray's except below displays his clarification of the task requirements before carrying out task-related calculations and filling out the table.

> "Twenty percent of infected people were hospitalized. Then she asks us week by week." (Think-aloud, Eray)

In addition, some participants engaged in the orientation process to both make sense of givens and clarify task requirements. For instance, Zerrin engaged in orientation both to gain an understanding of the givens in the first task and to clarify the aim of the task before starting to perform it. She first tried to comprehend what was given to her, such as the bar graph and calculator. Then, she clarified task requirements before starting to carry out task related operations.

> "Ok. Right now, I have a number of cases per week. And there is something that looks like a calculator. And here it asks me to write down the new cases recorded that week. I think. If I understand correctly." (Think-aloud, Zerrin)

Secondly, participants engaged in the orientation process to obtain a general overview of the virtual materials provided to them. The VR environment includes a variety of virtual tools, such as a calculator, a pen, interactive graphs, and a watch, that can be used to operate learning processes. Students were informed about how to apply these virtual tools by the pedagogical agent. As an example, two excerpts below show instances where Esra used orientation to clarify herself about how to benefit from virtual tools.

> "She says I can use the buttons on the side" (Think-aloud, Esra),
> "She wants me to take the pen and go over the graph." (Think-aloud, Esra)

Lastly, students used orientation to comprehend what the multiple-choice questions were about before beginning the solution process. VR Module 2 included four tasks, and three of them were concluded by answering multiple choice questions. While the first and last tasks included one question, the participants solved two questions in the third task. The results of this study indicated that after they were asked these questions, the participants displayed a common pattern in how they proceeded. The first thing that they did was to read the question sentence silently or loudly, then to state what the question was about with their own words. This was an orientation process, which enabled them to be clearer about the questions before commencing the solution. For instance, Itır first listened to the question sentence from the pedagogical agent, and she read it silently by herself. Then she said:

> "Now it is telling me how the graph will be shaped if both the mask and social distance are removed." (Think-aloud, Itır)

This was her attempt to comprehend what the question was about by engaging in the orientation process at the onset of solving a multiple-choice question.

4.1.1.2 Strategic planning

Strategic planning is a task analysis process which refers to selecting an action plan and choosing the strategies to proceed in the task. Making strategic plans is essential for students' self-regulation because it provides a structured approach to managing one's learning process effectively (Panadero & Alonso-Tapia, 2014; Sonnenberg & Bannert, 2015). The results of this study showed that half of the participants used strategic planning to manage their learning during the virtual tasks. Participants employed strategic planning to utilize the interactive features of the VR environment and to define the steps they would follow in the virtual environment.

Firstly, strategic planning facilitated the utilization of the interactive functions within the VR environment. The VR environment included a variety of virtual tools, such as the pen and tablet. Some participants exerted strategic planning for deciding how to benefit from these tools effectively. For instance, the first task was about filling out a table by considering an interactive bar graph. Didem set out a plan to use the tablet for carrying out task-related calculations. At the beginning of her experience, she used the tablet just for writing the numbers. She utilized the calculation feature of the tablet when the numbers got bigger. So, she acted according to her initial action plan. As the task became more complicated, she changed the way she utilized the virtual tablet. In another example, Demet decided to use the virtual pen in the third task while sketching the graph of the exponential function. In this task, most of the participants were not clear about how to use the pen to proceed, so they did not prefer to benefit from the pen. Demet set out a plan for using the pen to draw a sketch of the graph, and she first constructed the graph by using the pen instead of using the automatic drawing feature of the VR environment.

Secondly, participants employed strategic planning to navigate through the virtual environment efficiently. The VR learning environment offered a highly immersive experience for the participants. They engaged in strategic planning by defining the steps that would follow to achieve their task-specific goals. For instance, Aylin stated:

> "I start by writing the first week's thing (the number of cases)." (Think-aloud, Aylin)

Her think-aloud excerpt above shows the instance when she specified the first step of her pathway. Her overall objective was to fill the whole table, but the starting point was planned as the first week's case number. Similarly, Erden's excerpt below displays the steps to be followed to reach the aim of constructing a graph.

> "When I say it in a different way, for example, I will write it as five times five times five or five to the power of two and five to the power of three so that we can create a graph and see the amount of increase." (Think-aloud, Erden)

Erden specified what to do step by step and clarified how to benefit from his action plan while solving the task. His action plan enabled him to navigate the immersive environment by specifying his objectives and deciding what to do with the tasks. In brief, participants who used strategic planning for the task analysis process established at least the initial steps of their pathways in the VR learning environment.

4.1.2 Monitoring

Monitoring is an SRL process in the performance phase, and it refers to "informal mental tracking of one's performance processes and outcomes, such as one's learning processes and their effectiveness in producing learning" (Zimmerman & Moylan, p. 303, 2009). Students used monitoring processes in a variety of ways in the VR learning environment. Sub-categories of the monitoring process were content understanding, system and task understanding, monitoring of progress, relying on the system's feedback, and recognizing errors. Table 7 demonstrates these sub-categories, their definitions and examples about monitoring processes.

4.1.2.1 Content understanding

One of the motives for participants to employ the monitoring process in the VR learning environment was to interpret their mathematical understanding. The curricular focus of the VR learning environment was exponential functions. Students were expected to explore exponential growth, write an exponential function, draw the graph of that function, and carry out a set of mathematical operations to reach solutions. They mentally tracked their understanding of this mathematical content as they progressed through the virtual tasks. Content understanding served as a standard for evaluating students' progress in learning. Through regular monitoring of their understanding of the subject matter, learners determined the extent to which they were successfully acquiring the information. As an example, Aziz utilized content understanding to assess his comprehension of the learning material while performing the second task.

> "I figured out the connection between them. It currently accepts all of them as true." (Think-aloud, Aziz)

He mentioned the relationship between the numbers in the table (1, 25, 125, 625, and 3125) and their exponential notations. He used content understanding to assess the accuracy of his performance. His monitoring of content understanding in the second task also helped him in the third task. His interview data below showed how he

Table 7. Monitoring Processes: Their Descriptions and Examples

Sub-Category	Definition	Example
Content Understanding	Informal mental tracking of mathematical content	My equation was made exponentially. Because it increased by 5 to the power of 1 in the first week. The exponent in the second week is 2. Because the week and exponent are proportional, I calculated 5 to the power t. That is correct. Ok. (Think-aloud, Itır)
System and Task Understanding	Indications of the extent to which the task and the handling of the VR have been understood and implemented	I need to write a function right now. It wants me to write a function. There is a zoom location. I can enlarge or reduce the graph of the function. I need to write the function. I'm currently trying to figure out how to do that. She actually showed it to me. But I do not know. Still, it seems difficult. (Think-aloud, Aylin)
Monitoring of Progress	Checking behavior and mathematical solutions/conjectures to proceed during the task	After 4 weeks, I got stuck The first four were right. But I got to the fifth week. I don't know where the fifth week is. (Think-aloud, Aylin)
Relying on System Feedback	Behaviors indicating that the system influences one's actions in the VR learning environment.	In the 5th week, it was 3125. This means that it will be limited before the fifth week. I answer as 5. I am sending the answer. (The system gave an incorrect warning). It didn't work. Because? Twenty percent are hospitalized. (Think-aloud, Aziz)
Recognizing Errors	Identifying errors in calculations, functions and graphs	Equation editor. I made a mistake somewhere. I'll take this. (He decides that the equation he wrote is wrong by looking at the graph.) (Think-aloud, Aziz)

constructed the connection between the exponential numbers and the exponential function that mapped one variable to the other. His content understanding assisted his progress in the third task.

> "There was a function there that was constantly increasing as a multiple. I found it. From there, I learned what the exponential function was. I've never seen the exponential function before. Thanks to this VR experience, I learned what the exponential function is." (Interview, Aziz)

In Aylin's experience with the second task, she initially could not recognize the connection between the numbers and exponential notations. She stated that:

> "I had to multiply. It took me a long time to realize this, but I thought I really needed data." (Think-aloud, Aylin)

Since she did not understand this connection, the amount of time she spent on this virtual task increased. This example showed the student's use of monitoring her content understanding to identify gaps in her knowledge. As the learning task progressed, the student evaluated how well she understood mathematical connections in the virtual task and evaluated the effectiveness of her learning outcomes. Thus, she monitored her content understanding, which enabled her to recognize her misunderstanding about the mathematical subject matter.

While trying to carry out calculations for the last task, Banu remarked:

> "I am currently equating 3125 to 15000. Because in order for the number of people hospitalized to be 3000, we need to have 15000 patients." (Think-aloud, Banu)

She explained how the number of people hospitalized was related to the number of patients in the fourth task. In this task, students were responsible for filling out the second column of a table by calculating 20% of the number of new cases in the first column. Then, they were expected to solve a multiple-choice question to complete the task. Banu showed her comprehension of the content, and she identified the calculation steps to follow for the solution to the multiple-choice question.

Monitoring of content understanding encouraged her to reflect on her decisions about how to solve the mathematics question and to set connections between two variables of the question. In sum, such excerpts showed that content understanding as a monitoring process could prove to be essential for students in virtual learning tasks for assessment of learning progress, awareness of weaknesses and strengths, identification of solution steps, and reflection on learning progress.

4.1.2.2 System and task understanding

System and task understanding refers to the extent to which learners comprehend and apply both the task at hand and the operations of the VR system itself. Learners' progress in the VR learning environment was dependent on their understanding of the VR system and the VR tasks. Since all participants experienced Pandemic by Prisms for the first time in this study, they were unfamiliar with the VR system itself and the virtual tasks. Therefore, students frequently employed the monitoring processes for system and task understanding while performing the virtual tasks. The results of this study showed the significance of system and task understanding as a monitoring process to execute the virtual tasks. Participants engaged in monitoring processes to indicate jointly how well they understood the VR system itself and to what extent the requirements of the virtual task were comprehended. The following examples illustrate how participants utilized system/task understanding while performing virtual tasks.

Aylin's experience demonstrated how understanding the task requirements made her progress easier on the virtual tasks. Her think-aloud data illustrated monitoring processes for system and task understanding at different time periods in VR Module 2. At the beginning of the game, she could not figure out how to proceed with the virtual tasks. (I'm trying to progress in the game, but I don't understand how to do it. Think-aloud, Aylin). Then, she stated that she understood the aim of the game. (I understand the game better now. Think-aloud, Aylin). Thereafter, she could manage the virtual tasks easier due to her awareness of the task's requirements. (Once you get used to the game, it becomes easier to do things. But it was difficult when I first started. So, I wasn't quite sure what to do. Think-aloud, Aylin). I asked her about her experience in the interview. The interview excerpt below also showed how monitoring regarding system and task understanding facilitated her progress in the virtual tasks. Even if the first task seemed meaningless, she could solve the following tasks easily thanks to understanding the course of the virtual tasks.

> "At first, what I did seemed pointless. I couldn't grasp it. Afterwards, as you got used to the flow of the game and understood what you were trying to do, it got a little easier." (Interview, Aylin)

The first and second tasks were required to fill two tables. Some participants could not complete these tasks easily. However, Zerrin filled out the tables quickly. The first excerpt below shows her monitoring for system and task understanding. She stated that she grasped the logic behind writing the number of cases for the fifth week. In the stimulated recall part of the interview, I shared the records of her experience. She pointed out the impact of her task understanding on her rapid progress in the first and second tasks.

> "Of course, I think it would be five to the fifth power." (Think-aloud, Zerrin)
> Researcher: "Now I am sharing my screen. You are given tables. Then you quickly fill in the table. Afterwards, you are given another table. You go through the questions very quickly. You went through these parts very quickly. What do you attribute this to?"
> Zerrin: "I think I understood what she wanted correctly. That's why I passed through this quickly because I knew the subject. It didn't put much pressure on me." (Interview, Zerrin)

In sum, the findings of this research demonstrated the importance of system and task understanding as a monitoring process in order to execute virtual tasks. The participants actively engaged in monitoring processes for system and task understanding in order to collectively assess their level of comprehension regarding the VR system itself and the virtual tasks' requirements.

4.1.2.3 Monitoring of progress

Monitoring of progress refers to checking behavior and mathematical solutions and conjectures to proceed during the task. Students applied a series of mathematical calculations and reached certain solutions for each virtual task. They also constructed some conjectures about their task solutions. Participants tracked their progress in the VR learning environment by individually controlling their mathematical operations and assumptions. Monitoring of progress allowed students to investigate alternative solution paths, verify their results, and analyze their mathematical conjectures while engaging in virtual tasks based on the results of this study.

Firstly, monitoring of progress assisted learners to self-regulate their learning processes effectively in virtual tasks. When students recognized that they were struggling or making errors, they could adjust their strategies, seek help from virtual resources, or employ alternative methods to overcome obstacles and make progress in virtual tasks. For instance, participants were required to fill out a table based on the number of new cases on an interactive bar graph in the first task. While the table included five weeks, the interactive bar graph showed four weeks. The following participants shared their struggles regarding this situation in the task.

> "It says five weeks but I see it's four weeks. I'm checking again to see if I missed something." (Think-aloud, Metin)
> "I did the first four weeks right. But I made it to week five. I can't find the fifth week." (Think-aloud, Aylin)
> "I'm still at the table. Well, I entered week by week." (Think-aloud, Esra)

Even if they filled in the first four weeks in the table by interacting with the bar graph, they could not notice any information about the number of cases in the fifth week. Their initial strategy involved manipulating the interactive bar graph in an attempt to observe the fifth week. However, they could not achieve this because of the limitations of the bar graph in the fourth week. The task's solution path included making an educated guess for the fifth week by considering the pattern in the number of cases in the four weeks. Nevertheless, some participants did not discover the solution path initially, and they tried other methods, such as adding the numbers, in the four weeks. For instance, Eray could not easily complete the first task. His think-aloud data shows a monitoring process, which shows his initial guess for the solution of the task was finding the sum of all numbers for the fifth week.

> "As far as I understand, we will actually write the sum of all of them in the fifth week." (Think-aloud, Eray)

I asked about his experience in the stimulated recall part of the interview by showing the moments when he struggled to continue the task.

> "During those two and a half minutes, I was still trying to figure out what the game wanted from me. I'm trying to figure out what we should do and stuff. After that, I said there is a pattern here. Why am I trying to go and add all of these? Let me go and continue this cover. It's the most reasonable one. Actually, I wasn't focused on that at all; I was trying to figure out the game. That's why I tried to add them up. I remember this very well. I struggled for 2 and a half minutes. It seemed shorter than that." (Interview, Eray)

As seen in the interview excerpt, he could not figure out the task's solution path and concentrate on the solution of the task well. Then, he reached a solution by being aware of the pattern in numbers after the monitoring process. He was continuously engaged in monitoring of progress and found the right solution for the number of cases for the fifth week. Put simply, use of monitoring of progress encouraged them to detect their error, produce further strategies to solve the task, and proceed along with the virtual task afterwards.

Secondly, students monitored their progress on virtual tasks to check their solutions and verify results. This provided them with an opportunity to make a decision about the correctness of their solutions.

> "The graph looks correct now." (Think-aloud, Engin)
> "When I type 1, it comes out 5, and when I write 2, it comes out 25. Okay." (Think-aloud, Yakup)
> "I wrote up to the fourth power of five. 25, 125, 625. If I take 5 times 625, I think I'll make an accurate guess." (Think-aloud, Gülden)

In the examples above, students checked their answers before finishing the tasks. In these instances, monitoring their progress helped them decide the accuracy of their solutions, and then they proceeded with virtual tasks.

Lastly, monitoring of progress also assisted learners in examining mathematical conjectures that they constructed while performing immersive tasks. Monitoring of progress encouraged learners to identify and elaborate on their mathematical conjectures.

> "I'm trying to write the equation right now. It gave me the unknown t. Since the unknown t shows weeks, it will be 5 to the power of 1 in the first week and 5 to the power of 2 in the second week. That's why I wrote five to the power t in the equation section." (Think-aloud, Zerrin)

For example, Zerrin clarified her conjecture about the solution to the third task, which involved writing an exponential function based on the data in the table.

> "There are 3125 new cases. One fifth of 3125 will be five (625 cases will be reached in the fifth week). So, it's week six." (Think-aloud, Gülden)

Gülden also established a conjecture before answering a multiple-choice question in the fourth task and illuminated her assumptions by using monitoring of progress as an SRL process.

4.1.2.4 Relying on system feedback

The VR learning environment involved some feedback mechanisms that were offered to the users in cases of giving wrong answers and losing a long time in a virtual task. The VR system warned participants by a voice alert and a visual mark, or the pedagogical agent offered help to the participants to proceed with the learning tasks. Participants utilized the feedback generated by the system to monitor their progress and implement adjustments based on the feedback provided by the virtual system. The system-generated feedback might serve multiple purposes, such as to understand the task, notice their errors, become confident in their answers, recognize virtual tools' functions, and get extra help.

Some participants benefited from system-generated feedback to gain a better understanding of the task requirements. Two examples below illustrate how students monitored their understanding of the task by relying on the VR system's feedback.

> "I wrote two cases for the first week. I pressed the enter button. (System's voice alert) But now I understand." (Think-aloud, Banu)
> "Patient zero. New case. One. (System's voice alert). That's it; I'll do it." Okay. (Think-aloud, Fatih)

The VR system provided students with voice alerts when they did something right or wrong. Students were required to complete a table utilising data presented in an interactive bar graph for the first task, which is addressed in both of the aforementioned passages. While Banu figured out how to fill the table after getting feedback about her mistake, Fatih initially tried to fill the table by counting the numbers in the interactive bar graph, and he understood what the task required him to do by means of the system's positive feedback towards his answer.

Students' monitoring by relying on the system's feedback enabled them to be aware of their mistakes. Students immediately recognized their faults after getting the system’s voice alerts. An excerpt from Gülden’s think-aloud data shows the moments when she noticed her errors while performing the first task.

> “I'm trying to submit. Because I filled them all. (System's voice alert). Let me try to enter this again for a second. I think there is a slight mistake here. (System's voice alert). Of course. I think the number of cases I wrote for week zero was wrong.” (Think-aloud, Gülden)

Gülden filled all weeks’ cases correctly, but she could not submit her answer for the first task because of her mistake about week zero’s cases. She got two negative voice alerts, then she noticed that she wrote an incorrect number in the zero week’s row. Gülden detailed how she recognized her error for the zero week’s cases in the interview following her performance.

> Researcher: “How do you spot week zero? Let's watch it if you want. This is where you notice week zero. You said there is a small mistake here. How did you notice this? You're not looking at the chart there. What did you think there?”
> Gülden: “My logic there was this. I actually didn't look at the people around me at first. I was more interested in filling in the table. I was looking at the chart. I was looking at human animations. Later, I realized that there was a mistake there. The voice was saying right and wrong, but I didn't pay much attention at first. I guess I didn't care at first. Later, when I noticed there was no tick on its side, I realized it was a mistake. Since the others were already 5 to the 2nd power and 5 to the 3rd power, I guessed more from there. I remembered why you do it like this—it had to be like this. I said zero at first because I was thinking about the cases spreading from the case we chose. Now I can understand why the answer is one.” (Interview, Gülden)

The system generated feedback as a visual mark, which triggered her monitoring process and helped her to notice her error. Thus, she reached the right solution by considering the relationship between the week number and the number of cases in terms of exponential numbers.

> “Again, it all adds up fivefold. This is 75 for 625. (System's voice alert). Oops. Not 625. 705.” (System's voice alert). (Think-aloud, Banu)
> “This time, I say option B, because it will spread a little slower. (System's voice alert). Uhh uhh. It was wrong. It wasn't true.” (Think-aloud, Zerrin)

Students’ monitoring by relying on the system’s feedback helped them to be confident in their answers. When students gave a correct answer, the VR system provided them with a positive voice alert. This positive voice alert made students clear about their solution paths, and they continued their solutions in a more confident way. For instance, participants were expected to fill out a table by using the number of cases shown on an interactive bar graph in the first task. In some situations, they could be sure about their solution paths thanks to the feedback they received from the VR system. The following think-aloud excerpts illustrate how relying on the system's feedback was used as a monitoring process by two participants in the first task.

> (System's voice alert). "Huh. I had to fill it according to the image on the front." (Think-aloud, Esra)
>
> (System's voice alert). "I really had to make a guess. I've been searching for so long in vain." (Think-aloud, Gülden)

Esra tried to fill the table by counting the number of new cases in the interactive bar graph. She heard the positive voice alert in the VR environment, which made her feel certain about the way she proceeded with the task. In continuation of the same task, students were responsible for filling in the number of cases in the fifth week by making a calculation. Some participants could not realize how to figure out this issue. After a few trials, Gülden decided to follow the pattern in the numbers 1, 5, 25, 125, and 625 and to multiply 625 by 5. She noticed the correctness of her answer by means of the system's positive feedback.

The VR learning environment made a set of virtual tools available for the students. Some participants were not sure about the functions of those virtual tools. For instance, some participants could not distinguish between multiplication and exponent buttons. Even if they thought the answers were correct, the VR system rejected the written answers because they pressed the wrong buttons.

> "Enter. (System's voice alert). Hmm. I think this is a multiplication button." (Think-aloud, Sude)

> "I make 5 to the power 2. I will continue. (System's voice alert). It isn't happening." (Think-aloud, Metin)

Relying on the system's feedback helped participants become aware of the functions of the virtual tools. The examples above illustrate instances when participants engage in monitoring processes by relying on the system's feedback. For instance, Sude recognized the multiplication button after getting positive feedback, or Metin decided how to write an exponential number by using the virtual calculator after hearing a positive voice alert while performing the second task.

The VR system provided feedback not only for students' right or wrong answers but also for moments when students could not proceed with the tasks. This system generated feedback also offered extra support to the participant, which assisted them in changing their actions in the virtual tasks. The following examples show how participants decided to use the support mechanisms of the VR system.

> (System's voice alert). Are you stuck? If you are, you can press this button at any time for support. Pedagogical Agent's Offer). "She said it was wrong." (Think-aloud, Didem)
> (System's voice alert). Are you stuck? If you are, you can press this button at any time for support. Pedagogical Agent's Offer. "Huh. Ok". (Think-aloud, Banu)

Didem and Banu got confused about how to maintain the tasks. They realized that they needed extra support because of the system's offer to them. They changed the strategy they persistently made use of, such as trial and error, and showed help-seeking behavior to proceed with the tasks.

4.1.2.5 Recognizing errors

Recognizing errors refers to the ability of learners to identify their mistakes in calculations, functions, and graphs as they perform virtual tasks. VR Module 2 included four virtual tasks that required performing a variety of calculations, writing an exponential function, and drawing graphs based on generated functions. Participants mainly made a set of mistakes as a matter of course while carrying out these operations, and some of them used recognizing errors as a monitoring process to detect their mistakes.

Participants identified their errors regarding mathematical operations. These mathematical operations included conducting a set of calculations, interacting with graphs, writing functions, and filling the tables. For instance, Fatih’s think-aloud excerpt below shows how he recognized his error while performing the last task. He decided that the exponential function he wrote for the numbers of 1, 5, 25, 125, and 625 was incorrect.

> “I did wrong. Let's take this one. Ok. I'm entering the count now. How many should I enter? Four. I should enter four. No, I should enter five.” (Think-aloud, Fatih)

Screen recording data also showed his attempts to write an exponential function by using 2 as the base of the function. I asked him why he focused on the powers of 2 in the interview.

> Researcher: “You start by examining the graph first. You said there are 128 and you wanted to continue using powers of 2. I wonder where you saw 128?”
> Fatih: “I think I read this graph wrong. Let me confess that. The last time I minimized it, 640 corresponded to one point. At least that's how I saw it. I may have seen it wrong. I said, 640 is coming to a point, but I thought for a moment what kind of function it could provide. Then I brought it over. My thing, my arm. By the way, I brought it randomly. And I realized that there was a feature mentioned in the tutorial. At that moment, I forgot that the feature mentioned in the tutorial existed. When I held it, it showed the real location of the dot. As I see it, it does not intersect with 640. They intersect at 4 by 625. And I said okay, then. There are multiples of 5. But there is also a multiple of 4. There is a multiple of 2. Then definitely, the power of 4 cannot be something, and the power of two cannot be anything. But the power of 5 must be something. I said 4 to the power of five gives 625. I found such a function. Actually, I'm reading the graph wrong. I'm having a problem with it.” (Interview, Fatih)

He explained in detail how he recognized his error in the interview. The interview excerpt above demonstrates monitoring of his mathematical operations in the task. Since the numbers Fatih saw initially in the graph were not powers of 5, he could not write the correct function. However, he detected more accurate points in the graph by zooming in on it. Then he identified his mistake and resolved the task successfully.

The VR system provided students with four multiple choice questions. Participants also engaged in monitoring processes for recognizing their errors in these multiple-choice questions. Zerrin's experience illustrates the way she monitored her understanding of a multiple-choice question. She initially listened to the question, but she missed some parts of it. Thus, she could not decide how to make progress in this question. I asked her experience in the stimulated recall part of the interview.

> "I thought at first that the graph we drew was the situation, but I thought it was the picture we see when neither mask nor social distance are applied. So, I just thought it would go slower if social distancing was practiced and masks were not worn. But when I returned to the question, it said that if we stop wearing masks, this time I said that all precautions were taken in the beginning, but if the wearing of masks was stopped, then it will start to spread faster. So, I misunderstood the question when I first listened to it. I noticed it here." (Interview, Zerrin)

The interview data above showed that reading the question sentence enabled her to realize her mistake about what the question asked her and figure out the multiple-choice question correctly.

4.1.3 Self-control strategies

Self-control strategies are SRL processes in the performance phase, and they refer to the processes of sustaining concentration and interest by means of self-regulatory strategies (Panadero & Alonso-Tapia, 2014). Appendix F displays sub-categories regarding self-control strategies, their definitions and an example for each one.

4.1.3.1 Elaboration

Elaboration refers to students' deeper processing such as paraphrasing, connecting, inferring (Sonnenberg & Bannert, 2015), summarizing, and interpreting while carrying out virtual tasks. Participants of this study engaged in elaboration processes by summarizing and paraphrasing the virtual instructions, revealing mathematical connections in virtual tasks, and interpreting and inferring the virtual learning materials.

The virtual tasks provided students with instructions in video, audio, and written formats. Participants in this study elaborated on those instructions by making a summary with their own words during or after the instructions. For instance, Erden engaged in an elaboration process after a multiple-choice question was asked of him. He initially listened to the voice instruction of the pedagogical agent, then read the question sentence. After that, he summarized what the question asked him by paraphrasing the question sentence. In a similar context, Itır used elaboration as a task control strategy by summarizing what she heard and saw in a video instruction.

> "She says: If you wanted the results of the 6th week, what would you do after the 5th week to get the 6th week?" (Think-aloud, Erden)
> "20% of newly infected people are hospitalized. Currently, I have 3000 patients in the hospital." (Think-aloud, Itır)

Think-aloud excerpts below belong to Aziz and Didem. Their experience delineated the use of elaboration after they needed support to proceed to the third task, which was about writing an exponential function. Most of the participants had difficulty completing the third task; thus, they required assistance from the VR system. Aziz and Didem also applied for extra support to continue the third task. The VR system provided them with more detailed video instructions, which explained the exponential growth in the table. They elaborated on the instructions of the support video by making an exhaustive summary of it with their own words.

> "She tells me that I can take the number of weeks as a base. She explained that the graph goes as powers of five. The first week is five to the first power, the second week is five to the second power, and the fifth week is five to the fifth power." (Think-aloud, Aziz)
> "It has increased fivefold every week, she says. She says we write the first week as five to the power one. The second week is five to the power of two. Five to the third week there. She says the exponents should increase one by one. Five to the power of t. Every week. For example, base five in the first week. The second week is five to the power of t. She says there should be five to the power t per week." (Think-aloud, Didem)

Participants utilized elaboration to figure out mathematical connections in the virtual tasks. VR Module 2 was composed of four interrelated virtual tasks. Participants established mathematical relations among the tasks and within each task. At the beginning of the first task, students were provided an interactive bar graph. As an example, Itır stated the exponential notations of the cases, and she explained how the graph depicted a scenario for exponential growth.

> "So, it constantly moves in powers of 5. In the early days, it was like 5 to the power 0, then 5 to the power 1, 5 to the power of 2, 5 to the power 3 and 5 to the power 4." (Think-aloud, Itır)

In the second example, Erden connected the numbers he wrote in the first task and the second task. While he wrote whole numbers in the first task, he was expected to write these numbers as expressions using powers. He set the relationship between the whole numbers and their exponential expressions.

> In other words, it actually increases as a power of 5. (Think-aloud, Erden)

Damla used the elaboration process to solve the third task, which was about writing an exponential function. She explained the pattern among numbers, their connection with exponential numbers, and how to generate an exponential function by means of those numbers.

> "5 cases emerged in the first week. In the second week, 25 cases emerged. In the third week, 125 cases emerged. So, there is a pattern here. According to the pattern, 5 to the power of x must be a function." (Think-aloud, Damla)

In the last excerpt below, Engin set the connection between the function he wrote in the third task and the function he needed in the fourth task. He elaborated the mathematical connections between the tasks while filling in the table.

> "The same number of people are hospitalized as the number of patients in the previous week. So, 5 to the power of t-1." (Think-aloud, Engin)

Students' use of elaboration processes enabled them to interpret and infer the virtual learning materials according to the results of this study. The VR learning environment provided students with a variety of virtual learning materials, such as graphs and tables. Students elaborated their thinking by interacting with these learning materials. For instance, the graph of the exponential functions encouraged Bartu's use of the elaboration process. He looked at the points in the graph and elaborated his thinking by means of his observation.

> "Our function multiplied by 5 per week." (Think-aloud, Bartu)

In the following excerpt, Aziz initially summarized the voice instructions of a multiple-choice question, then interpreted the previous graphs he observed before answering the question.

> "She's asking me questions right now. She asks what the graph would be like if we stopped wearing masks. We see that when we stop wearing masks, the number of patients increases faster, and everyone gets sick before the fourth week." (Think-aloud, Aziz)

The last example included both screen recording data and think-aloud data. Screen recording data showed participant's interaction with the graph. Later on, she inferred from her observation of the graph that she attempted an elaboration process to perform the task.

> She observed the graph. Then she observed the numbers in the table carefully. (Screen Recordings, Gülden).

“What I need to do is put t in base 5.” (Think-aloud, Gülden)

In brief, participants employed elaboration processes such as summarizing and paraphrasing the virtual instructions, identifying mathematical relationships in virtual tasks, and analyzing and drawing conclusions from the virtual learning materials based on the results of this study.

4.1.3.2 Reading

The VR system provided students with various written instructions in different circumstances, such as multiple-choice questions, titles of tables and graphs, task instructions, and feedback for the wrong answers. Since it is a natural act for students to read a written text when they initially see it, reading cannot be labeled as a self-control strategy. Thus, in this study, the code of reading was used if students read a written text in virtual tasks with the intention of regulating their learning. Reading refers to re-reading out loud text (Sonnenberg & Bannert, 2015; Greene & Azevedo, 2008), which is a conscious act of a student contributing to his/her performance. Participants of this study used reading as a self-control strategy for better understanding multiple choice questions, deciding what a table or graph showed, comprehending task demands, and making use of the system’s feedback.

VR Module 2 included four multiple choice questions. Even if the virtual agent vocalized the question sentence, a written format of the questions and answers was presented to the students. All the participants read the question sentences and answers once in this study. However, some of them re-read them to be sure about their understanding of the question. Fatih think-aloud excerpt below shows his use of reading as a self-control strategy to maintain the task. He checked whether he correctly comprehended the question sentence. His screen recordings externalized his use of virtual hands to assist his reading strategy.

> "One minute. I read it correctly, didn't I? If we stopped wearing masks... Ok, now let's understand what the question says. If we stop wearing masks, we are only socially distanced." (Think-aloud, Fatih)
> "He follows the question sentence with his virtual hand." (Screen Recording, Fatih)

Another sample that illustrates the use of reading for understanding multiple choice questions belongs to Zerrin. She initially did not use reading as a self-control strategy. She answered the question with her first reading of the question. Then, she got feedback from the VR system about her mistake. Then, she read the question sentence again for comprehension. Afterwards, she reached the correct answer.

> "How many weeks from now will the number of weekly hospitalizations exceed 3000." She whispered while reading (Screen Recording, Zerrin)

VR Module 2 included a set of tables and graphs. Those tables and graphs were labeled with written texts. Bartu listened to the voice instructions of the pedagogical agent, saw the table in the video instruction, then stopped the voice instruction by saying "Okay, I understand" (Think-aloud, Bartu). However, he came close to the table and read the label of the table to be sure about what to do in the task. The screen recording data showed an instance when he used reading as a self-control strategy.

> "New cases in terms of growth factor." He whispered while reading (Screen Recording, Bartu)

The VR system provided a written format for tasks' requirements. The pedagogical agent provided voice and video instructions at the beginning of each task to explain its requirements. Participants' reading text instructions again for better understanding of the tasks' demands was shown in the following screen recordings and think-aloud samples. Didem and Eray changed their position in the VR environment to apply and observe what they read in the written texts. This showed me that the use of reading as a self-control strategy enabled learners to decide where to focus on the virtual tasks.

> "Fill in the third column of your table to find...Fill in the third column of your table." She whispered while reading, then turned to the left to see the table (Screen Recording, Didem)
> "What does it say here?" (Think-aloud, Eray)
> "New infections in the first five weeks." He whispered while reading, then he turned to the left to see the table. (Screen Recording, Eray)

VR Module 2 contained some feedback mechanisms. These feedback mechanisms were in voice format mostly. However, the third task included written feedback in addition to the voice format. Bartu and Esra also made use of this written feedback to guide their decisions on how to write a precise function.

> "You can make an equation with that piece. Ok" (Screen Recording, Bartu)
> "You can make an equation." (Screen Recording, Esra)

In sum, participants employed reading as a self-regulation technique to enhance their comprehension of multiple-choice questions, interpret the information shown in tables or graphs, understand the requirements of the task, and utilize the feedback provided by the system according to the results of this study.

4.1.3.3 Environmental structuring

Environmental structuring refers to changing the position of the tablet or deleting what is written for "increasing the effectiveness of one's immediate environment" (Zimmerman & Moylan, 2009, p. 303). Participants were able to hold some virtual objects, such as the pen and the tablet, and change their positions in the virtual space. In addition, it was possible for them to write in the virtual space and erase what was written. These attempts to structure the virtual environment promoted students' effective use of the virtual learning environment.

Most of the “environmental structuring” codes emerged based on the observational data source of the screen recordings in this study. In short, participants changed the position of an object to reach a better view or locate objects closer to each other. Initially, I will focus on two counterexamples who did not effectively use environmental structuring as a self-control strategy in virtual tasks. One of them is Gülden who relocated the virtual tablet only once throughout the VR Module 2 experience. Figure 7 shows a screenshot of the first task from Gülden’s experience. As seen in Figure 7, there is a table on the left, and the location of the tablet is far away from the table. Since participants could use the tablet for many mathematical operations such as calculations, constructing functions, or filling tables, most of the participants preferred to locate the tablet close to the area where they were conducting those operations. However, Gülden was not one of them. Since she did not change the position of the tablet, she repeatedly turned left and right throughout the first task. In addition, there was an interactive bar graph on her right, as shown in Figure 8. The tablet also hindered the appearance of the interactive bar graph, which was significant for the first task of filling in the table. I showed the recordings of these moments to her in the stimulated recall interview. When I asked her why she did not change the position of the tablet, she attributed it to forgetting the video instruction, which explained how to carry the tablet in the virtual space. Then, she explained how things became easier for her after figuring out how to relocate the tablet.

> “I carried it afterwards, but I guess I was a little late. It was actually shown in the video, but I remembered it later”. (Interview, Gülden)
> “Afterwards, I carried the calculator. So that they can be side by side at the same time. To make it easier for me. But not at first. I left it because it came out right there when I opened it. I fixed it later, when I realized it.” (Interview, Gülden)

Figure 8. A screenshot of Gülden’s experience

Sude had a similar experience with the last task. She could not understand how to fill in the third column of the table. She made a lot of mistakes. Then, the pedagogical agent offered to support her to maintain task progress. However, the location of the tablet was similar to Gülden’s and Sude could not notice the button she needed to press to reach video instructions for support. I used her screen recordings to remind her of her experience with the fourth virtual task, and I asked questions during the stimulated recall interview. She explained how the improper location of the tablet prevented her from getting the system’s support.

> Researcher: “The video was left behind the calculator. You had to listen to the video over and over again.”
> Sude: “I clicked many times, hoping that he would say it slower or bring the question to me. It was the same every time, I actually didn't understand. 20 in my mind, 3,000 in my mind. I saw 20% in the video. But combining the two did not occur to me at that moment.”
> Researcher: “She says, "Are you stuck?" here.”
> Sude: “She already understood that I couldn't do it.”
> Researcher: “Yes, that's why she would support you. Where to get support screen question.”
> Sude: “In the back.”

> Researcher: “Yes, it is left behind. You cannot see it.” (Interview, Sude)

In addition, she gave the details of how it was so exhausting not to use environmental structuring as a self-control strategy in the virtual tasks.

> Researcher:” If you were doing it over again, what would you do differently?”
> Suzan: “First, I would buy the calculator from there. Because it really pushed me hard. I couldn't see the things I wanted to see. I moved many times, turning to my right to do it continuously. I would change it. I guess I wouldn't change anything else that much.” (Interview, Sude)

Most of the participants in this study used environmental structuring as a self-control strategy to make the virtual environment more functional for learning. For instance, Demet’s think-aloud data is an example of moments when she changed the location of the tablet in the third task, which was about writing an exponential function. Demet opened her tablet first to write the function. Even if the tablet was opened away from the equation editor, she carried it in front of the equation editor. This attempt helped her to jointly see both the tablet and the equation editor. Moreover, she lifted up the tablet to find the best location for using it. Her experience was a typical use of environmental structuring as a self-control strategy in VR Module 2.

> “I took the keyboard (tablet). But a lot. I'm currently installing the keyboard.” (Think-aloud, Demet)

In a nutshell, the participants were granted the ability to manipulate virtual objects, alter their positions within the virtual environment, write in the virtual space, and remove their own writing. These efforts to structure the virtual environment encouraged students to utilize the virtual learning environment more effectively, based on the results of this study.

4.1.3.4 Calculation

The mathematical subject matter in VR Module 2 was exponential growth. Students were responsible for managing a variety of mathematical operations to proceed in the virtual tasks. A tablet was provided to the users, which included a calculator function. In addition, a pen was available in VR Module 2, through which the users were able to carry out needed calculations. According to the results of this study, participants used calculation as a self-control strategy to maintain their progress in the tasks.

Using calculations to direct mathematical operations helped participants make their progress faster. For instance, Ezgi had difficulty deciding the number of cases by observing the interactive bar graph in the first task. She made some mistakes while trying to find answers without using the calculator function of the tablet. I recalled her experience with the first task and requested her comments on those moments in the interview. She explained how using the calculator helped her finish the task faster.

> "For example, 625, I try to calculate it in my head at first. There is already a calculator here. Then, when I calculated all the others with a calculator, I went faster." (Interview, Ezgi)

Some participants, such as Aziz and Engin, preferred to use the pen for calculations instead of using the tablet's calculator. Their think-aloud and screen recording data showed how they used the pen to assist his mathematical operations. For instance, Figure 9 illustrates Aziz's calculations by using the pen in the fourth task while solving the multiple-choice question. I asked about his experience with performing calculations with the pen in the interview. His interview excerpt below shows his motivation behind using the pen for calculations. Since writing in the virtual space provided a visual image of mathematical reasoning, he benefited from calculating with the pen to ensure the accuracy of his operations.

> "I can perform incomplete operations when doing it mentally. I may forget the numbers because I was doing a lot of transactions at that time. Maybe I can mix up the numbers. I can write 15125 instead of 15625. I may answer the question wrong. It stayed in my mind because I wrote it. It was also good to have it in front of my eyes all the time, as I could write wherever I wanted in virtual reality rather than on paper." (Interview, Aziz)

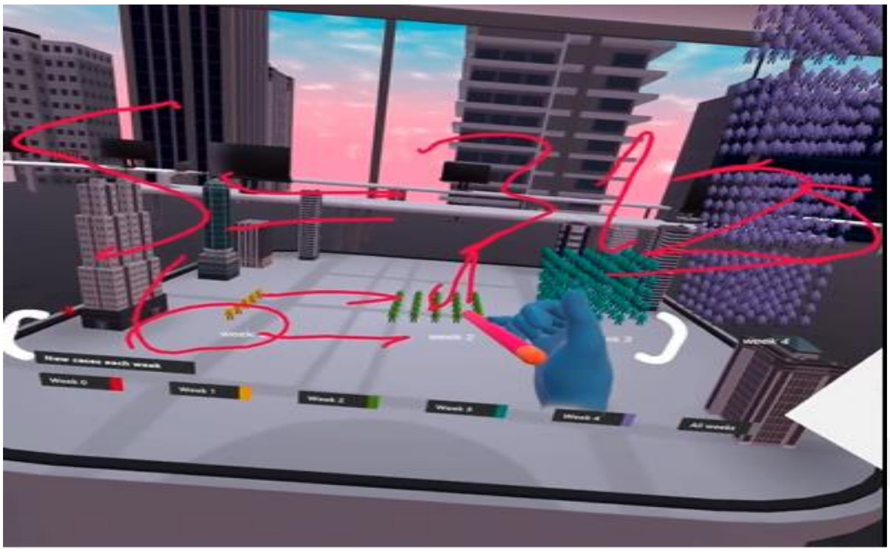


Figure 9. A screenshot of Aziz's experience

Engin also used calculation as a self-control strategy by means of the pen. His interview data below showed the ways he made use of calculations. Writing calculations in the virtual space enabled to apply mathematical operations with ease, to be clear about his operation, and to achieve impeccable results.

> "Sometimes, in some places, it was easier to do the operations by writing them down. For that reason." (Interview, Engin)
> "It prevents confusion. Therefore, it allows me to make more accurate operations." (Interview, Engin)

In summary, based on the results of this study, participants employed calculation as a self-control strategy to sustain their progress in the tasks. Utilizing calculations enabled them to achieve more expedient and precise solutions.

4.1.3.5 Mental operation

Mental operation is a self-control strategy that means carrying out task-related calculations mentally. While the number of occurrences of “mental operation” code was 59, it was 28 for “calculation” code, as represented in Table 6. In other words, participants preferred to use mental operations instead of the calculator function of the tablet in this study. The main motive behind conducting mental operations on virtual tasks was “to finish quickly” (Interview, Zerrin). Participants benefited from mental operations to maintain their progress in the first and last tasks of VR Module 2, which contained four virtual tasks.

In the first task, participants were expected to fill out a table by considering the number of new cases in an interactive bar graph. The number of cases was 1, 5, 25, 125, 625, and 3125. There was a pattern among these numbers. Each number could be calculated by multiplying the previous number by five. Even if some participants counted the number of cases in the interactive bar graph to fill the table or used the calculator to carry out operations, some of them focused on the pattern and finished the task quickly by calculating the number of cases by multiplying mentally. For instance, Bartu was one of the participants who easily and quickly filled the table for the first task. His think-aloud data excerpt below shows his mental operation steps while calculating the number of cases for each week in the table. He progressed with the task quickly after deciding the number of cases in the first week.

> “There is one patient in the first week. It was increasing fivefold every week. 25. 125. What is it in the 4th week? 625. There is no week 5, though. 5. What will I write next week? Should I write five times that too? 3125.” (Think-aloud, Bartu)

I noticed a remarkable event in Bartu’s experience based on the screen recording data. He conducted these mental operations while the pedagogical agent’s voice instruction was continuing. The VR system provided him with video instructions and voice instructions, respectively. Bartu just listened and watched the video instructions carefully, right after he started filling the table by carrying out mental operations without waiting for the voice instructions to end. In sum, he immediately attempted to complete the task by using mental operations just after he realized the task's demands, which enabled him to finish the first task in a short time.

The last task was about finding the number of hospitalizations by calculating 20% of the number of new cases each week. Participants were responsible for filling the second column of a table by considering the numbers in the first column. The numbers in the first column were 1, 25, 125, 625, and 3125. Figure 10 is the screenshot from the fourth task, which shows Hakkı's use of mental operations to fill the second column of the table. Hakkı mentioned that "1 person in the first week. 5 people in week 2. If we divide 125 by 5, we get 25 people. It will always be 5 times the other. 125. And 625." (Think-aloud, Hakkı). He initially carried out mental operations by dividing the numbers in the first column by five. Then he recognized the pattern in the second column: 1, 25, 125. Each number could be calculated by multiplying the previous number by five. Thus, he continued his mental operations by considering this pattern between the numbers. In the same task, Engin conducted mental operations only, focusing on the relation between the numbers in the first column and the second column for each week. He just multiplied each number in the first column by 1 over 5, or divided them by 5, to fill in the second column of the table.

> "There are 5 cases in the first week. If there are 5 cases, 20% of them is 1.25 times 20/100. 25 times 1/5, the answer is 5.625 times 1/5. The result of dividing 625 by 5 is 125. Last week. From 3125 divided by 5, the answer will be 625." (Think-aloud, Engin)

The possible reason why participants did not use mental operation as a self-control strategy in the second and third tasks was the mathematical requirements. While the second task required students to convert the numbers (1, 25, 125, 625, and 3125) to exponential numbers, the third task's focus was writing an exponential function regarding exponential numbers constructed in the second task. Since the need for mental operations was very limited, participants did not engage in any mental operation processes for their progress in these two tasks.

Overall, the participants in this study showed a preference for utilizing mental operations. The primary objective of performing mental operations on virtual tasks was to expedite completion. Participants utilized mental operations to sustain their advancement in the initial and final tasks of VR Module 2.

Figure 10. A screenshot of Hakkı's experience

4.1.3.6 Task solution

Task solution refers to solving task related questions to proceed in the tasks. VR Module 2 consisted of four tasks and these tasks included four multiple choice questions in total. Students were responsible for solving each multiple-choice question and the questions asked in the tasks to maintain their progress. The task solution code emerged in the data to represent participants' actions toward reaching solutions. How students engaged in task solution processes will be displayed for each task by focusing on a common example from the data.

In the first task, students were expected to recognize a pattern between numbers. An interactive bar graph assisted them in filling a table with the numbers 1, 5, 25, 125, 625, and 3125. However, the interactive bar graph did not include any information about the number of cases in the fifth week. While some of the participants persistently tried to find a clue in the graph about the fifth week, others just focused on the pattern in the numbers. For instance, Erden initially insisted on manipulating the interactive bar graph to see the number of cases in the fifth week. When I showed his struggle with the graph in the stimulated recall part of the interview, he stated that "there was an error in the graphic there." (Interview, Erden). Sude's experience was different from Erden's. Sude filled the first four weeks of the table by investigating the number of cases in the interactive bar graph. She carried out a set of calculations by means of mental operation in this process. At the end of the task, she noticed the relationship among the numbers. She associated each number with its exponential notation. The think-aloud expert below shows the instance when Sude found the solution to the task by detecting the pattern in terms of exponential numbers.

> "Then week 5. 5 to the power 1. 5 to the power 2. 5 to the power 3. 5 to the power 4. 5 to the power 5 in week 5." (Think-aloud, Sude)

The second task was about restating numbers (5, 25, 125, 625, 3125) by using exponential notations. Students who realized the pattern between the numbers and their exponential notations reached the solution easily. Engin was one of the students who immediately attempted to solve tasks after getting the VR system's instructions. He listened to the pedagogical agent's voice instructions, then changed the position of the tablet (i.e., environmental structuring) and started the task solution.

> "I can write it as 5 to the first power. Correct. 25 is 5 to the 2nd power. 125 is 5 to the 3rd power. 625 is 5 to the 4th power. I can write 3125 as 5 to the 5th power." (Think-aloud, Engin)

In the third task, students were responsible for writing an exponential function that represented the exponential growth in the numbers 5, 25, 125, 625, and 3125. While some of the participants had some difficulty performing this task, some of them applied task solution steps easily. For example, Eray reached the solution after one trial. He noticed what the t represented in the function. Thus, he selected the most appropriate function type for the virtual tablet. He made the decision to write 5 in the function's base since the numbers increased by multiples of 5. The quotation below belongs to Eray's think-aloud data, it depicts his way of thinking while achieving the task solution in the third task.

> "Then let's do it again. The exponent is t, and t is the number of weeks. Let's write 5 as the base." (Think-aloud, Eray)

The fourth task's focus was filling out the table for the number of hospitalizations by calculating 20% of the numbers in the second column of the table. Metin was one of the participants who engaged in the task solution process by setting the relations among numbers. He first watched the video instruction, then applied task solution steps to fill in the third column of the table by calculating the number of hospitalizations. He also constructed mathematical relations among numbers while engaging in the task solution process.

> "Since twenty percent is gone, I enter the number 1. I enter 1 in 5, the number 5. It's something that can be explained with functions and exponents. I do it this way. They are proportional to each other. After entering the next value, I send it to the console." (Think-aloud, Metin)

In general, task solution pertains to the solution of questions that are directly related to the tasks in order to progress with the tasks. Participants were obligated to respond to every multiple-choice question and the assignments presented in the tasks to sustain their progress. The task solution code emerged to represent the actions of participants in their actions of solutions.

4.1.3.7 Searching

Searching means investigating something required in the VR environment to proceed with the virtual tasks. The VR Module 2 provided students with the freedom to move around in the virtual environment. Students were able to move around to some degree. They could rotate 360 degrees and investigate virtual tools, graphs, tables, and visuals in the virtual environment. This freedom enabled participants to investigate the VR environment and progress in the virtual tasks. Students especially benefited from searching as a self-control strategy when they have difficulty maintaining their progress in virtual tasks, according to the results of this study. The ways of using searching as a self-control strategy in this study will be displayed by focusing on specific participants' experiences.

In the first task, participants were required to fill a table by observing an interactive bar graph. Some of the participants had difficulty finding the number of cases in the fifth week. For instance, it took a long time for Aylin to complete the first task. Her think-aloud data below and her screen recording data show her effort in finding the number of new cases in the fifth week. "She turned right, walked, and went near the bar graph" (Screen Recording, Aylin). As her think-aloud data indicates, she could not see any information about the fifth week. I also reminded her of the moments when she struggled with searching the number of cases for the fifth week and asked the reason why performing the first task took a long time in the stimulated recall part of the interview. Her interview data below shows the use of a searching strategy to discover something concrete that could assist her progress in the task. Since the interactive bar graph did not include any information about the number of cases for the fifth week, Aylin's searching trials directed her to apply some other strategies for completing the task.

> "She (the pedagogical agent) wants the fifth week. The fifth week does not appear here. Yes, the fifth week is not here. It shows four weeks." (Think-aloud, Aylin)
> "You know, I wanted to see numbers. I searched for a clue or something for a long time. I mean, I hope I can find it somehow. The reason it took so long is that, as I said, I was looking for something concrete. So I wanted to find something to show me for a week. That's why it took so long." (Interview, Aylin)

The third task was about writing an exponential function, and most of the participants had experienced some difficulties finding the correct answer. However, some participants could not complete the task even if they discovered the solution and wrote the accurate function in the function editor. Damla was one of those participants. She found the right answer, but she could not finalize the task. In the think-aloud data below, she summarized the confusion she experienced due to a lack of progression after her answer.

> "It doesn't accept it that way. 5 to the power t. It does not accept the answer. She (the pedagogical agent) said to send it to the console. Nothing happens. That's why I'm confused." (Think-aloud, Damla)

I showed Damla how she got confused before finishing the task in the stimulated recall part of the interview and asked about her experience regarding those points in the third task. She explained her searching process in detail in the interview. She searched each virtual object in the virtual space to find a way to complete the task. At the end of her effort, she turned around and recognized the panel through which she could submit her answer and finish the third task. Figure 11 illustrates the instance when she was pressing it just after noticing the submit button by moving around.

> “I constantly tried to interact with different things—anything that I found interactive. I clicked all the buttons you see. I moved the things I could move. And when there was nothing in front of me to move, I decided to look behind me. Then I remembered the panel behind me. When I turned around a little bit, I said, "Oh, there was a panel here." I thought I'd look there too. And I already saw the submit button.” (Interview, Damla)

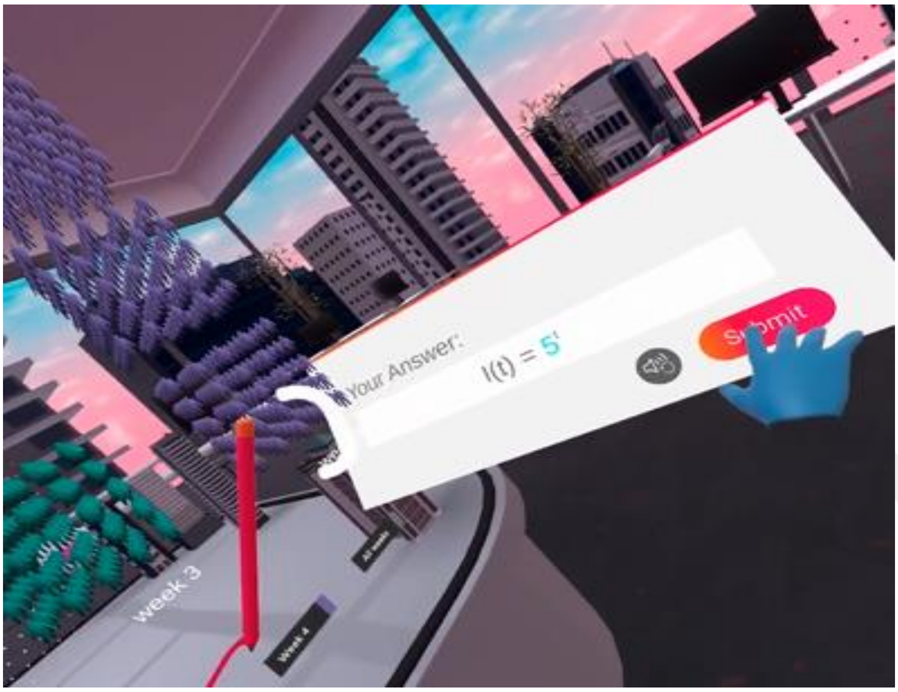


Figure 11. A screenshot of Damla’s experience

In brief, searching refers to the act of investigating and looking for something that is necessary within the VR environment in order to continue with the virtual tasks. The results of this study indicate that students derive particular advantages from utilizing searching as a self-control strategy, particularly when they encounter challenges in sustaining their performance in virtual tasks.

4.1.3.8 Self-instruction

Self-instruction means "overt or covert descriptions of how to proceed as one executes a task, such as self-questioning as one reads textual material" (Zimmerman & Moylan, 2009, p. 302). Participants of this study used self-instruction for two main purposes in accordance with this definition. The first one was identifying their solution paths, and the second one was asking questions about what to do for progression in the tasks.

Participants used self-instruction as a self-control strategy to describe how to proceed in the virtual task, according to the results of this study. Aylin was one of the participants who benefited from self-instruction throughout her experience with various tasks. For instance, she explained what to do for the first task in the excerpt below. She did not directly start to fill the table after getting the VR system's instructions; she clarified her solution path before taking action towards the solution instead.

> "Now. I will describe how the number of coronavirus patients increases from week to week." (Think-aloud, Aylin)

Some participants in this study also utilized self-instruction while performing multiple choice questions related to the tasks. For example, there was a multiple-choice question at the end of the fourth task, which asked the relationship between the number of hospitalizations and the number of cases in each week. The key information guiding the solution was the hospitalization of 20% of new cases each week. Aylin decided to conduct a calculation to reach the solution as displayed in her think-aloud data. In addition, she specified the tool that would assist her in answering the question.

> "Now. I'll calculate this. Let me take my pen. It will be easier." (Think-aloud, Aylin)

In the third task, for instance, Aziz used self-instruction to identify the solution steps, which were about the base and the power of the exponential function. He described how to write an exponential function while performing the task.

> "Likewise, I will use the week as power. I'll take 5 as the base." (Think-aloud, Aziz)

Participants also used self-instruction with the intention of self-questioning to carry out two points regarding the virtual tasks. Initially, participants asked self-questions to decide how to use virtual tools to maintain their progress on tasks. A tablet and a pen were the main virtual tools provided to the students in VR Module 2. It was needed to use these virtual tools effectively for task execution. The following excerpts illustrate some participants' self-questions that aim to decide what to do with the virtual tools.

> "Can I operate?" (Think-aloud, Demet)
> "Do I use the star to write exponents?" (Think-aloud, Demet)
> "Where do I delete it?" (Think-aloud, Aylin)

For instance, Demet asked herself about how to benefit from the tablet in two distinct tasks. In the first task, she initially filled out the first four weeks of the table by considering the numbers in the graph, then she decided to use the tablet for carrying out a set of calculations after her self-question about the possibility of using the tablet as a calculator. The second excerpt displayed Demet's experience with the second task. She decided to use the exponent function of the tablet to fill the table by self-questioning. In the last example, Aylin made a mistake while filling out the table for the first task. She looked at the tablet and decided to use the delete button to fix her error following the self-questioning.

The second point that participants used self-instruction by self-questioning was to decide what to do in tasks for their progress. Some participants asked self-questions to identify the next steps in the virtual tasks. For instance, the following think-aloud samples of three participants show how they utilized self-questioning in the third task, which was about exploring an exponential function based on information given in a table.

> "Do I have to fill in all the circles?" (Think-aloud, Aylin)
> "How do we make the graph?" (Think-aloud, Bartu)
> "What can be done right now? How can I extract the function of this?" (Think-aloud, Bartu)

Since Aylin asked herself about the circles in the function editor, she initially tried to use more than one algebraic notation while writing the function. Her initial trials based on self-questioning failed because of the need for only one algebraic notation for the function. In the same task, Bartu also used self-instruction by self-questioning. He asked self-questions about how to benefit from the graph for writing the function. Thus, he focused on the graph and tried to relate coordinates of the points in the graph with exponential numbers. For instance, (2, 25) was one of the points in the graph, and 25 was equal to the second power of 5. He observed this point after self-questioning and clarified the relation between the week number and the number of cases as 5 to the power t. Therefore, his self-instruction assisted him in deciding where to focus on the third task.

I also want to share Eray's experience. He used self-instruction five times in the first task until he reached the right solution. He struggled with finding the number of cases in the fifth week. He could not observe any information about the fifth week in the interactive bar graph. Initially, he asked himself what to do with the first task and decided to add all the numbers in the table.

> "Shall we write the total here then? Let's write the total." (Think-aloud, Eray)
> "Let me collect them now and write them down." (Think-aloud, Eray)

However, he could not get positive feedback from the VR system and realized his mistake. Then he made a new decision by giving new self-instructions. He asked himself what to do in the fifth week and chose a new solution path. He decided to imagine a fifth week in the table by considering the pattern in the numbers of the previous weeks, which enabled him to reach the solution in the first task.

> "The others were correct. Aren't we going to write the total for all week? Should we create a fifth week ourselves?" (Think-aloud, Eray)
> "So, let's create a fifth week ourselves." (Think-aloud, Eray)

Overall, self-instruction refers to explicit or implicit directives regarding the proper way to perform a task. (Zimmerman & Moylan, 2009). As defined, the participants of this study engaged in self-instruction for two primary objectives. The first involved the participants identifying the solution paths, while the second involved them posing questions regarding the necessary actions to advance in the virtual tasks.

4.1.3.9 Help-seeking

Help-seeking is a self-control strategy which means "soliciting assistance when learning or performing" (Zimmerman & Moylan, 2009, p. 303). The results of this study showed that participants used help-seeking as a self-control strategy while performing all virtual tasks. Esra and Gülden's interview data below displayed their points of view about the use of help-seeking in virtual tasks. When I asked them about what their strategies were, they reported only help-seeking as a strategy they used while performing the virtual task.

> "Because I got help where I couldn't find a solution. Yes, if we say strategy, getting help is for me". (Interview, Esra)
> "We could get hints whenever we wanted. It was beautiful there. Other than these, I did not follow a very special strategy. I used the resources given to me." (Interview, Gülden)

In VR Module 2, students were able to listen to or watch any instructions whenever they needed them. The VR system also included some hints in video format, and the participants were free to receive support from those hints when they had difficulty performing the tasks. I will focus on each task in terms of how and why participants requested the VR system's assistance to proceed.

In the first task, students were expected to fill a table by observing the cases in an interactive bar graph. Since Itır did not understand the task's demands at the beginning of the task, she could not attempt to fill the table. She got confused about how to write numbers in the table as integers or exponential numbers. She stated that "right now I have to write my cases week by week. But. I want to watch the video again. I didn't understand how to write exponents." (Think-aloud, Itır). In this way, she sought help in the virtual environment and decided to re-watch the video instructions for task comprehension.

The most frequently used sentences in think-aloud data were "I will watch the video again." (Think-aloud, Eray) before the help-seeking process. Some of the participants, such as Eray, had difficulty finding the cases of the fifth week in the first task. Since the interactive bar graph did not include any information regarding the fifth week, some participants could not proceed with the first task easily. They preferred to watch the video instructions again to comprehend what to do for the cases of the fifth week. Their think-aloud data showed the use of a help-seeking strategy while performing the task. Even if some participants did not put their intentions into words, screen recording data displayed how they sought to find a solution to the tasks. For instance, Figure 12 illustrates a participant's help-seeking process. Aylin could not decide the cases of the fifth week. In the screenshot, Aylin was trying to click on the button that provided her with video instructions. Thus, she watched the video instruction one more time, which assisted her in deciding how to solve the problem regarding the fifth week in the first task.

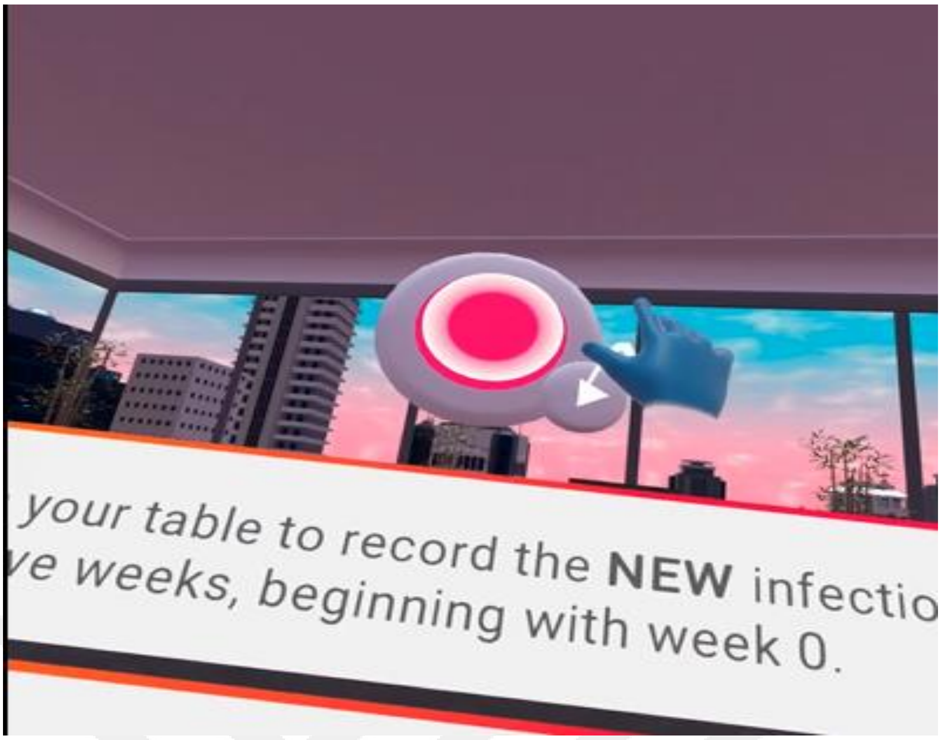


Figure 12. A screenshot of Aylin's experience

The second task required converting numbers (5, 25, 125, 625, and 3125) into exponential form. In this task, students filled in a secondary column in the table by examining the numbers in the initial column. Most of the participants did not need to use help-seeking strategy while performing the task. Even if some of them could not use the exponent function of the tablet, they did not engage in a help-seeking process to overcome this problem. For instance, I asked Demet the reason why she did not use the exponent button on the tablet to write numbers with exponential notations. She stated that she could not recognize the function of that button on the tablet.

> "Yes, I didn't notice that. Moreover, it was enough to click directly with our hands on the tablet. I tried things by pressing buttons and stuff. Oh, and I wrote some ridiculous numbers for a while anyway." (Interview, Demet)
> However, Itır stated that "I'm watching the video again" (Think-aloud, Itır)

Even if she did not realize the function of the exponent button on the tablet, she decided to use help-seeking as a self-control strategy and re-watched the video instructions, which provided her with assistance for the functions of the tools.

Subsequently, she noticed the function of the button by means of the VR system's assistance and used the exponent button for filling in the table.

In the third task, students were required to compose an exponential function illustrating the exponential growth of the numbers 5, 25, 125, 625, and 3125. In this task, the majority of participants faced challenges in determining the function. For example, Bartu could not comprehend what t means in the function. He said, "Can I listen to the tutorial again?" (Think-aloud, Bartu) while performing the task. Then, he re-watched the video instruction, which helped him recognize what t represented in the exponential function. Then he constructed the correct function owing to the VR system's assistance.

> "I felt stuck when I couldn't find it by trying. When I came to a dead end, I thought I wouldn't be able to find it by trying so that it wouldn't take too long. That's why I wanted to go back to the video to help." (Interview, Bartu)

In the same task, Didem said, "Now. I pressed the get help button to watch again." (Think-aloud, Didem) after making a number of mistakes. The pedagogical agent offered her assistance to maintain task progress. This support mechanism of the VR system provided her with more detailed video instructions. Figure 13 displays the instance when Didem pressed the get help button to watch the exhaustive video, which enabled her to solve the exponential function assignment of the third task. In addition, I reminded her of the moments when she got stuck in the stimulated recall part of the interview and requested that she share her experience with the third task. She explained how help-seeking strategy provided her with the opportunity to reach a clear explanation of the task and solve the problem.

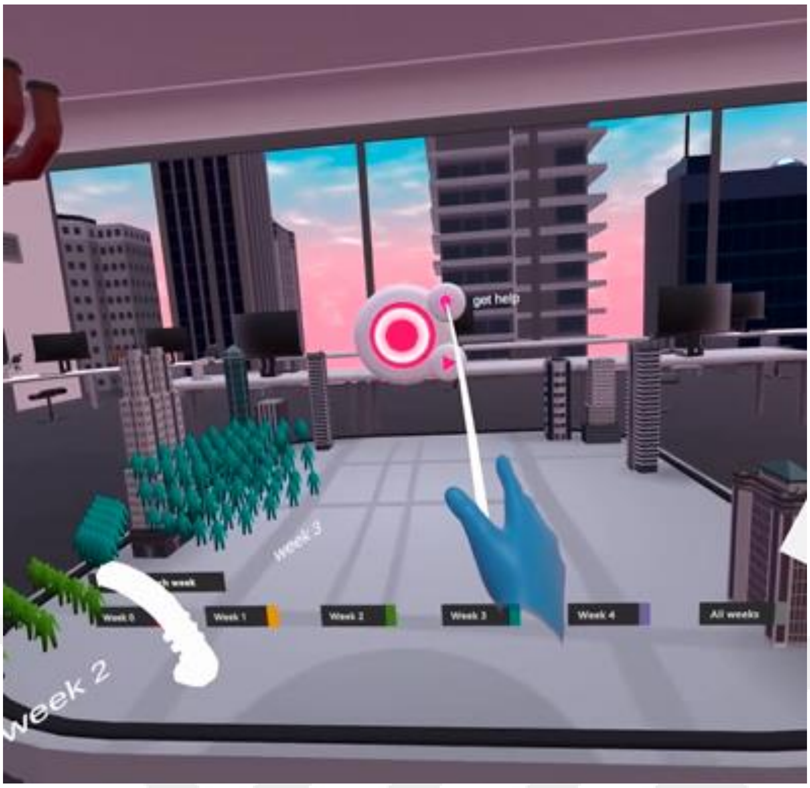


Figure 13. A screenshot of Didem's experience

> "So, I tried it, and there was a more descriptive explanation in the clue. So, I was able to figure it out by listening to the clue. Exactly what I should do." (Interview, Didem)

The goal of the fourth task was to complete the second column of the table, which depicted the count of hospitalizations. The revised values could be derived by calculating 20% of the values in the initial column. Eray, Etır, and Metin's think-aloud excerpts indicated participants' use of help-seeking strategy in the fourth task.

> "I wonder if I should watch this again." (Think-aloud, Eray)
> "I will watch the video again so that I can remember the numerical values." (Think-aloud, Itır)
> "She gave a rating, but I missed it." (Think-aloud, Metin)

The main point that participants sought for the system's assistance was about remembering the mathematical relation between the number of new cases and the number of hospitalizations. They wanted to be sure about the percentage that would be used to calculate values in the second column of the table. Thus, they engaged in help-seeking processes while performing the fourth task of VR Module 2.

In summary, help-seeking when performing or learning is an example of the self-control strategy (Zimmerman & Moylan, 2009). The findings of this research indicated that participants employed the self-control strategy of help-seeking while engaging in all virtual tasks.

4.1.3.10 Interacting with tables and graphs

Interacting with tables and graphs refers to students' interactions with the tables or graphs to solve a problem or understand the tasks. Participants completed four virtual tasks in VR Module 2, and they most often utilized interacting with tables and graphs as a self-control strategy to maintain their progress in virtual tasks. Since each task included a table or a graph participants interacted with them very often. However, all interactions were not analyzed as interacting with tables and graphs. When participants interacted with a table or graph to solve or comprehend a problem, that segment of data (think-aloud, screen recordings, or interview) was coded as interacting with table/graph/chart. I will focus on each virtual task and explain how participants utilized interacting with table/graph/chart as a self-control strategy in each task.

Students were expected to identify a pattern between numbers in the first task. They utilized an interactive bar graph to populate a table with the values 1, 5, 25, 125, 625, and 3125. The VR system initially provided an interactive bar graph before filling out the table assignment. Some of the participants directly interacted with the interactive bar graph to understand what the task was about. Aziz is one of those participants who observed the interactive bar graph and interpreted his observations in order to gain an initial comprehension of the task. His think-aloud excerpt below illustrated how he constructed the pattern between numbers. His initial understanding of the numbers helped him a lot in filling out the table assignment. Since he had already recognized exponential relations in numbers, he easily populated the table without any hesitation.

> “Right now, I'm seeing how many people have been infected over the weeks. Although it first infected a single person, it infected 5 people in the first week, 25 people the next week, and then continued exponentially.” (Think-aloud, Aziz)

Not all of the participants were able to complete the initial task with the same level of ease as Aziz. For instance, Esra wanted to benefit from the interactive bar graph after the table assignment was given to her. However, she did not construct a pattern between numbers. She preferred to count the number of cases represented for each week in the interactive bar graph. Figure 14 shows an instance of her experience where she was counting the numbers by using her virtual hand. However, her initial answer for the fourth week was incorrect because she did not move the interactive bar graph to its widest position. Thus, she could not observe all the cases in the fourth week. Esra insisted on her strategy of interacting with the graph, and she drew the graph to see all the patients. Then, she counted the number of all patients in the fourth week and filled the table for the first four weeks by interacting with the bar graph.

> “I'm still in week 4. Can I draw it a little like this?” (Think-aloud, Esra)
> “There are five in each row. In the bottom row, 5 times 5 times 5 is 125. 125, 250…” (Think-aloud, Esra)

The second task involved expressing numbers (5, 25, 125, 625, and 3125) using exponential notation. In this task, students filled a second column in the table by considering the numbers in the first column. None of the participants used interacting with a table/graph/chart as a self-control strategy. They simply looked at the first column of the table and expressed those numbers in terms of exponents.

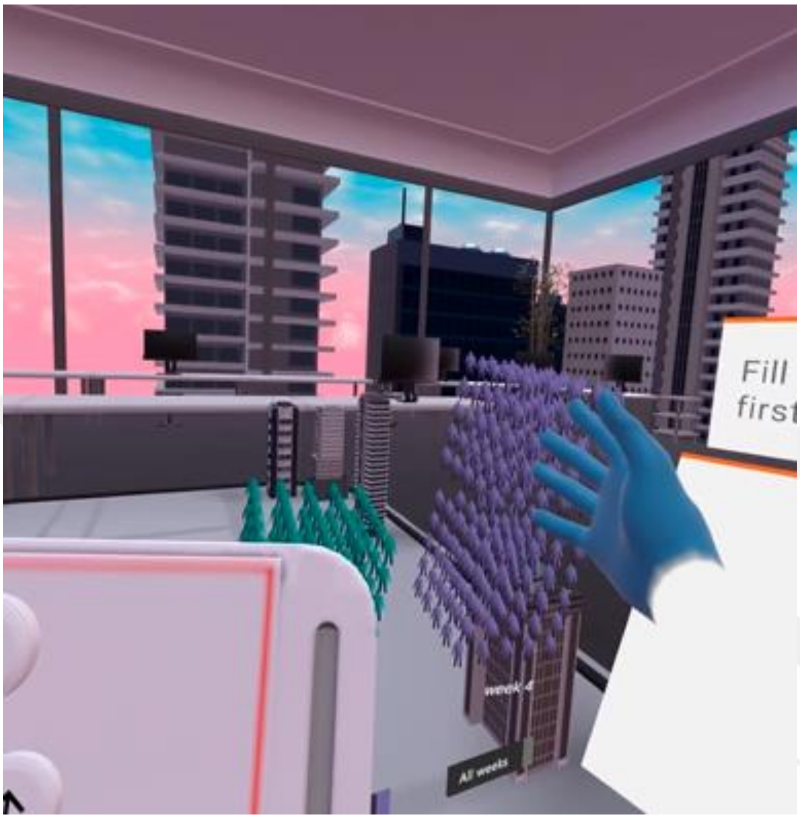


Figure 14. A screenshot of Esra's experience

For the third task, students had to write an exponential function that showed how the numbers 5, 25, 125, 625, and 3125 grew exponentially. In this task, most of the participants had difficulty deciding what the function was. Interacting with the chart was the most frequently used self-control strategy that assisted participants in completing the task. The VR system provided students with a chart that showed the number of weeks and patient numbers in a binary system. For example, there were 5 patients in the first week. The point (1, 5) in the chart served as a representation of this point. In addition, students could draw a graph of their functions and check whether the constructed function fits the data points or not. The interview excerpt below displays Banu’s experience with the third task. Banu could not find the correct solution at the beginning of the task. She initially tried a set of strategies and engaged in monitoring processes. However, she could not realize what the letter t represented. Then, at the end of the task, she decided to look more closely at the chart. She interacted with the chart only once in the third task. This interaction gave rise to her noticing of the t. Banu recognized that t represented the number of the week. In this way, she reached the solution and completed the third task.

> Banu: “Well, I didn't look at t in that graph at first. Then I tried to solve the given things. I tried to understand what happened. Then, I looked at the chart. Oh, it says t here. It was changing every week anyway, so I decided to do it directly over 5. I had a hard time because I didn't look at t, so I didn't know what to do directly.”
> Researcher: “Didn't you look at the t on this calculator?”
> Banu: “The chart said t for the week. I didn't think of that t as a week.”
> Researcher: “Isn't it what is written below?”
> Banu: “Exactly.”
> Researcher: “Did you solve it after you noticed it?”
> Banu: “Yes.” (Interview, Banu)

The objective of the fourth task was to fill the second column of the table, which represented the number of hospitalizations. By computing 20% of the values in the first column, one could determine the new values. Itır and Eray’s interview data showed how they utilized interacting with the table to solve the fourth task. The numbers in the first column were 5, 25, 125, 625, and 3125. While some participants computed 20% of these values to fill the column of the table, some of them, such as Itır and Eray focused on the pattern in numbers. They realized that 20% of each value also resulted in a similar pattern of 1, 5, 25, 125, and 625. The number of hospitalizations in a week was equal to the number of new cases in the previous week. Itır and Eray discovered this pattern by interacting with the table. Thus, they utilized interacting with the table as a self-control strategy, which assisted them in solving the assignment.

> “It was beneficial for me to be able to see them all together in tabular form. It made me realize there was a pattern there. I noticed that the number directly opposite it appears here. OK, then 625.” (Interview, Itır)
> “I like to have an order. So that I can write both in the new case section and the hospitalization section. There was already a certain pattern among them. I noticed. There was the pattern of the previous week. I thought I would write too.” (Interview, Eray)

In sum, when students engage with tables and graphs to solve problems or comprehend assignments, it's referred to as "interacting with a table or graph." In VR Module 2, participants finished four virtual activities, and the most common self-control strategy they used to keep up their progress was interacting with tables, graphs, and charts.

4.1.3.11 Drawing

Drawing refers to students’ actions for constructing graphs to assist their progress in the virtual task. Although VR Module 2 was composed of four tasks, participants used drawing as a self-control strategy in the third task. This can be related to the nature of the assignments that students were expected to complete. In the first assignment of the third task, students were required to formulate an exponential function that demonstrated the exponential increase of the numbers 5, 25, 125, 625, and 3125. Most of the participants encountered difficulty determining the function of this task. Drawing was the self-control strategy that participants used for checking the correctness of their answers. The second and third assignments were two similar multiple-choice questions that asked students how the graph of the exponential function changed in different circumstances.

Most of the participants utilized drawing to check whether their answer was correct or not. I will focus on Aziz’s experience because it illustrates a common experience regarding drawing strategy in the first assignment of the third task. His initial answer was l(t) = $5t^2$. He checked his answer by pressing the graph button. His screen recording data in Figure 15 displayed the instance when he drew the graph of the function. The deviation of the graph from the actual data points can be observed in Figure 15.

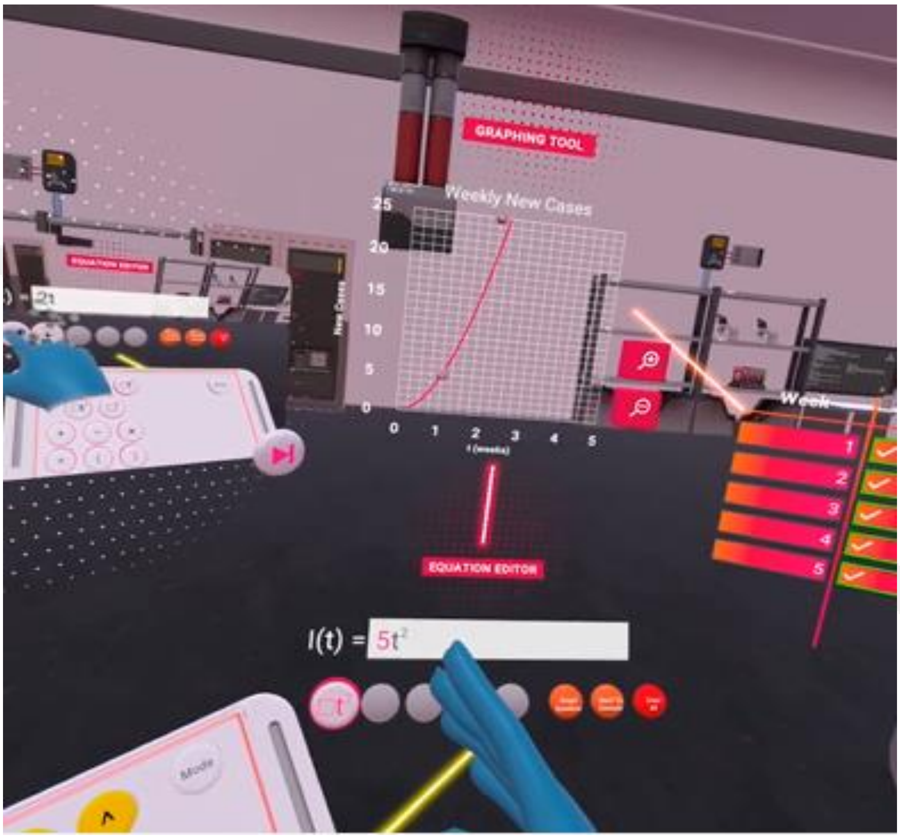


Figure 15. A screenshot of Aziz's experience

If 2 is written in the function l(5) = 5.2^2, the coordinates of the point becomes (2, 20) instead of (2, 25) which is the actual data point. Thus, Aziz also observed the graph he drew, and decided his mistake. He tried other functions such as l(t) = $5t^2$- 1 or l(t) = 5t. He drew the graph at each time and recognized his errors. At the end he wrote l(t) = 5^t in the function editor, pressed the graph button, observed the graph, decided the accuracy of his answer, and completed the assignment.

In the same assignment, Itır used drawing as a self-control strategy in an unusual way. She preferred to use the pen for drawing the graph manually instead of pressing the graph button which was an automatic way of drawing. Think-aloud data below represents how she drew the graph by pen. She initially decided the points of (1, 5) and (2, 25) by looking at her answers in the table. Then, she identified the locations of those points on the chart and drew the graph by using the pen. Figure 16 displayed the view of the graph constructed manually. Thus, she checked the accuracy of the function, l(t) = 5^t and solved the assignment.

> "Now I'm going to the chart. Ok. I said 5 in week 1. I'm marking 1 out of 5. I draw graphs for myself. I said 25 in the second week. Now 2. I draw 25 a week. Well, my graph will be like this. Ok." (Think-aloud, Itır)

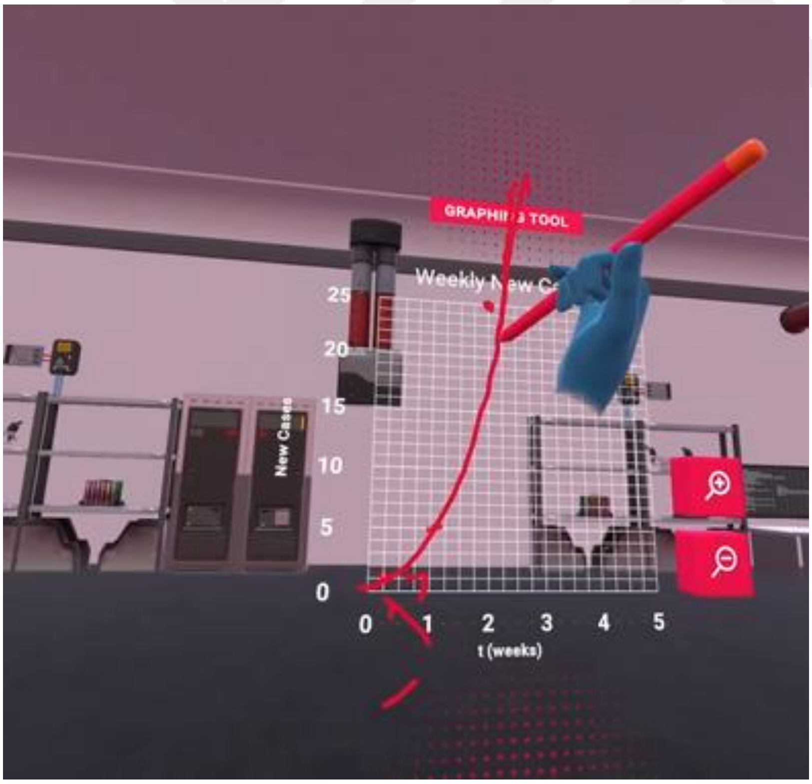


Figure 16. A screenshot of Itır's experience

Some participants also benefited from drawing strategy in the second and third assignments of the third tasks. The second and third assignments were two similar multiple-choice questions. They asked participants how the graph of the model changed in different situations. Hakkı, for instance, utilized drawing strategy to make a decision in the second assignment as displayed in Figure 17. The second assignment was about what happens to the graph in the first assignment when people stop wearing masks. This was reducing the number of containment protocols, which would result in a faster spread of the virus. Thus, the number of cases would increase rapidly. Hakkı explored this relation by depicting the new position of the graph for the recent situation. His use of the drawing strategy in the multiple-choice question stemmed from his active use of the pen for solving the problem.

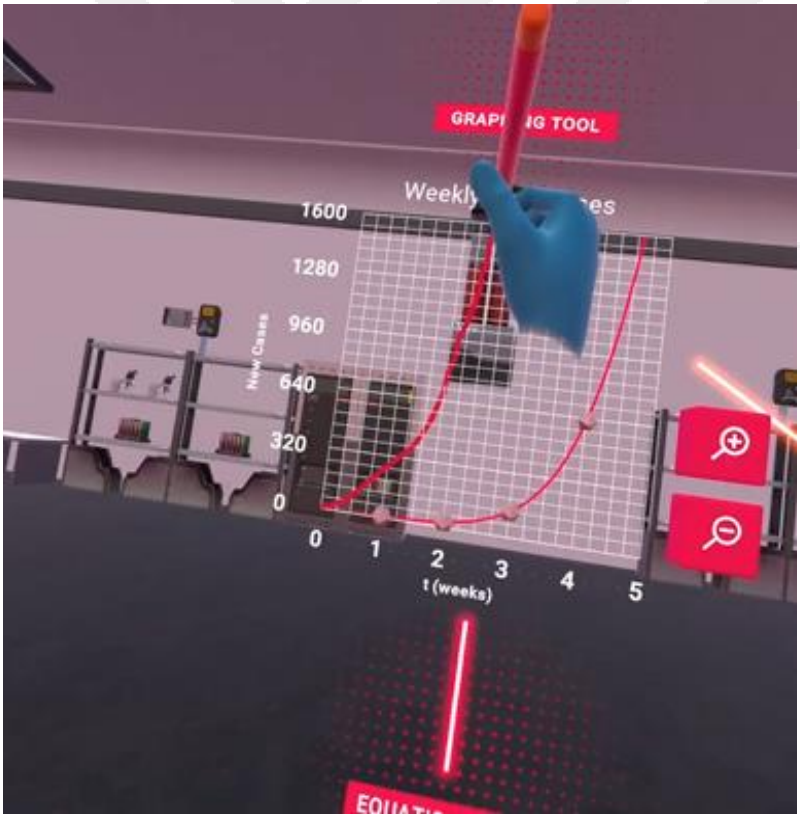


Figure 17. A screenshot of Hakkı's experience

In brief, drawing describes the activities students do to build graphs that help them advance in the virtual assignment. The self-control strategy participants employed in this study to verify the accuracy of their responses was drawing.

4.1.3.12 Trial-error

Trial-error is a self-control strategy which means trying, making errors and trying again to solve a problem or understand the tasks. When I asked participants about the strategies they used in virtual tasks, the most common answer was trial-error. For instance, Aziz claimed that he used trial-error as a learning strategy, and it made his learning permanent. Bartu argued that trial-error made learning enjoyable for him. Sude shared that trial-error provided her more experiences, which made learning more memorable. In brief, trial-error was regarded as a favorable learning strategy that made learning more enjoyable and memorable for the participants.

> "I learned the subject through trial and error. It has become more permanent." (Interview, Aziz)
> "I enjoy what I do more when I try to find it." (Interview, Bartu)
> "I think you learn better by trying everything. As I said, you can learn better by trying because experiences are more memorable." (Interview, Sude)

Participants used trial-error in all tasks, according to the results of this study. In the first task, students were expected to discern a pattern among the numbers. They utilized an interactive bar graph to complete a table with the values 1, 5, 25, 125, 625, and 3125. Participants had difficulty filling the first and last rows of the table. They used trial-error as a self-control strategy to maintain their progress on the task. For instance, Metin could not decide how to write the number in the fifth week's row. He initially tried to add all the numbers that he saw in the table. Then, his initial trial failed. This error enabled him to investigate a new perspective to solve the problem. Therefore, the use of trial-error strategy helped him search for and find an accurate solution to this task.

"Or should I enter the total? Yes. I'm trying it. 781." (Think-aloud, Metin)

The second assignment required representing numbers (5, 25, 125, 625, 3125) using exponential notation. In this task, students populated a secondary column in the table by examining the figures in the initial column. Participants did not require trial-error strategy to recognize the exponential notations of the numbers. Fatih was the only one who used trial-error strategy in this task. Even if he understood what to do in this task, he could not detect the exponent button in the tablet. Thus, he used trial-error strategy to decide the functions of the buttons on the tablet. Then, he completed the task after deciding the functions of the buttons on the tablet.

In the third task, students were required to formulate an exponential function illustrating the exponential growth of the numbers 5, 25, 125, 625, and 3125. During this task, the majority of participants struggled to determine the function. Trial-error was one of the strategies they used to proceed the task. The sentence that they used as the sign of trial-error was "I want to try this, too" (Think-aloud, Bartu). Bartu struggled with finding the correct function that represents the exponential growth of the numbers 5, 25, 125, 625, and 3125. In the stimulated recall part of the interview, I showed the moments when he had difficulty in writing the right function. He shared that he had problems following the pedagogical agent's instructions on this task. Thus, he applied a trial-error strategy to handle the third task. He guessed the potential answers for the function until he made an accurate and reasonable prediction. Even if it took some time, he succeeded in completing the task by means of trial-error strategy.

> "In those sections, for example, when creating the equation from the graph. So I experienced such an incident. I tried to solve it on my own. It took a while, but it happened. I did." (Interview, Bartu)

In addition, participants, such as Bartu, who preferred to utilize trial-error as a strategy in the third task, used trial-error and drawing together. For instance, Figure 18 illustrates Aziz's joint use of trial-error and drawing strategies. He initially guessed l(t) = $5t^2 - 1$ as the answer of the assignment. He wrote the function in the equation editor for trial. Then, he pressed the graph button to check the accuracy of his answer. Thus, he recognized his error in his trial, which assisted him in judging his answer until he reached an accurate solution.

Figure 18. A screenshot of Aziz's experience

The aim of the fourth task was to complete the second column of the table, indicating the number of hospitalizations. The updated values could be calculated by determining 20% of the values in the initial column. Only one participant used the trial-error strategy for solving the fourth task. Didem watched the video instruction at the beginning of the task. However, she did not recognize the solution steps initially. I asked her about her experience in the stimulated recall part of the interview. The interview data confirmed my observation based on think-aloud and screen recording data about her misunderstanding about the task solution.

> "At first, I thought... There are 3000 beds. I thought it was 20% of 3000 beds. That's why I thought that if there were 5 patients, there would be enough beds for each patient, up to 3000. But I realized by watching that it was not directly 20% of 3 thousand, but 20% of 25. It didn't seem clear to me in the first video." (Interview, Didem)

Didem utilized trial-error strategy three times in this task. When she tried her answers and noticed her errors, she employed other strategies, such as help-seeking and elaboration, to proceed with the task. In sum, the use of trial-error strategy assisted Didem in trying other strategies for grasping the task's demands and the solution steps of the fourth task.

Overall, "trial and error" is a self-control strategy that involves several attempts, making mistakes, and then trying again in order to solve a problem or comprehend tasks. When I asked about the strategies employed by participants in virtual tasks, the prevailing response was trial and error. Essentially, "trial and error" was considered a beneficial learning approach that enhanced the participants' enjoyment and retention of information.

4.1.3.13 Observation-emulation

Observation-emulation refers to "vicarious induction of a skill from a proficient model and imitative performance of a general pattern or style of a model's skills by social assistance" (Zimmerman, 2000, p. 29). The VR system provided students with a set of video instructions in VR Module 2. These video instructions included not only information about the subject matter but also a model of how to use the virtual tools. The analysis of screen recording data showed how participants' initial observations of the pedagogical agent's behaviors guided their actions in the virtual tasks. I will focus on how participants benefited from observation-emulation for their progress in each task.

Figure 19 below displays Engin's experience in the early seconds of the first task. At the beginning of the task, video instructions were given to students. The video instruction showed them how to move the interactive bar graph. Most participants imitated the pedagogical agent's behaviors while observing her. Engin also looked at the video instructions. He repeated the pedagogical agent's behaviors to make the graph smaller or bigger. Figure 19 illustrates Engin's manipulation of the graph simultaneously with the pedagogical agent by using observation-emulation as a strategy.

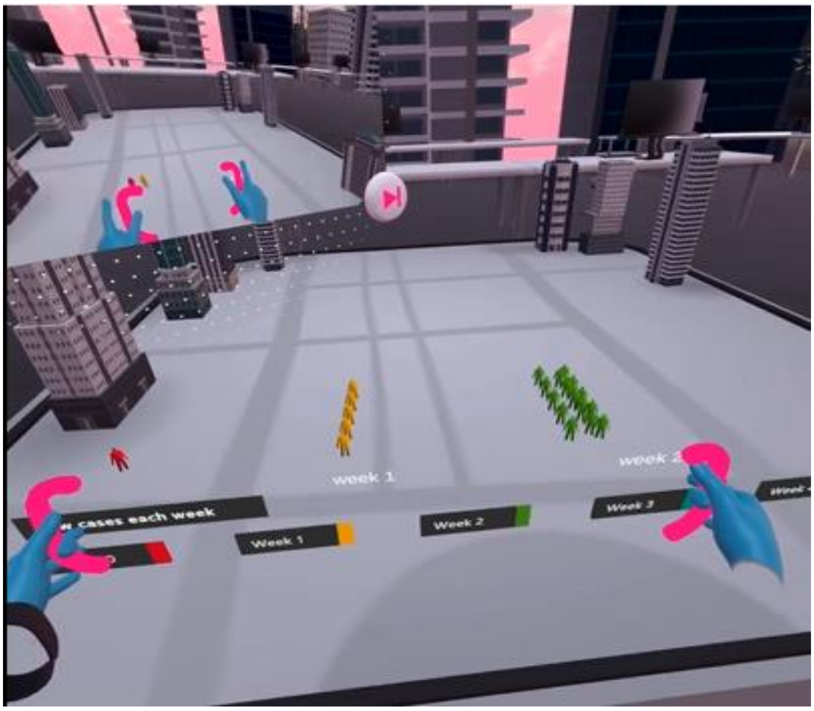


Figure 19. A screenshot of Engin's experience

Afterwards, I noticed that some participants used the virtual pen to calculate the number of cases each week. For example, Figure 20 depicts Erden's use of the pen for counting the number of cases week by week. I showed him his experience in the stimulated recall part of the interview. He associated his actions with the pedagogical agent's behaviors in the video instruction. Since the pedagogical agent presented the pen as an assistant tool that could be used for counting the number of cases, Erden preferred to repeat the actions of the pedagogical agent to proceed with the task.

> The reason why I drew them one by one was because they were drawn in the video, so I wanted to apply what I saw in the video. (Interview, Erden)

One of the self-control strategies was environmental structuring, as discussed before. Most participants changed the position of the tablet for effective use of the tablet. Their first experience about changing the position of the tablet stemmed from their use of observation-emulation strategy in the first task. The VR system introduced students to moving the tablet in the virtual space in the first task. Participants observed and imitated the pedagogical agent's behavior to change the location of the tablet, and they used this experience in the following moments for environmental structuring. The second task required expressing numbers (5, 25, 125, 625, and 3125) in exponential form. In this assignment, students filled a secondary column in the table by analyzing the figures in the primary column. Participants did not use any observation-emulation strategy for this task. They just filled the second column of the table by exponential numbers.

In the third task, students were required to formulate an exponential function illustrating the exponential growth of the numbers 5, 25, 125, 625, and 3125. At the beginning of the second task, the VR system showed a video instruction that included the use of zoom in and zoom out buttons to better observe the points in the exponential functions constructed by the participants. Some participants, such as

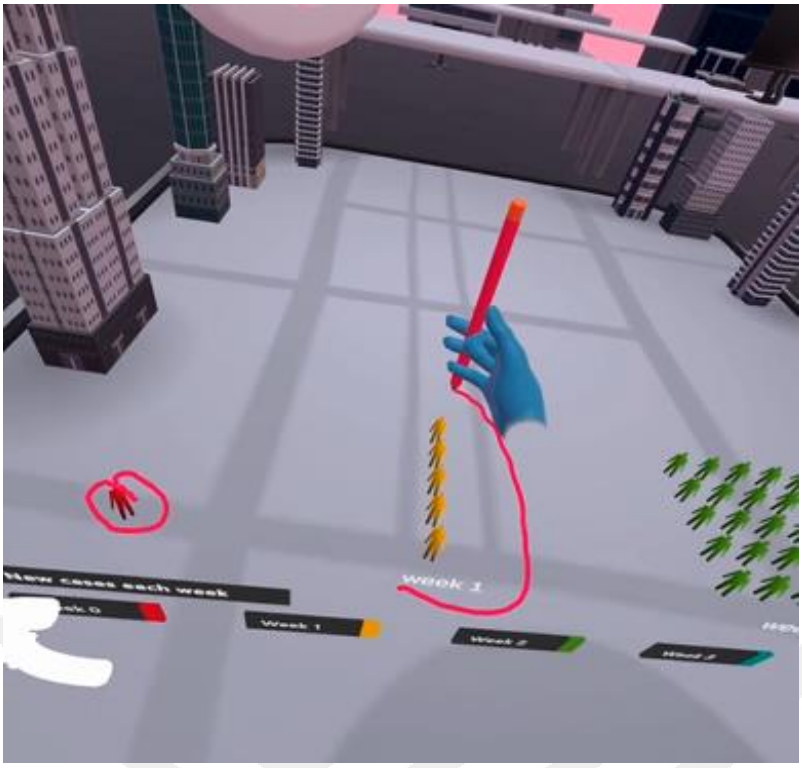


Figure 20. A screenshot of Erden's experience

Engin, directly practiced these buttons before writing an exponential function in the equation editor. Figure 21 represents Engin's action after observing the pedagogical agent in the video instruction. He copied the pedagogical agent's behavior and experience by clicking the zoom in and zoom out buttons near the chart. In addition, participants engaged in an observation-emulation process to change the position of the tablet in the third task. The VR system provided a second video instruction that explained how to write an exponential function in the equation editor. However, the location of the tablet was far away from the equation editor. Thus, the pedagogical agent moved the tablet closer to the equation editor without giving any voice instructions. Most participants observed this behavior of the pedagogical agent and repeated it based on their observations.

In addition, one participant imitated the pedagogical agent's use of the pen for drawing the graph of the exponential function in the third task. Zerrin observed how the pedagogical agent took the pen and used it for drawing the graph, and initially repeated the pedagogical agent's behavior of taking the pen in the third task. Later on, she used the pen for the drawing strategy to proceed with the task.

The objective of the fourth task was to fill the second column of the table, representing the count of hospitalizations. The revised values could be computed by calculating 20% of the values in the initial column. None of the participants utilized the observation-emulation strategy in the fourth task. They merely focused on the calculations for solving the task.

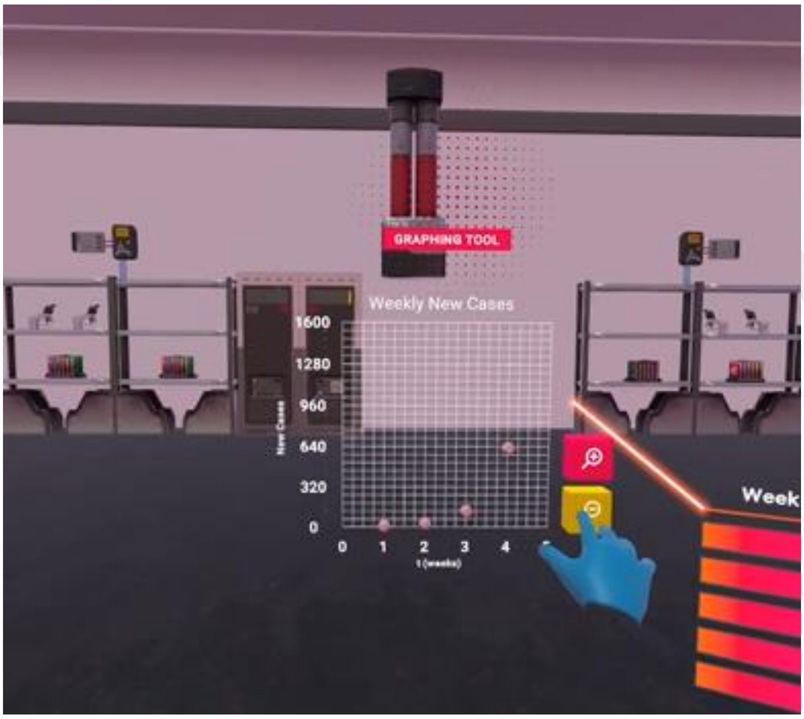


Figure 21. A screenshot of Engin's experience

In summary, the acquisition of a skill from a competent model and the imitation of an overall pattern or style of a model's skills through social assistance define observation-emulation (Zimmerman, 2000). In VR Module 2, the students were presented with a series of video instructions. In addition to providing subject-matter information, these video instructions also demonstrated how to operate the virtual tools. The analysis of the screen recording data revealed that the participants' initial observations of the pedagogical agent's behavior had an impact on their actions in the virtual tasks.

4.2 Features that are conducive to students' SRL processes

The second research question that guided this study was "how is the VR-based learning environment conducive to students' SRL processes?" The learning environment consisted of a combination of the VR learning environment and traditional learning activities. To address this question, think-aloud, screen recording, and interview data were jointly analyzed by using content analysis with an inductive approach (Miles et al., 2015; Patton, 2015). Six main features of the VR-based learning environment enabled students to engage in SRL processes while performing virtual tasks. Interactions, assessment and feedback mechanisms, agency, visual and auditory elements, instructions, and instructional activities were categories that assisted high-school students' SRL processes in virtual tasks. Table 8 displays definitions of categories regarding features that support students' SRL processes. Table 9 shows minimum and maximum values, absolute frequencies, means and standard deviations of all coded features that are conducive to students' SRL processes. Each feature, their sub-categories, and the ways in which they are conducive to students' SRL processes will be explained in this chapter.

4.2.1 Interactions

Interactions are crucial for creating immersive and engaging experiences in the VR learning environment, and they primarily arise from the level of embodiment that the user experiences (Fowler, 2015). Interaction includes a set of activities that students can carry out, such as moving in the virtual space, changing the positions of the virtual objects, and manipulating the object. Table 10 represents how interactions occurred in the VR learning environment. Students interacted in the VR learning environment in three ways: by manipulating the graphs, relocating the objects, and moving around.

Table 8. Categories for Features that Are Conducive to SRL Processes

Category	Definition
Interactions	"Interactions resulting mainly from the degree of embodiment experienced by the user" (Fowler, 2015, p.413)
Assessment and Feedback Mechanisms	The tools and processes used to evaluate and provide information on the progress and performance of learners engaged in immersive educational experiences facilitated by virtual reality technology
Agency	"The degree of freedom and control that a learner is given to perform meaningful actions in a learning environment." (Makransky et al., 2020)
Visual and Auditory Elements	The visual and audio components that create the virtual world within the VR learning environment
Instructions	Having access to a tutorial or to instructions on how to use the VR application and how to perform the learning tasks. The instructions can be conveyed through text, audio, or video formats (Radianti et al., 2020).
Instructional Activities	Paper-based tasks that are designed to facilitate learning in VR.

Table 9. Absolute Frequencies and Means of All Coded Features

	Min	Max	Absolute Frequency	M	SD
Interactions	0	11	104	5.20	3.55
Manipulating the Graph	0	8	40	2.00	1.92
Relocating Objects	0	7	40	2.00	1.92
Moving Around	0	4	24	1.2	1.2
Assessment and Feedback Mechanisms	3	12	144	7.20	2.55
Providing Feedback	0	7	67	3.35	2.08
Offering Extra Support	0	2	9	0.45	0.76
Providing Practice Activities	1	4	68	3.40	0.88
Agency	0	11	91	4.55	2.70
Being Free to Try	0	7	52	2.60	2.39
Being Free to Re-watch Videos	0	4	28	1.40	1.31
Being Free to Use Objects	0	4	11	0.55	1.15
Visual and Auditory Elements	2	14	135	6.75	3.32
Providing Graphs	1	10	90	4.50	3.05
Providing Tables	0	7	41	2.05	1.73
Providing Extra Support by Video	0	1	4	0.20	0.41
Instructions	2	15	154	7.70	4.85
Written Instructions	0	6	40	2.00	1.59
Voice Instruction	0	9	35	1.75	2.31
Video Instruction	0	10	79	3.95	2.67
Instructional Activities	2	4	40	2.00	1.30
Pre-Training	0	3	27	1.35	1.04
Summarizing	0	1	13	0.65	0.49
Sum all Coded Features	18	63	668	33.40	10.43

4.2.1.1 Manipulating the graph

Manipulating the graph is one of the ways for participants to interact in the virtual learning environment. It refers to making alterations to the graphs in virtual tasks. Results of this study showed that students monitored their progress and utilised searching and interacting with tables and graphs as self-control strategies by manipulating the graph.

Firstly, manipulating the graph as a way of interaction assisted students' monitoring of progress in the VR learning environment. Monitoring of progress means checking the behaviour and mathematical solutions and conjectures to proceed during the virtual tasks. The interactive nature of the VR learning environment enabled participants to track their learning through virtual tasks. For instance, one of the participants shared that:

> "The game was very interactive. Thus, I understood better in the game when I had some difficulty or when I did not understand." (Interview, Gülden)

Table 10. Sub-categories of Interactions

Sub-Category	Definition	Examples
Manipulating the Graph	Making alterations to the graphs	It was provided. Ok. That's it. One minute. Let's zoom out the graph. (Think-aloud, Fatih). The student drew the graph of the function and wanted to check his answer by zooming out the graph. (Screen Recording, Fatih)
Relocating Objects	Moving and changing the position of virtual objects	Let me get the thing first. I bought this. Let me pull this here too. (Think-aloud, Fatih) The student took the calculator. And changed its position to see the table clearly (Screen Recording, Fatih)
Moving around	Exploring the virtual environment on their own by walking and turning (Radianti, 2020)	I can't see it around either. Oh okay. I found it. (Think-aloud, Fatih) The VR system responded to the student's request for assistance by providing video. He could not realise the location of the video at first. (Screen Recording, Fatih)

She regarded the interactive features of the VR learning environment as facilitators for her understanding of the virtual tasks. Participants could distinguish instances when they had difficulty progressing thanks to interacting with the VR environment, which helped them to check their behaviours and solutions to reach accurate solutions. For instance, manipulating the graph as an interaction method enabled participants to monitor their progress in the third task. The third task included an assignment regarding writing an exponential function that represents the exponential growth in the numbers 5, 25, 125, 625, and 3125. Participants, who wanted to check the answers after writing a function in the equation editor, initially drew the graph of the function. While some participants checked their answers without making any changes to the graph, some of them preferred to manipulate the graph by using zoom in and zoom out buttons near the graph. Their purpose was to explore certain points in the graph and determine the correctness of the exponential function written in the equation editor. Hakkı's experience in this task illustrates a typical example in terms of monitoring of progress by means of graph manipulation. Figure 21 displays his experience in the third task while checking a specific point in the graph after manipulating it. Hakkı firstly wrote 5 to the power t as the exponential function that represents the exponential growth in the numbers 5, 25, 125, 625, and 3125. Then, he drew the graph of the function and observed the graph by using the graphing tool. However, he noticed the inadequacy of observable points in the graph and decided to manipulate the graph by using the zoom-out button near the graphing tool. He could then observe more points on the graph. For instance, he could see the point (3, 125) after zooming out in the graph, as seen in Figure 22. His think-aloud excerpt below shows the moments when he observed all points in the graph by zooming out. When he saw all the points in the graph that belonged to the exponential function he wrote, he realized the accuracy of his answer for the assignment.

> "The data for the 4th week is not visible. But. There's 25. For week 3? Let me zoom out a little further. Here's where I need to look. 125. When you zoom out a little further away, other data also comes. Ok." (Think-aloud, Hakkı)

In addition, eight other participants shared a similar pattern with Hakkı in terms of their interactions with the VR environment and their SRL processes. I also asked about how interacting with the graph by zooming in and zooming out assisted their learning in the stimulated recall part of the interview. The common element in their responses can be represented by the following explanation, voiced by one of the participants:

> "To see if I did it right. I thought I did it right, but I still wanted to check" (Interview, Bartu)

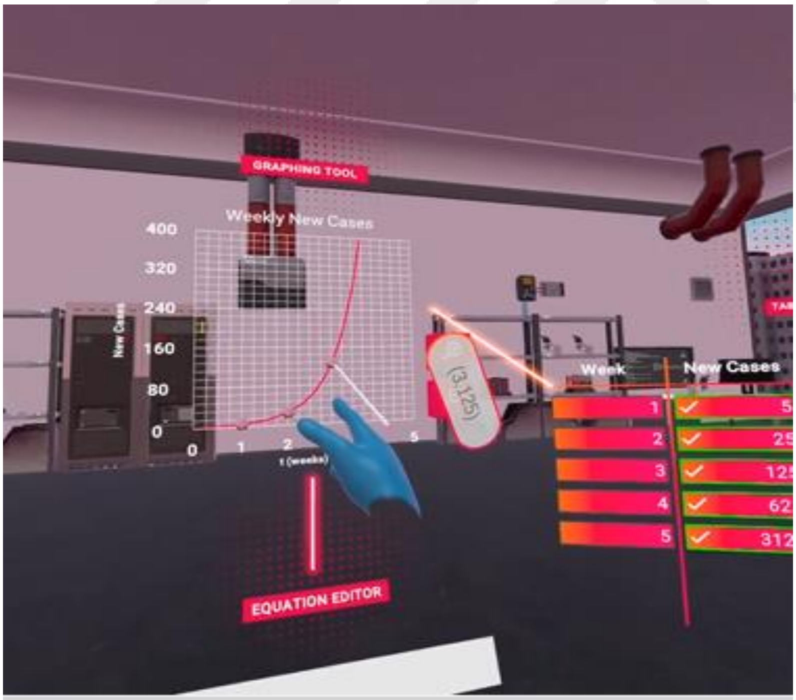


Figure 22. A screenshot from Hakkı's experience

The responses articulating the reasons for manipulating the graphs focused on the use of manipulating the graph mechanism of the VR learning environment for monitoring their progress on the task.

Secondly, manipulating the graph is conducive to students' use of searching as a self-control strategy. Searching means investigating the VR environment to proceed with the tasks. In the first task, for instance, eight participants utilized the searching strategy by manipulating the graph. In this task, participants were expected to fill out a table by considering the number of new cases in an interactive bar graph. The number of cases was 1, 5, 25, 125, 625, and 3125. Since the final week's cases could not be observed in the graph given initially, participants tried to manipulate the graph by making it smaller and bigger. They used the searching strategy to find a solution to the problem they faced in the first task. Aylin's think-aloud excerpt below shows her attempt to investigate the number of cases in the fifth week by changing the size of the interactive bar graph that was observed in the participant's screen recordings.

> "I need the number of cases for the 5th week. But there is no week 5 here. I cannot see. There is a four weeks' report. Yes, 4 weeks." (Think-aloud, Aylin)

Thirdly, eight participants utilised the interacting with table and graph strategy by manipulating the graph. They could change the size of the interactive bar graph in the first task, and they could zoom in and zoom out to the graph of the exponential function in the third task. Interacting with tables and graphs was a self-control strategy that was used for solving a problem or understanding the task, as displayed in Sude's utterances below.

> "Here I can show the values by enlarging or reducing the size. Hmm. Week zero is here. It says 25 for 2, 125 for 3." (Think-aloud, Sude)

Sude used the zoom in and zoom out buttons to change the values in the graph. She first sketched the graph and then examined the plotted points. She was unsure, however, of the graph's purpose due to the restricted number of points that were visible in the graph. Then, she explored how she could manipulate the graph, and she benefited from it by understanding the aim and use of the graph to solve the exponential function assignment of the third task.

4.2.1.2 Relocating objects

Relocating objects refers to moving and changing the position of virtual objects. Students were able to change the position of the tablet in the VR learning environment. The tablet served as a highly practical instrument for pupils, allowing them to input numbers and functions and perform calculations. Students had the ability to physically manipulate the calculator and relocate it within the virtual environment. This feature assisted participants in utilizing the self-control strategy of environmental structuring.

Environmental structuring means changing the position of the tablet or deleting what is written to “increase the effectiveness of one’s immediate environment” (Zimmerman & Moylan, 2009, p. 303). The relocating objects feature of the VR system allowed students to use environmental structuring strategies in the VR learning environment. Fifteen participants employed the environmental structuring strategy to increase the effectiveness of the VR learning environment. Most of the environmental structuring codes emerged while participants were relocating the virtual tools. Thus, screen recordings were the main data source for exploring participants’ environmental structuring strategies in the VR learning environment. Nevertheless, the subsequent participants explicitly described their actions as they were performing them. For instance, Gülden interacted with the tablet by changing its position. She had some difficulty with the first task. She could not find the cases in the first and fifth weeks. She decided to focus on the interactive bar graph to proceed with the task. Then, she relocated the tablet to get a better view for observing the interactive bar graph.

> “Let me carry the tablet like this.” (Think-aloud, Gülden)

Demet switched on her tablet to write the function in the third task. The initial position of the tablet was away from the location of the equation editor. Thus, she relocated the tablet in front of the equation editor for effortless use of the tablet without turning left or right.

> “I took the keyboard (the tablet). I will write the function. I'm currently locating the keyboard.” (Think-aloud, Demet)

For a similar purpose, Metin used the environmental structuring strategy in the first task. He changed the location of the tablet near the table editor for easy use of it while filling out the table.

> “I'm holding it. I can carry it with me. Calculation. I write the data into the table.” (Think-aloud, Metin)

Fatih utilized the environmental structuring strategy in the fourth task. He interacted with the tablet by relocating it. Fatih was expected to fill out the second column of a table by calculating 20% of the number of new cases in the first column of the table.

> I'll take the tablet first. Let me pull this here too. (Think-aloud, Fatih)

The think-aloud excerpt above illustrates the instance while he was holding the tablet and recording it in the virtual space in a way that could not prevent him from seeing the table clearly.

4.2.1.3 Moving around

Moving around refers to exploring the virtual environment on their own by walking and turning (Radianti, 2020). Moving around is a mechanism that is related to the navigation feature of virtual reality. The VR learning environment allowed the participants to rotate 360 degrees and walk in virtual space. This feature assisted participants in utilizing the self-control strategy of searching.

Searching refers to investigating the VR learning environment to proceed with the tasks. The virtual environment allowed participants to explore virtual tools, graphs, tables, and visuals while rotating 360 degrees. Participants were able to explore the VR environment and make progress in the virtual tasks due to this freedom. Fourteen participants benefited from this freedom to utilize the searching strategy. Two participants' experiences are presented in this section as examples of how interaction through moving around supports self-control strategy of searching. While one of them used the searching strategy at the end of the task, the other used it at the beginning of the task.

Firstly, Eray’s experience illustrates one of the common uses of the search strategy by moving around to end a task. Figure 23 shows three screenshots while he was trying to finish the first task. The problem he faced involved submitting his response to the answer console.

Figure 23. Screenshots from Eray's experience in a temporal sequence

He turned right and tried to press the submit button, as seen in the first image of Figure 23. The button remained inactive due to his failure to submit a response. As he continued his search while orienting himself in the virtual space's center, he noticed the video instruction. He attempted to activate the video instruction with his virtual hand, as seen in the second image of Figure 23. He stated, "Now. Should I watch the video again? Huh. Ok." (Think-aloud, Eray) between the second and third images. He changed his decision about re-watching the video when he realized the "send to console" button was turned left in the virtual space. He then managed to send his answer to the answer console and end the task by submitting it, thanks to the searching strategy he used by moving around in the virtual space.

Secondly, Figure 24 displays how moving around the virtual space assisted Fatih to apply searching strategy and find a way to start the fourth task. He watched the video instruction, but he could not comprehend how to start the task. He turned right and read the written instruction, as seen in the first image of Figure 24. Then, he turned left and observed the graph he drew in the previous task, as shown in the second image. At the end, he turned to the middle of the virtual space, saw the table, and said, "Huh. Number of hospitalisations." (Think-aloud, Fatih). He noticed the title of the table and decided where to focus on the fourth task. In brief, his use of the searching strategy of moving around in the virtual space helped him find a way to start the task.

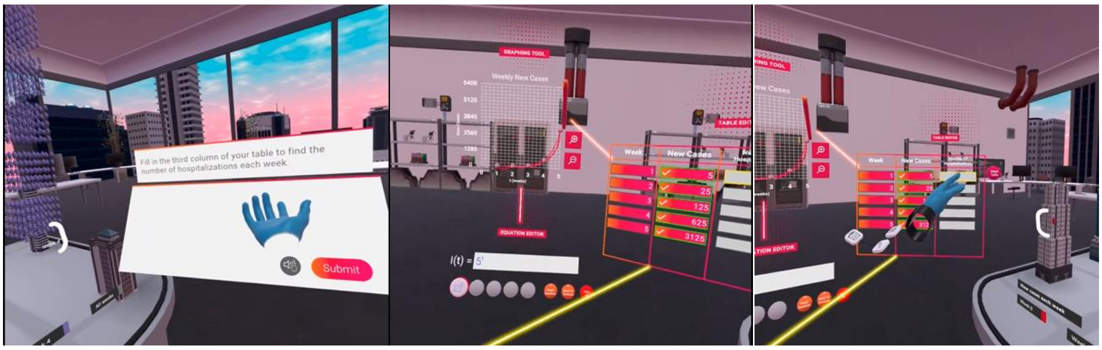


Figure 24. Screenshots from Fatih ’s experience in a temporal sequence

4.2.2 Assessment and feedback mechanisms

Assessment and feedback mechanisms are the tools used to evaluate and provide information on the progress and performance of learners engaged in immersive educational experiences facilitated by VR technology. In this study, the VR system included a set of tools that provided students assessment and feedback for their performance in virtual tasks. The VR system provided audio feedback for each answer of the students, offered extra support when students could not proceed with the tasks, and contained practice activities as assessment tools. Each sub-category regarding assessment and feedback mechanisms will be explained in this section.

Table 11. Sub-categories of Assessment and Feedback Mechanisms

Sub-Category	Definition	Example
Providing Feedback	Evaluating and providing information on students' performance by means of audio alerts	I filled them all. Let me try to enter this again for a second. I think there is an error here. Of course. I think I wrote the number of cases in the first week wrong. Yes 1. (Think-aloud, Gülden). The student made a mistake while filling in the table. She could not end the task. She realised her mistake by the VR system's audio feedbacks (Screen recording, Gülden)
Offering Extra Support	Offering extra help when students get in stuck	I pressed the get help button. (Think-aloud) The VR system offers support when the student cannot proceed in the task. "Are you stuck? If you are, you can press this button at any time for support." (Screen Recording, Damla)
Providing Practice Activities	Checking students' learning progress through knowledge tests (Radianti, 2020)	It asks me a question (Think-aloud, Aylin) VR system provided a question about repetitive multiplication in exponential functions (Screen recordings, Aylin)

4.2.2.1 Providing feedback

The VR learning environment included a specific feedback mechanism to evaluate and provide information on students' performance by means of audio alerts.

Following each response the students gave, the VR system provided audio alerts as a form of feedback. This feedback mechanism facilitated students' use of monitoring processes such as relying on the system's feedback and system and task understanding and employing self-control strategies such as task solution, self-instruction, and interacting with tables and graphs.

Firstly, assessment and feedback mechanisms facilitated most students' monitoring processes by relying on the system's feedback. Relying on the system's feedback refers to the behaviours indicating that the system influences one's actions in the VR environment. The VR system provided students with two types of voice alerts for each answer. While the first one was a positive voice alert, which was a sign of correctness for the answer, the second one was a negative voice alert, which was a sign of a wrong answer. This system-generated feedback mechanism helped students decide on the accuracy of their actions, which shaped their subsequent actions in the virtual tasks. Fifteen participants benefited from the feedback mechanisms of the VR learning environment to engage in the monitoring process by relying on the system's feedback. Three participants' experiences will be presented to demonstrate how positive and negative voice alerts influence the actions of students in the VR learning environment. For instance, Banu attempted to fill out the table in the first task, which could be done by considering the number of cases presented in an interactive bar graph. Banu's initial idea was to create her own graph that shows exponential growth. Therefore, she wrote 1 in the row for week zero. Then, she wrote 2 in the row for the first week by multiplying 1 with 2. Thus, her initial action plan was to fill out the table with powers of 2. However, the VR system provided her answer with a negative voice alert after she wrote 2 in the row for the first week, as seen in the excerpt below.

> "I registered two patients for the first week. I pressed enter for that answer. (Negative voice alert.) Hmm." (Think-aloud, Banu)

Then, she engaged in the monitoring process by judging her initial solution path, which facilitated her to change her initial action plan, focused on the cases in the interactive bar graph, and proceeded with the task by considering the pattern in the numbers of the cases presented to her thanks to the VR system's feedback. In another example, Metin could not decide how to solve the problem regarding the number of cases in the last week. He wrote 1, 5, 25, 125, and 625 to the five rows of the table in the first task. However, he did not notice the pattern among the numbers to write the next number. The screen recording and think-aloud data below summarise his experience.

> "He wrote 781 in a row. A negative voice alert was heard." (Screen Recording, Metin)
> "The way I thought was not correct." (Think-aloud, Metin)

He just added the previous numbers and wrote it in the next row. He realised that his initial idea about solving the problem was wrong after getting negative feedback from the VR system. Because of the feedback the system generated, he changed his solution path from just adding the numbers to looking for patterns within them. In addition, positive voice alerts were also conducive to students' monitoring processes by relying on the system's feedback. For instance, Fatih shared that "Patient zero, new case 1. (Positive voice alert). Hmm. That's it; I'll do it" (Think-aloud, Fatih). He initially did not recognise how to fill out the table. He tried some numbers for different rows of the table and got negative feedback. At the end, he decided to write 1 in the row of week zero by exploring the cases in the interactive bar graph. Then, the VR system provided him with positive feedback, which assisted him in continuing the way he decided to fill out the table. In other words, the VR system's positive voice alert made him sure about the accuracy of his recent action plan to proceed with the task.

Secondly, assessment and feedback mechanisms facilitated students' monitoring processes of system and task understanding. System and task understanding refers to the informal mental tracking of the extent to which the task and the handling of the VR have been understood and implemented. Three participants' experiences will be shared to illustrate how positive and negative voice alerts assisted students' system and task understanding in the VR learning environment. For instance, Metin could not decide on the function of a button in the second task, in which participants were expected to re-write the numbers (5, 25, 125, 625, 3125) in the second column of the table by using exponents. The following think-aloud example displays how the system's feedback assisted him in recognising the function of the button.

> "I will write 2. I will continue. (Negative voice alert). It isn't happening. Hmm. It is the sign of multiplication. It means multiplication." (Think-aloud, Metin)

Even if he intended to write 5 to power 2 as the exponential expression of 25, he could not write the correct answer in the table due to the use of a multiplication sign instead of an exponent sign on the tablet. Therefore, the VR system warned him with a negative voice alert. Then he recognised the right button that could be used to write an exponential number. Put simply, the feedback offered within the VR learning environment served to enhance his system understanding. In a situation similar to the one below, Sude also misused the multiplication button in the first task.

> "5 to the power of 1, 5 to the power of 2, 5 to the power of 3, 5 to the power of 4, and 5 to the power of 5. Enter. (Negative Voice Alert). Hmm. I think this is multiplication." (Think-aloud, Sude)

The first task’s requirement was filling out a table with the numbers 1, 5, 25, 125, 625, and 3125. Sude recognised the pattern in numbers and decided to write 5 to power 5 instead of 3125. However, the VR system did not accept her answer due to the use of a multiplication sign instead of an exponent sign on the tablet. Sude realised the button, which could be used for writing exponential numbers thanks to the system’s negative voice alert. Namely, the feedback provided within the VR learning environment promoted her system understanding. Positive voice alerts also enabled participants to engage in the system and task understanding processes. For example, Fatih stated, "Ok, 5 to the power 1. (Positive Voice Alert). Okay. Now I understand the issue.” (Think-aloud, Fatih). His think-aloud excerpt illustrates his use of the system’s feedback to monitor his task understanding in the second task while rewriting numbers in terms of exponents. At the beginning of the second task, Fatih could not comprehend the task’s requirements. He tried some possible solutions to fill out the table. Then, he decided to use exponential numbers, and the VR system’s positive voice alert made him confident with his last decision about the requirements of the task. In brief, a positive voice alert facilitated his involvement in monitoring the system and task understanding.

Thirdly, the VR system's feedback enabled students to complete task solutions. Task solution means to find and apply a way to solve task related questions. Participants in this study utilised the system generated feedback to determine the proper way to solve the task related questions. There was a pattern between the system generated feedback and the task solution. Especially when the system provided a positive voice alert, participants became sure about their solution path, and they applied their initial solution step to the whole task. For instance, in the second task, participants were required to write exponential notations of the five numbers. Some participants expressed uncertainty regarding how to solve the task. Their initial reaction to the question was to try to write the number in the first row as an exponent. As illustrated in Yakup's think-aloud excerpt below, Yakup also became sure about his way of solving the task by means of the system's feedback. Subsequently, he continued with the task solution step by applying what he did in the first row to the other rows.

> "It will be 5 to the power 1. (Positive voice alert). Yes, that's true." (Think-aloud, Yakup)

In addition, negative voice alerts also helped students continue with the task solution step. For example, Bartu decided on a solution path for the second task. His goal was to re-write the numbers by using exponential notation on the tablet. Thus, he wrote 5 to the power zero in the first row. However, the system provided him with a negative voice alert, which enabled him to recognise his error, and he revised his initial solution path. Thus, he proceeded with the task by applying the right task solution steps, thanks to the system's feedback.

> "5 to the power 0. (Negative voice alert). Why didn't it happen? This is the first week. Ok. Not week 0." (Think-aloud, Bartu)

Self-instruction was another self-control strategy that the system's feedback was conducive to. Self-instruction is a self-control strategy which refers to "overt or covert descriptions of how to proceed as one executes a task, such as self-questioning as one reads textual material" (Zimmerman & Moylan, 2009, p. 302). In some participants' experiences, self-instruction came after the system's feedback. When the VR system provided a positive or negative voice alert, the participants asked themselves questions about what to do or described how to proceed with the tasks. For instance, Esra was not sure how to fill out the table in the first task. She tried to examine the interactive bar graph and use the number of cases in that graph while filling out the table. She wrote 5 to the second row of the table and got positive feedback from the VR system, which made her confident in her solution. Then, she utilised a self-instruction strategy by describing her next step for working on the third row. She stated that after a positive voice alert: “Hmm. I need to fill it according to the graph on the side. I'm on week two now. I will count the greens” (Think-aloud, Esra). Her plan was to count the number of the second week’s cases in the interactive bar graph. Negative voice alerts also facilitated students’ use of the self-instruction strategy in the virtual tasks. For example, Eray benefited from the negative voice alert in the first task when his initial answer was not accepted. His initial plan for the fifth week’s cases was to add all the numbers from the previous weeks. However, he realised his mistake when the VR system did not accept it by providing a negative voice alert. Then he described a new plan to progress with the task. He decided to think of the fifth week’s cases independently from the interactive bar graph.

> (Negative voice alert). “It disapproves. Then we will create a fifth week ourselves.” (Think-aloud, Eray)

In another example, Demet also utilised self-instruction in the second task after getting negative feedback from the system. She uttered that after a negative voice alert: “it says the answer is wrong. Do I need to write it in exponential number format?” (Think-aloud, Demet). She was required to write numbers by using exponents. However, she filled out the third row of the table with 5 times 5 to the power 2. Her answer was equal to 125, and it was numerically correct. However, it was not suitable for the task’s requirements. Following the system's negative voice alert, she engaged in a process of self-instruction by self-questioning. In other words, Demet's experience with the second task demonstrated the pattern in which the participant's self-instruction came after the system generated feedback.

Interacting with tables and graphs was another self-control strategy that the system's feedback helped to facilitate. Participants interacted with the tables or graphs to solve a problem or understand the task. In some situations, they used this self-control strategy due to the system generated feedback. For instance, Esra uttered that after receiving a negative voice alert: “Did I count wrong? Let me count again.” (Think-aloud, Esra). Her excerpt displays how negative voice alerts enabled her to use interacting with tables and graphs as a strategy to maintain her progress with the first task. The initial task involved an interactive bar graph that the students could manipulate. Esra attempted to fill out the table without manipulating the graph. This means that she could not see all parts of the graph, so the number of cases she explored in the graph was missing. Therefore, the VR system provided her with negative voice alerts since her answers were not correct. These negative feedbacks culminated in her interacting with the bar graph repeatedly by manipulating it. Thus, she could write the accurate numbers in the table by interacting with the graph.

4.2.2.2 Offering extra support

Offering extra support means asking whether they need extra help when students get stuck. When students had difficulty progressing in the virtual tasks, the pedagogical agent interfered with the situation and offered them some extra support. The pedagogical agent offered extra support in two conditions. While the first one was in the case of participants losing a long time on a task, the second one was making mistakes one after another. In these situations, the pedagogical agent popped up in the VR learning environment and suggested additional help by means of extra video instructions. These extra video instructions were different from general video instructions because they included clear step by step guidelines, which helped students solve the virtual tasks easily. The system's offers for extra support via the pedagogical agent facilitated students' monitoring process of relying on the system's feedback and self-control strategy of help-seeking. Participants who benefited from the system's extra support showed a similar pattern after getting the pedagogical agent's offer. They engaged in a monitoring process by relying on the system's feedback after receiving the pedagogical agent's offer, followed by immediately implementing the help-seeking strategy. In what follows, this pattern will be elaborated upon extensively via examples that demonstrate how offering extra support assisted students in sequentially monitoring by relying on the system's feedback and employing a self-control strategy of help-seeking. Figure 25 displays Didem's experience in the third task, where she was expected to write an exponential function that represents the exponential growth of numbers (5, 25, 125, 625, and 3125) in the table. She had some difficulty completing this task and lost a long time because she could not decide on the correct function that shows the exponential growth in numbers. The initial image in Figure 25 shows one of her answers before submitting it. However, her answer was wrong, and the system provided her with feedback about her mistake, as seen in the image in the middle of Figure 25. She stated that "she (the pedagogical agent) said it was wrong" (Think-aloud, Didem). Thus, she engaged in a monitoring process and recognised her mistake by relying on the system's feedback. Immediately, the pedagogical agent offered support by stating, "Are you stuck? If you are, you can press this button at any time for support." Then, she utilised the help-seeking strategy to proceed with the task. The third image in Figure 25 displays the moment when she accepted the agent's offer. She said that "I pressed the get help button to watch the video." (Think-aloud, Didem) which shows the same moment while she was starting to watch the support video with a specific intention.

Figure 25. Screenshots from Didem's experience in a temporal sequence

In a similar situation, Metin did not accept the pedagogical agent's offer as quickly as Didem did. He was also trying to solve the third task. When he made a number of subsequent mistakes, the pedagogical agent also offered him extra support. However, Metin preferred to ignore this offer at the beginning. He continued his trials without getting any support. Even though he recognised his errors by means of the system's feedback, he did not use the help-seeking strategy. I asked about his experience in the stimulated recall part of the interview. The dialogue below shows how the lack of help-seeking strategy after getting the extra support offer influenced Metin's progress in the third task.

> Researcher: "Let's remember, if you want. At the 19th minute, something like this happens. When you had a difficulty here, the system came into play."
> Metin: "Yes."
> Researcher: "But you did not look there. You kept trying."
> Metin: "Actually, I said it there. I would check it out a little later. I said, I looked, and she said. Then I went back and watched the video."
> Researcher: "This was exactly what happened here. After three minutes and a half later, at 22:30. Here, she offered help. You asked for help here. You got that help. Then you solved the problem anyway."
> Metin: "I had to listen to the tutorial at first; actually, I didn't pay attention." (Interview, Metin)

Since Metin did not accept the pedagogical agent's offer, he lost more than three minutes trying to find a way to solve the third task. After three minutes, he utilised the help-seeking strategy and got the pedagogical agent's support by pressing the get help button. Then, he managed to write the correct exponential function in the equation editor and conclude the task thanks to the extra support video. In sum, both Didem's and Metin's experiences showed how relying on the system's feedback and help-seeking pattern after getting the VR system's offer for extra support influenced participants' progress when they had difficulty completing the virtual tasks.

4.2.2.3 Providing practice activities

The VR system provided students with four practice activities for checking their learning progress through knowledge tests. Practice activities served as assessment mechanisms for virtual tasks, and participants could judge their learning progress on virtual tasks through the practice activities. In these practice activities, students were able to engage in the task analysis process of orientation as well as employ self-control strategies such as elaboration and task solution. Orientation, elaboration, and task solution show a general pattern that students followed after the VR system provided them with a practice activity. By utilising the experience of one of the participants in a practice activity, this recurring pattern will be elaborated upon.

Two multiple-choice questions were asked after the third task. Erden's experience in the first one will be used to illustrate the general pattern after a practice activity. Most participants engaged in the orientation process after the VR system provided them with a practice activity. Orientation is a task analysis process that refers to task clarification and an overview of the material (Sonnenberg & Bannert, 2015). Erden initially read the question sentence out loud right after he listened to the

VR system's instructions regarding the question. Then, he restated the task requirements with his own words, as displayed in the following think-aloud excerpts. The first image of Figure 26 shows the instances after he read the question sentence while he was clarifying what the question required from him.

> "She asks how the graph would change if we just paid attention to our social distance and did not wear masks." (Think-aloud, Erden)

Then, Erden focused on the first two options. He read these options first. Then, he utilised the elaboration strategy. Elaboration is a self-control strategy, and it includes deeper processing such as paraphrasing, connecting, inferring (Sonnenberg & Bannert, 2015), summarizing, and interpreting. Two think-aloud excerpts below illustrate Erden's use of elaboration strategy.

> "The slope of the graph would increase, meaning people would become infected more quickly." (Think-aloud, Erden)
> "It would go more shallowly. In other words, the spread of the disease would decrease." (Think-aloud, Erden)

Erden interpreted different slopes of the graph, such as steeper and shallower, in terms of the number of cases. He made a connection between the slope of the graph and the spread of the virus. The slope of the graph could increase due to an increase in the number of infected people. The second image of Figure 26 shows how Erden pointed out the options with his virtual hand while engaging in the elaboration process. While some of the participants used the elaboration strategy before concluding the practice activity, as Erden did, others just continued with the task solution step after the orientation process.

Task solution means solving task related questions. Erden engaged in the task solution process by interpreting the question sentence, spread of the disease, and slope of the curve together, as seen in the following think-aloud excerpt.

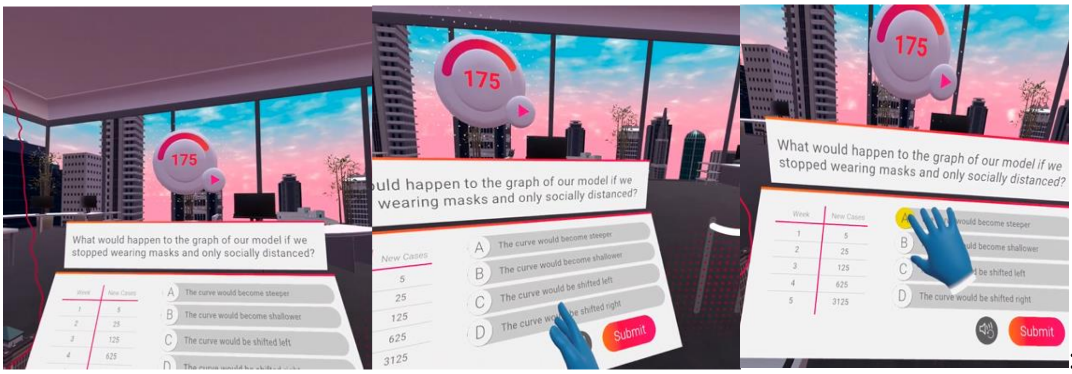


Figure 26. Screenshots from Erden's experience in a temporal sequence

> "If they had just removed the mask, the spread would have accelerated. So, the curve would be steeper. So, the slope would increase faster. Option A." (Think-aloud, Erden)

Specifically, he condensed the information he presented during the orientation and elaboration processes and connected them to select an option as the solution to the practice activity. The final image in Figure 26 depicts the moment when he successfully completed the practice activity by selecting one of the options following the task solution process.

In sum, practice activities functioned as assessment mechanisms within virtual tasks. Participants could evaluate their learning progression in virtual tasks through these activities. During these practice exercises, students could participate in the task analysis process of orientation and utilise self-control strategies such as elaboration and task solution. Orientation, elaboration, and task solution demonstrate a typical pattern that students followed to solve the practice activities provided in the VR learning environment.

4.2.3 Agency

Agency refers to the extent to which a learner is granted the ability to exercise meaningful actions within a learning environment, as defined by Makransky et al. (2020). The study involved participants engaging in a VR learning environment known as Pandemic by Prisms. Students possessed some sort of autonomy, which was conducive to their use of some specific SRL processes in this learning environment. Students experienced agency by being free to try, to re-watch video instructions, and to use virtual objects while performing the virtual tasks. They made use of this autonomy to proceed with the virtual tasks by engaging in a variety of SRL processes. Table 12 displays sub-categories regarding agency, their definitions and examples. In the following sections, each sub-category and how they facilitated students to utilise some specific SRL processes will be explained in detail.

4.2.3.1 Being free to try

The VR system provided students with agency by giving them autonomy to try a variety of things while performing the virtual tasks. Some participants appreciated being free to try as an advantage of being in a VR learning environment, as Aziz shared in the interview.

> "I can instantly apply everything I learn. I can try. It was nice." (Interview, Aziz)

Students were free to try different solution paths, various answers, functions of the buttons, etc. Being free to try in the VR learning environment assisted them to engage in monitoring processes of monitoring of progress, relying on the system's feedback and system/task understanding, and employ the self-control strategy of trial-error. Each SRL process and how being free to try can be conducive to it will be explained in this section.

Table 12. Sub-categories of Agency

Sub-Category	Definition	Example
Being free to try	Students' autonomy to try in VR	Let's try to learn what it is. Yes. Let's press the enter button. (Think-aloud, Fatih)
Being free to re-watch videos	Students' autonomy to watch video instructions once and again in VR	It had just given me a rate. I missed it. What does it say here? Twenty percent go to the hospital. (Think-aloud, Metin) The student did not follow the first video instruction well and he could not start the task solution. Thus, he re-watched the video instruction. (Screen recording, Metin)
Being free to use objects	Students' autonomy to use virtual objects such as pen or calculator in VR	Now, since I can't open the calculator, I'm doing multiplication on my own. I multiply 625 by 5 to find the 4th week. (Think-aloud, Itır) The student was unable to activate her calculator. Thus, she activated her pen to carry out task related calculations. (Screen recording, Itır)

Firstly, the agency, regarding being free to try, assisted participants to engage in monitoring of progress to check their behaviour and mathematical solutions/conjectures to proceed during the virtual tasks. When participants wanted to check their solutions for the virtual tasks, the VR system provided them with autonomy to try. Yakup's interview excerpt exemplifies how the agency, regarding being free to try, assisted him in verifying his response. He thought that he made a mistake in the third task while writing the exponential function. However, his answer was correct. Thus, he erased his answer in the equation editor. He wrote it again and drew the graph for it again. Then, he checked his answer in the graph one more time before sending it to the answer console. Since Yakup had control over trying to write an exponential function, draw its graph, and check it in the third task, he could engage in monitoring of progress process whenever he needed to.

> "I did it wrong, I thought. I did it again." (Interview, Yakup)

In the same task, Bartu also checked his answers, thanks to being free to try as if Yakup did. His think-aloud excerpt below shows how he decided to try two answers he thought. He wrote two exponential functions in the equation editor and drew their graph to check whether they were correct or not before sending the answer console.

> "Not this. It could be like this. I want to try this too. This is what happens with 1. How about with 3?" (Think-aloud, Bartu)

In the last example, Gülden used monitoring of progress at the end of the first task when she could not see the cases of the fifth week in the interactive bar graph. Then, she made a guess for the fifth week by considering the pattern in the previous numbers. She decided to check her mathematical conjecture and control its accuracy by using the freedom provided by the VR system.

> "Should, I guess? Or was it this? Let me try. I wrote up to the 4th power of 5. 125. 625. If I multiply 625 by 5, I think I will make a correct guess." (Think-aloud, Gülden)

Secondly, the agency, regarding being free to try, assisted participants in engaging in the monitoring process of system/task understanding, which refers to behaviours indicating the extent to which the task and the handling of the VR have been understood and implemented. Participants mainly monitored their system understanding by means of multiple trials in this study. Since all of the participants experienced Pandemic by Prisms for the first time, they sometimes faced difficulty with the functions of the tools. Being free to try virtual tools multiple times helped them monitor their system understanding. For instance, Fatih had difficulty finding the function of the exponent sign. Thus, he engaged in the monitoring process by questioning his understanding of the function of a specific button on the tablet, and he decided to try to find the aim of the button. The think-aloud excerpt below shows the change in his system understanding while trying the button. While he stated he did not understand the function of the button at the beginning, he recognised it after trying the button.

> "This is the multiplication sign. I don't understand what that sign is. Let's try to find out what it is. Let's press the enter button. No results came when I pressed the enter button. So, this is the exponent button." (Think-aloud, Fatih)

I asked Fatih about his learning in the VR learning environment in the interview. He shared how he found solutions when he could not progress on tasks. For instance, he tried and learned the functions of virtual tools such as graphs when he did not understand their features.

> "There were also points where I got a little stuck. Because, for example, I noticed a feature in the graphic that existed while I was trying it." (Interview, Fatih)

In another example, Zerrin recognised how to write an exponential function in the equation editor thanks to the multiple trials. Initially, she couldn't understand how to use the tablet for writing an explanation function in the equation editor. Her initial trial is seen in the first image of Figure 27. In the second image, her failure to put the selected function type in the equation editor is seen. The first two sentences in her think-aloud excerpt below display her monitoring process of the system understanding concerning these two images. Then, she could comprehend how to write the function by trying it, as seen in the last image of Figure 27.

> “I'm trying to write the equation. But I can't find how to do it right now. Hmm. I'll do it this way. Ok.” (Think-aloud, Zerrin)

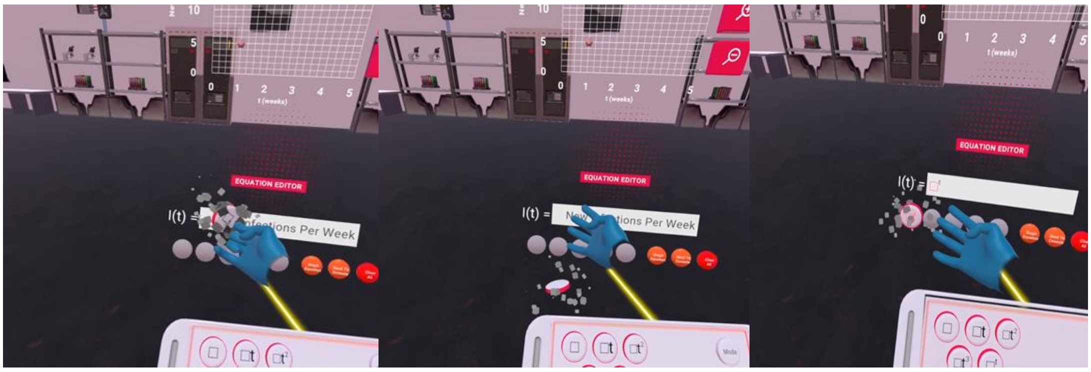


Figure 27. Screenshots from Zerrin’s experience in a temporal sequence

Thirdly, the agency, regarding being free to try, assisted participants in engaging in the monitoring process by relying on the system’s feedback, which refers to behaviours indicating that the system influences one's actions in the VR environment. Being free to try allowed students to have the chance to make errors while engaging in virtual tasks. Since the VR system provided them feedback about the accuracy of their answers, students could progress in tasks by learning from their mistakes thanks to the multiple trials. Gülden’s interview excerpt shows her point of view about her autonomy to try and make mistakes. She explained how she benefited from making mistakes without any loss.

> “There was not much loss when we made mistakes. We could always bounce back from mistakes.” (Interview, Gülden)

In the following interview excerpt, Fatih stated how he tracked the accuracy of his answers by drawing the graphs of the exponential functions he wrote in the third task. Being free to try, make errors, and try again in the VR learning environment assisted them in monitoring their performance and progress by relying on the system’s feedback.

> “I was drawing a graph. I could see exactly that this graph was not actually that graph. I could test it. I could draw another graph accordingly.” (Interview, Fatih)

Lastly, the agency regarding being free to try assisted participants to utilise the self-control strategy of trial-error which means trying, making errors, and trying again to solve a problem or understand the tasks. Participants' use of trial-error as a strategy in virtual tasks was encouraged by the autonomy provided to them by the VR system. They experienced alternative solutions to task related problems. For instance, Eray’s experience illustrates the common use of trial-error strategy to choose the correct solution among the possible options. In the third task, Eray had alternative answers for the exponential function that shows the exponential growth of numbers (5, 25, 125, 625, 3125). He dedicated himself to try possible solutions of the problem until he reached the right solution. However, his attempts were not just to try whatever he wrote in the equation editor. They were similar educated guesses that were judged before and after his trials, thanks to the autonomy provided to him by the VR system.

> “If I take this. I already bought this. If I take this. It wasn't happening. 5 to the power of t. If it's not 5 to the t, let me take t squared. I need to remove this then. I removed the first one. I will try the others. I'll try to graph this. If I call this number 5, let me try.” (Think-aloud, Eray)

In sum, the VR system supported students by giving them autonomy to try a variety of approaches while completing virtual tasks. Students had the freedom to explore different solution paths, experiment with various answers, and interact with the functions of buttons. The freedom to try within the VR learning environment facilitated their engagement in monitoring processes, including monitoring progress, relying on the system's feedback, and understanding the system/task. Additionally, it enabled them to employ the self-control strategy of trial-error.

4.2.3.2 Being free to re-watch videos

The VR system provided students with agency by giving them autonomy to watch the video instructions again in VR. Even if the VR system automatically showed students each video instruction once, they were free to re-watch each video instruction again whenever they needed while performing the virtual tasks. The autonomy that the VR system offered students supported their monitoring of system/task understanding and self-control strategies of help-seeking. This study revealed a pattern between the monitoring process of system/task understanding and the self-control strategy of help-seeking. This pattern and how being free to re-watch videos supports it will be explained in this section by focusing on one of the participants' common experiences.

The agency, regarding being free to re-watch videos, assisted participants to engage in the monitoring process of system/task understanding, which refers to behaviours indicating that the extent to which the task and the handling of the VR have been understood and implemented, and to utilise the self-control strategy of help-seeking which means “soliciting assistance when learning or performing” (Zimmerman & Moylan, 2009, p. 303). A common pattern that participants showed was deciding that they had difficulty comprehending how to use the VR system or the task’s requirements by monitoring their system/task understanding, using the help-seeking strategy of watching video instructions again, and then deciding that they understood how to use the VR system or the task’s requirements by monitoring their system/task understanding. Gülden’s experience, for instance, illustrates this common pattern between the monitoring system/task understanding, and help-seeking strategy by means of re-watching video instructions. The interview excerpt below displays how being free to re-watch videos enabled her to comprehend task requirements and the use of virtual tools.

> "I realised that I could have paid more attention to the wording in some places. For example, somewhere I had to guess the 5th week. I would guess it from the graph. I didn't listen very carefully. When I watched the video again, I remembered what she said about predicting. It helped me continue that way. I had difficulty understanding the commands given in many places. I think it's because it's the first time I've had such a virtual reality experience. I especially had difficulty holding and carrying things. Or, for example, I accidentally kept pressing too many things on the tablet. So, it was good for me to watch them again in videos. Having videos together somewhere, I can always watch them again." (Interview, Gülden)

She was one of the participants who actively used video instructions by re-watching them for her progress in the virtual tasks. She engaged in monitoring the system/task understanding process when she had difficulty comprehending the use of the VR system, such as using the tablet or changing the position of the virtual tools and following task instructions step by step. She associated these difficulties with a lack of experience with the VR. The monitoring process directed her to use the help-seeking strategy by re-watching the video instructions. Since she was aware of her agency regarding re-watching the video instructions, she preferred to utilise help-seeking strategy, which assisted her in comprehending how to use the VR system or the task's requirements by engaging in monitoring the system/task understanding process again. The following three excerpts belong to her think-aloud data and display the pattern she explained in the interview.

> "I know what I need to do, but I'm having a hard time doing it using the tools. I think this is the hardest part for me." (Think-aloud, Gülden)
> "I will watch the video once again. Because I didn't understand what to do." (Think-aloud, Gülden)
> "I guess it wouldn't happen again if I didn't watch it. Because last time I didn't understand what I was supposed to do." (Think-aloud, Gülden)

She engaged in monitoring the system/task understanding process, as seen in the first excerpt. Even if her mental tracking of her performance resulted in determining her understanding of the task requirements in the third task, she noticed that she could not understand how to use the VR system for carrying out the task requirements. Then, she decided to watch video instruction again, which was a help-seeking strategy that could be used thanks to her agency regarding re-watching videos. The second excerpt shows her use of the help-seeking strategy. In the last excerpt, Gülden engaged in the monitoring process of system understanding after getting the system's help by re-watching the video instruction again. She recognised how to use the virtual tablet for writing exponential functions in the third task.

4.2.3.3 Being free to use objects

The VR system provided students agency by giving them autonomy for using objects such as pen and calculator in the VR learning environment. Students were free to benefit from a virtual pen and the calculator function of the tablet whenever they wanted while carrying out the solutions to virtual tasks. These virtual tools assisted participants in utilising the self-control strategy of calculation.

Participants' use of tools was dependent on the difficulty of the operation they needed to carry out. If they could execute task related operations easily, they preferred to use mental operations as a self-control strategy, as Aylin pointed out in the following interview excerpt.

> "I tried to use the pen. I think it works too. There were usually simple problems. It can be done mentally. But for more difficult problems, using that pen may be useful." (Interview, Aylin)

When the values of the numbers that they use to execute task related operations were great, they preferred to benefit from virtual tools such as the pen to carry out calculations. Itır's think-aloud excerpt displays how she performed calculations by using the virtual pen. This example also showed the importance of diversity in participants' options in a VR learning environment. Itır possessed the autonomy to use more than one object to carry out operations related to the task. Since she could not activate the calculator, she employed the virtual pen and calculated the operation manually by writing on the virtual space.

> "Now I'm doing multiplication on my own because I can't activate the calculator. I multiply 625 by 5 to find the number of cases in the 4th week. I check. I write 3125." (Think-aloud, Itır)

In a similar context, Engin also used the virtual pen to carry out task related operations. His think-aloud excerpt below shows his view about the contribution of using the virtual pen to his task execution.

> "Having a pen made everything easier." (Intervew, Engin)

Being free to use the virtual pen assisted his use of calculation as a self-control strategy in complex operations, as displayed in Figure 28. He used the virtual pen to write an inequality for the solution to the last multiple-choice question. This could be done only with the virtual pen in the VR learning environment. Thus, Engin's experience also showed the importance of being free to use multiple objects for carrying out task related operations in the VR learning environment.

Figure 28. Screenshots from Engin's experience in a temporal sequence

4.2.4 Visual and auditory elements

The VR learning environment included some visual and auditory elements that assisted students in engaging in a variety of SRL processes while completing the virtual tasks. The visual and auditory elements provided by the VR system were in graph, table, and video formats. Table 13 displays sub-categories of visual and auditory elements, their definitions and examples. In the following sections, each sub-category and how they assisted students to utilise some specific SRL processes will be explained in detail.

4.2.4.1 Providing graphs

The graphs, as an important visual element of the VR learning environment in this study, were available to students whenever they wanted to interact with them. Providing graphs by the VR system supported students' learning by enabling them to engage in various SRL processes in this study. Providing graphs as visual elements assisted students in engaging in the task analysis process of orientation, monitoring processes of monitoring of progress and recognising error, self-control strategies of mental operations, calculations, interacting with table/graph, and drawing. Firstly, the VR system provided graphs that encouraged students to engage in the orientation process. Orientation is a task analysis process, and it refers to task clarification and an overview of material (Sonnenberg & Bannert, 2015) at the beginning of the task. Providing graphs by the VR system supported students' orientation processes just in the first task. At the beginning of the first task, the VR system provided students with a bar graph that showed the increase in the number of cases per week. The following excerpt displays participants' orientation processes before performing task-related assignments.

Table 13. Sub-categories of Visual and Auditory Elements

Sub-Category	Definition	Example
Providing Graphs	Making graphs available to students in VR	Only 5 people appear in the first week. 25 people in the second week. In the third week, it is 125. After that, it increases by 5 again. So it constantly moves in powers of 5. (Think-aloud, Itır) The student observed the graph to construct mathematical connections (Screen Recording, Itır)
Providing Tables	Making tables available to students in VR	Do I have to answer this by looking at the data behind it? Oh, he already gave the table here. (Think-aloud, Fatih) Students solve the task related question by using the table provided near the question. (Screen Recording, Fatih)
Providing Extra Support by Video	Making extra help available to students by means of video instructions in VR	I think it would be better if I watched the tutorial. I clicked on the tutorial. (Think-aloud, Metin) The student sought help from support videos. (Screen Recording, Metin)

> "It shows how many people are infected with the disease week by week. In the fourth week, many people got sick." (Think-aloud, Sude)

By examining the bar graph that the VR system had presented, Sude engaged in the orientation process. She clarified the function of the graph for the task and gave an overview of the graph. Her experience shows a common use of the bar graph in the first task for the orientation process.

Secondly, providing graphs by the VR system encouraged students to use the self-control strategy of drawing and engage in the monitoring of progress simultaneously. While utilising drawing is a strategy that can be used to assist learning, monitoring of progress refers to checking behaviour and mathematical solutions/conjectures to proceed during the task. The VR system provided the graph as a visual element for the students who preferred the drawing strategy while performing the third task. The graph drawn thanks to the VR system encouraged students to check their solutions in the third task. Figure 29 below shows the sequence of SRL processes that Engin used before concluding the third task.

Figure 29. Screenshots from Engin's experience in a temporal sequence

In the first image of Figure 29, he pressed the button to apply the drawing strategy. The second image is the graph that Engin produced as a result of using the drawing strategy. Then, he engaged in monitoring of progress by exploring the graph to check whether the exponential function he constructed fit the graph or not. The third image of Figure 29 shows his virtual hand while pointing at the graph. At this instance, he engaged in monitoring of progress by stating that: "the expression 5 to the power t can be true. The graph looks correct now." (Think-aloud, Engin). I asked about his experience in the stimulated recall part of the interview.

> "Seeing it pass through the points on the graph made me confident in my answer." (Interview, Engin)

The main motive behind drawing the graph of the exponential function before concluding the task was being sure about the correctness of the answer. Thus, the graph provided by the VR system as a result of drawing strategy assisted him in checking his solution to the third task.

Thirdly, providing graphs by the VR system supported students in engaging in the monitoring process of recognising error and utilising the self-control strategy of interacting with table/graph simultaneously. As a common example, Engin's experience will be shared to illustrate how the pattern of interacting with table/graph strategy and recognising error occurred thanks to the graph provided by the VR system. The think-aloud excerpt below displays Engin's interaction with the table/graph and his recognition of his error in the first task.

> "5. 25. 50. 75. 100. 125. Hmm. This was the fourth week anyway. No, it wasn't. There are 125 of them here. Pardon. Yes. Ok." (Think-aloud, Engin)

Engin tried to fill the table by interacting with the interactive bar graph. He counted the cases displayed in the graph. He did not decide the number of cases for the fourth week. At first, he got confused about the cases in the third and fourth weeks. Then he recognised his mistake by exploring the graph again. He could continue performing the task by recognising his error by interacting with the graph provided by the VR system.

The fourth function of the graphs provided by the VR system was to support students' use of self-control strategies of mental operations and calculations. While "mental operations" means carrying out task related calculations mentally, students can carry out task related calculations by calculator or pen. Participants frequently utilised mental operations and calculations to carry out task-related operations by exploring the graphs provided by the VR system. The use of these two self-control strategies emerged in sequence with the self-control strategy of interacting with graphs. Participants performed task-related operations mentally or by using the pen or calculator after or while interacting with the graph. Two common examples will be shared to explain how each self-control strategy occurred while performing virtual tasks, thanks to the graph provided in the VR learning environment.

The first example belongs to Damla, and it shows a common example for the pattern of interacting with the graph and carrying out operations mentally. Her experience with the first task included this pattern three times while she was trying to fill out the table. Her serial interactions with the graph aided her progress in filling out the table. She observed and explored the cases in the graph and utilised the mental operations as a strategy to calculate the number of cases in the second, third, and fourth weeks.

> "I can see it spreading to five people in the first week. Next week, it should be 5 times 5. I can see that it spreads to five people. In the 3rd week, it's 5 times 5 times 5, which is 5 to the power of 3. So, I can see that it spread to 125 people. In the 4th week, I can see that it has spread to 5 times this, 5 to the power of 4, that is, 625 people." (Think-aloud, Damla)

The second example belongs to Zerrin, and it shows a typical example for the pattern of interacting with the graph and carrying out task operations by using the virtual calculator. Zerrin's pattern was similar to Damla's experience above. Zerrin's serial interactions with the graph also aided her progress in filling out the table. However, she preferred to use calculations by using a virtual tool instead of mental operations, as Damla did. Her think-aloud data below illustrates her sequential interactions with the graph and mental operations.

> "Since the numbers here are a little bigger, I can do it using the calculator. That's what I'm doing right now. I'm on my third week, by the way. And I write the cube of 5. Ok. I'm in week 4. I will write the 4th week as 5 to the power 4. So, I'm going to multiply 5 by itself 4 times. Isn't there 4? Yes. 4 units." (Think-aloud, Zerrin)

In addition, Figure 30 displays the pattern of interacting with graph and mental operation. This pattern belongs to the “I'm in week 4. I will write the 4th week as 5 to the power 4. So, I'm going to multiply 5 by itself 4 times. Isn't there 4? Yes. 4 units.” (Think-aloud, Zerrin) part of the think-aloud. She proceeded with filling out the fourth week of the table by using the pattern of interacting with graph and mental operation two times. She initially observed the graph and decided how to calculate the number of cases in the fourth week, as seen in the first image of Figure 30. Then, he returned to the virtual calculator to conduct the calculation, as seen in the second image.

Figure 30. Screenshots from Zerrin’s experience in a temporal sequence

In the fourth week, when she was uncertain as to how many fives, he needed to multiply in order to determine the number of cases, he revisited the graph, investigated it, and interacted with it to determine the number of fives required for the calculation.

4.2.4.2 Providing tables

The tables, serving as crucial visual elements within the VR learning environment in this study, were accessible to students whenever they desired to interact with them.

The results of this study revealed that tables provided by the VR system facilitated students' learning by allowing them to engage in various SRL processes. Providing tables as visual elements assisted students to engage in the monitoring of progress, self-control strategies of elaboration, and interacting with tables and graphs.

Firstly, providing tables as a visual element in the VR learning environment assisted students’ monitoring of progress in the VR learning environment. Monitoring of progress means checking behaviour and mathematical solutions/conjectures to proceed during the virtual tasks. Students engaged in monitoring of progress to check their solutions to multiple choice questions and submit answers to the tasks related to filling out tables. Gülden think-aloud excerpt below shows a typical use of tables provided by the VR system for monitoring of progress to conclude a multiple-choice question.

> “There are 3125 new cases. 1/5 of 3125 will be in the 5th week. Then it happens in the 6th week.” (Think-aloud, Gülden)

She benefited from the table that was provided to her near the multiple-choice question to check her answer. Even if she decided the answer to the multiple-choice question, she needed to check her solution one more time by using the table to be sure about the accuracy of her answer. In addition, participants utilised tables to check their solution before completing the tasks. Figure 31 displays Esra’s use of the table to monitor her progress in the fourth task. She was required to fill out the second column of a table by calculating 20% of numbers in the first column. As seen in the first image of Figure 31, she submitted her answer. In addition, tick signs are clearly seen in the first image, which were the VR system’s feedback about correctness of the numbers she wrote there. However, Esra turned to her right, looked at the table seen in the second image, and monitored her progress by stating that “1, 5, 25, 125. Ok. I will send.” (Think-aloud, Esra), to check her answer again before submitting it.

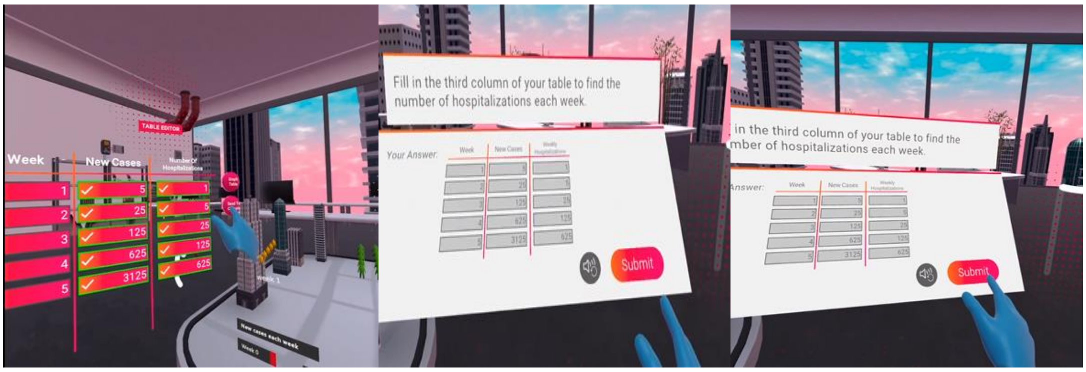


Figure 31. Screenshots from Esra’s experience in a temporal sequence

Secondly, providing tables as a visual element in the VR learning environment assisted students to utilise the self-control strategy of elaboration in the VR learning environment. Elaboration includes deeper processing such as paraphrasing, connecting, inferring (Sonnenberg & Bannert, 2015), summarizing, and interpreting. Tables helped participants elaborate on the mathematical connections in the virtual tasks. Engin’s experience below shows how he benefited from the table provided by the VR system to set mathematical connections between the third and fourth tasks.

> “Every week, as many people are hospitalized as the number of patients in the previous week. Well. 5 to the power of t minus 1.” (Think-aloud, Engin)

He wrote an exponential function in the third task to show the exponential growth in numbers of 5, 25, 125, 625, and 3125. He was just expected to fill out a table by calculating 20% of those numbers. Engin not only filled out the table but also inferred from the table. He explored the table and engaged in an elaboration process by constructing the mathematical connection between the numbers in the table.

Tables also assisted participants in elaborating the mathematical connections for solving the multiple-choice questions. For instance, the following think-aloud excerpt shows a common use of the table in the first task's multiple-choice question.

> "If in the fifth week they all increase one by one to the power of 5, then for the 6th week it will be 5 to the 6th power." (Think-aloud, Ezgi)

Ezgi made a summary of the table by setting the mathematical relations among numbers. Then, she inferred from those numbers which could be used in the solution of the multiple-choice question.

Thirdly, providing tables as a visual element in the VR learning environment assisted students to utilise the self-control strategy of interacting with table/graph in the VR learning environment. The use of interacting with tables as a self-control strategy was a natural result of the providing table by the VR system. The considerable thing regarding interacting with tables was how participants benefited from this strategy in virtual tasks. Interacting with tables enabled them to solve multiple choice questions, engage in the elaboration process, and achieve the task solution. Participants' common experience was interacting with the table while solving the last multiple-choice question. Figure 32 shows his interaction with the table while trying to solve the question. After the question was asked, Hakkı turned to the table, explored it and wrote numbers in the grey raws. Then, he relooked at the question and interacted again with the table to decide the relationship of the table and the question asked. Participants who explored the relationship of the table and the question could solve the multiple-choice question easily. In addition, interacting with tables assisted participants for elaboration and task solution.

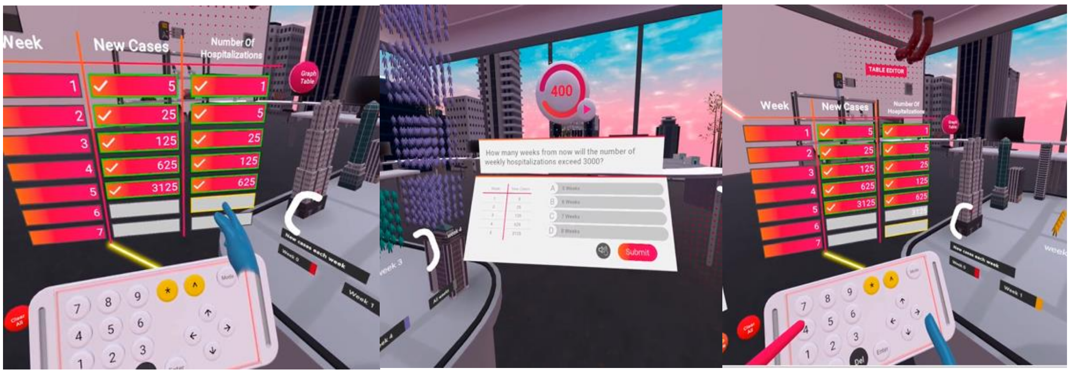


Figure 32. Screenshots from Hakkı's experience in a temporal sequence

Aziz's experience displays concurrent use of elaboration and task analysis by interacting with the table. His experience includes a pattern of interacting with the table, elaboration, and task solution. Aziz initially explored the table, as shown in the think-aloud excerpt below.

> "I'm currently examining the table again." (Think-aloud, Aziz)

Then, he made a summary of what he observed in the table, set mathematical connections among numbers, and made an educated guess for the number of cases in the fifth week, as displayed in the following excerpt.

> "The table shows that it goes as powers of 5. 1st week 5 to the 1st power. Week 2 is 5 to the 2nd power. The 5th week. 5 to the 5th power." (Think-aloud, Aziz)
> "For that reason, I take 5 as a base. I also take the number of weeks as the base." (Think-aloud, Aziz)

At the end, he started the task solution thanks to his interaction with the table and the elaboration process he engaged in. The last excerpt above shows the instances while Aziz was solving the third task by means of the table provided by the system.

4.2.4.3 Providing extra support by video

The VR system made extra help available to students by means of video instructions. When students could not proceed in the virtual tasks, they were able to get the VR system's support by means of detailed video instructions regarding the task solutions. This code is very similar to the "offering extra support" code explained in the "assessment and feedback mechanisms" section. The videos (regarding two codes) provided to the students were the same, but how they utilised them was different. If students used extra support videos after the VR system's feedback, this showed how "offering extra support" triggered students' behaviour in the VR learning environment. On the other hand, "providing extra support by video" code shows students' use of extra support videos without any offer of the VR system.

Providing extra support by video assisted students in utilising the help-seeking strategy. For instance, Metin's experience shows the typical use of an extra support video to continue the virtual task. He had difficulty completing the third task, which required him to write an exponential function. His initial strategy was trial and error. However, he recognised that he could not proceed with the task with his initial strategy and decided to get more detailed support from the VR system. The following think aloud excerpt displays the instances when he utilised the help-seeking strategy thanks to the extra support videos provided by the VR system.

> "I made various trials. Here., I think it would be better if I watched the tutorial." (Think-aloud, Metin)

He changed his self-control strategy from trial and error to help-seeking to continue the third task. In brief, Metin's experience was a common example of using extra support videos in virtual environments as the help-seeking strategy in situations of getting stuck.

4.2.5 Instructions

Students had access to tutorials "on how to use the VR application and how to perform the learning tasks" (Radianti et al., 2020, p. 14). The instructions can be conveyed through text, audio, or video formats. Table 14 displays sub-categories of instructions, their definitions, examples, number of occurrences, and percentages. In the following sections, each sub-category and how they assisted students to utilise some specific SRL processes will be explained in detail.

4.2.5.1 Written instructions

Written instructions means Having access to a tutorial or to instructions in text format on how to use the VR application and how to perform the learning tasks. The results of this study revealed that written instructions provided by the VR system facilitated students' learning by allowing them to engage in various SRL processes. Written instructions assisted students in engaging in the task analysis process of orientation, self-control strategies of elaboration, reading, and task solution.
Firstly, written instructions enabled students to engage in the orientation process after multiple choice questions were asked of them. Orientation means task clarification and an overview of the material (Sonnenberg & Bannert, 2015) before performing the task. The VR learning environment included four multiple choice questions. The pedagogical agent provided students with voice instruction regarding each multiple-choice question. Even if all participants listened to the voice instructions, most of them engaged in the orientation process by means of the written instructions. Yakup’s experience illustrates a general example of how to benefit from the written instructions for the orientation process in multiple choice questions. Figure 33 illustrates how he reacted to the first multiple choice question asked by the VR system. The first image in Figure 33 shows the pedagogical agent’s voice instruction regarding the multiple-choice question. Yakup directly looked at the pedagogical agent’s voice instruction, which showed that his attention was on the

pedagogical agent. Then, the multiple-choice question was shown on the screen in the second image, and naturally, he read the question sentence. The third image displays his orientation process after reading the question sentence. His virtual hand points out the part he focused on in the question sentence. The think-aloud excerpt below shows his orientation process after exploring the written instruction.

Table 14. Sub-categories of Instructions

Sub-Category	Definition	Example
Written instructions	Having access to a tutorial or to instructions in text format on how to use the VR application and how to perform the learning tasks	You can make an equation. It says you can do this with just one thing. (Think aloud, Esra) The student read the instructions written on the function box and decided what to do. (Screen Recording, Esra)
Voice instructions	Having access to a tutorial or to instructions in auditory format on how to use the VR application and how to perform the learning tasks	She asked me to draw a graph about the increase in cases. (Think aloud, Fatih) The student clarified his aim for the task by listening to the audio recorded instruction. (Screen Recording, Fatih)
Video instructions	Having access to a tutorial or to instructions in video format on how to use the VR application and how to perform the learning tasks	Twenty percent of infected people were hospitalized. Then he asks us, week by week. (Think aloud, Eray) The student clarified the task by watching the video instruction. (Screen Recording, Eray)

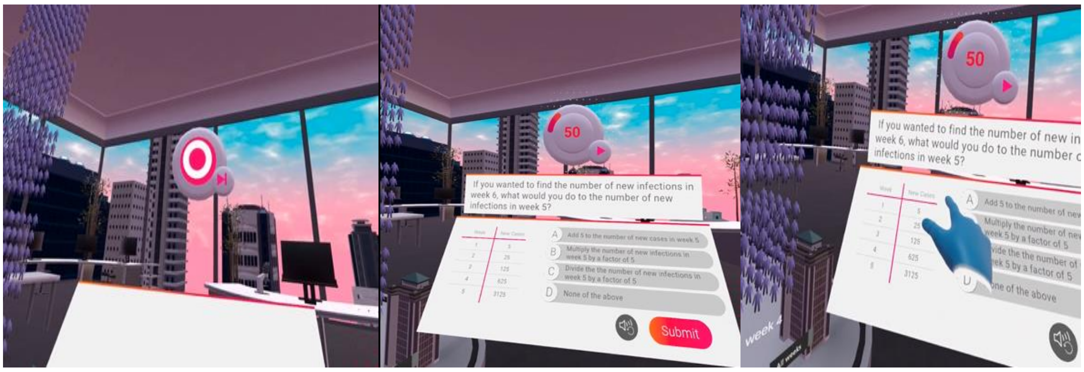


Figure 33. Screenshots from Yakup’s experience in a temporal sequence

> “It asks. What would you do to find the number of cases for the 6th week?” (Think-aloud, Yakup)

He clarified what the question asked of him and clarified himself about where to focus on this question by engaging in the orientation process by means of the written instruction provided by the VR system.

Secondly, written instructions enabled students to engage in the elaboration process on virtual tasks. Elaboration means deeper processing such as paraphrasing, connecting, inferring (Sonnenberg & Bannert, 2015), summarizing, and interpreting. Written instructions assisted students’ elaboration while performing the virtual task in sequence with other SRL processes such as orientation and reading. For instance, Hakkı’s excerpts below display the use of orientation and elaboration processes, respectively, in a sequence by means of written instructions provided by the VR system.

> “What would happen to the graph if we dropped the mask?” (Think-aloud, Hakkı)
> “It goes steeper. Because it will spread faster. Since it does not slow down, there is no shifting left or right.” (Think-aloud, Hakkı)

Hakkı initially explored the question sentence, then engaged in the orientation process by stating what the question asked. He clarified the most important words regarding the question. Then he inferred from those words and connected them with the change in the graph. Consequently, the sequential processes of orientation and elaboration were facilitated by the written instructions delivered by the VR system. In addition, Esra's think-aloud excerpt below illustrates how reading and elaboration were used in a pattern.

> "You can make an equation. (She read whispering.). You only need to make the equation with one thing." (Think-aloud, Esra)

Esra benefited from the pattern of reading and elaboration in the third task, which was required to write an exponential function. The written instruction was on the equation editor. It was just a one sentence text, but Esra recognised it. Then, she engaged in the elaboration process by summarizing it with her own words. Her deeper processing, thanks to reading and elaboration, enabled her to reach the solution to the task later on.

Thirdly, written instructions enabled students to use reading as a self-control strategy in virtual tasks. Since the VR learning environment included written instructions, it was a natural act of students to read texts provided them. Thus, reading means re-reading out loud a text (Sonnenberg & Bannert, 2015; Greene & Azevedo, 2008). When a participant read a text more than once, his/her behaviour was coded as reading. The main function of the reading strategy was to be sure about what was asked in the task. Fatih's experience illustrates a common use of the reading strategy in virtual tasks. As seen in the following think-aloud excerpt, he was not sure whether he read the question sentence correctly.

> "One minute. I read it correctly. Isn't it? if we stopped wearing masks... (he is whispering). if we stopped wearing masks, social distance. (He is whispering.)" (Think-aloud, Fatih)

Thus, he employed the reading strategy, thanks to the written instructions available, to be sure about what was asked of him. In addition, the other function of the reading strategy occurred in a pattern with elaboration which was discussed in the previous paragraph.

Lastly, written instructions enabled students to engage in task solutions and conclude the tasks. However, results showed a relationship between task solution and the orientation process. An orientation and task solution pattern occurred in multiple choice questions. Students initially read the text provided to them, then engaged in the orientation process by clarifying the task requirements. Didem think-aloud excerpt illustrates the orientation and task solution pattern in a multiple-choice question.

> "It says. How should we change the number of cases in week 5 to determine how many cases there are in week 6? We need to multiply by 5." (Think-aloud, Didem)

Didem engaged in the orientation process by giving an overview of the question asked to her. Then she directly started solving the multiple-choice question. In brief, clarifying what was asked to her by exploring the written instruction assisted her in continuing with the task solution process.

4.2.5.2 Voice instructions

Voice instructions mean having access to a tutorial or to instructions in auditory format on how to use the VR application and how to perform the learning tasks. The results of this study revealed that voice instructions provided by the VR system facilitated students' learning by allowing them to engage in a range of SRL processes. Voice instructions assisted students in engaging in the task analysis process of orientation and self-control strategy of elaboration.

The VR system provided students with instructions in audio format at the beginning of each task. These voice instructions assisted students in engaging in the orientation process by clarifying task requirements and giving an overview of the task. The following excerpt below shows Sude's orientation during the voice instruction.

> "She (the pedagogical agent) wants me to show the numbers in the table on the graph. She wants me to plot the function on a graph." (Think-aloud, Sude)

The VR system provided voice instruction at the beginning of the third task and explained how to utilise tools such as graphs. Sude's experience shows the common use of voice instructions for orientation. She clarified what the task required from her while voice instruction was in progress. This was the general behaviour of the participants who utilised the orientation process thanks to the voice instructions. They made an overview of what the pedagogical agent said to them as they were listening to the instruction.

Voice instructions also assisted students in engaging in the elaboration process by paraphrasing, connecting, inferring (Sonnenberg & Bannert, 2015), summarizing, or interpreting. Participants engaged in the elaboration process thanks to the voice instructions provided by the VR system after their help-seeking strategy. When participants had difficulty while performing the tasks, they utilised the help-seeking strategy and re-played instructions. Some of them benefited from voice instruction by making a summary of what the pedagogical agent stated in the instruction. Esra's expert below belongs to the instruction replayed after her help-seeking strategy.

> "She (the pedagogical agent) says there are 5 people in the first week. Second week, 25. Each week is multiplied by 5 people. She says to multiply by 5. She says 5 squared. She says. Do you see the connection between the numbers?" (Think-aloud, Esra)

When she could not proceed with the third task, she sought help from the VR system. She did not only listen to the instruction but also made a summary of it by paraphrasing the pedagogical agent’s sentences. This helped her to develop a deeper understanding of the task requirements, which enabled her to continue her progress in the third task.

4.2.5.3 Video instructions

Video instructions means having access to a tutorial or to instructions in video format on how to use the VR application and how to perform the learning tasks. This study's results indicated that the voice instructions provided by the VR system supported students' learning by enabling them to engage in a variety of SRL processes. Video instructions assisted students in engaging in the task analysis process of orientation and self-control strategies of observation-emulation and elaboration.

Firstly, video instructions enabled students to engage in the orientation process after the video instructions were provided to them for task clarification and overview of material. The pedagogical agent informed participants about the task requirements, solution steps, use of virtual tools, and mathematical relations in the tasks by means of video instructions. Video instructions shown at the beginning of each task assisted students in making an overview of the task by engaging in the orientation process. The video instructions helped students decide the steps to follow for reaching the task solution. In the interview excerpt below, Erden pointed out the importance of following the video instructions before performing the virtual task.

> “There is a video explaining what to do first. I think you need to listen to that video carefully.” (Interview, Erden)

When participants did not follow the video instructions at the beginning of the task, they did not recognise task requirements and the steps to follow for performing the assignments in the task. For instance, the following interview excerpt shows Gülden’s experience in the third task.

> “I think the next thing that bothered me was that I didn't watch the video well enough. I think I wasn't focusing on the video. So, I didn't follow the instructions given to me well enough. I worked on it a little myself instead of watching videos. I tried a little too hard.” (Interview, Gülden)

She had difficulty proceeding with the task because she watched video instructions carelessly. This led to the lack of the orientation process, so she could not clarify task requirements and the steps to follow for solving the task. On the other hand, Esra’s experience shows her use of video instructions to engage in the orientation process at the beginning of the fourth task.

> “I need to multiply by the common factor. Each week, it is 5 times the amount of the previous week. Everyone infects 5 people. By adding 5 to the linear function, multiply by 5 in the exponential function.” (Think-aloud, Esra)

The video instructions included both visual and auditory messages for the students. Most of the participants focused on both visual and auditory messages provided by means of the video instructions. Esra’s think-aloud excerpt above and screen recording below display her orientation process by watching and listening to the pedagogical agent’s messages. She synthesized the visual and auditory information she received from the video instructions provided by the VR system. For instance, the first image of Figure 34 shows the visual regarding exponential growth. The screenshot displays how Esra focused on the visual message of the video instruction. Meanwhile, the pedagogical agent was saying that “you took the number of new cases in each week and multiplied it by a factor of five to find the number of cases in the next week.” as an auditory message.

Figure 34. Screenshots from Esra’s experience in a temporal sequence

Esra thinks-aloud excerpt concerning these moments (I need to multiply by the common factor. Each week, it is 5 times the amount of the previous week.) illustrates her orientation process by using both visual and auditory messages provided to her in the video instruction.

Secondly, video instructions enabled students to utilise the self-control strategy of observation-emulation. Observation-emulation refers to “vicarious induction of a skill from a proficient model and imitative performance of a general pattern or style of a model's skills by social assistance” (Zimmerman, 2000). Most of the participants benefited from video instructions on how to use the virtual objects. Figure 35 below illustrates a common use of video instructions for observation-emulation strategy in virtual tasks. In the first image of Figure 35, Itır observed the video instruction while the pedagogical agent changed the position of the tablet. Then she decided to imitate the pedagogical agent’s behaviour. She gripped the tablet and changed its position, as seen in the second image. However, the position of the tablet was not the same as in the video instruction. She recognised it in the second image by looking at the video instruction. Then Itır held the tablet again and moved it in front of the equation editor, as she observed in the video instruction. This was the common use of video instructions for observation and emulation. Participants explored how to use virtual tools such as the tablet, watch, pen, graph, and calculator thanks to the video instructions provided by the VR system.

Figure 35. Screenshots from Itır's experience in a temporal sequence

Thirdly, video instructions enabled students to utilise the self-control strategy of elaboration in a sequence with help-seeking strategy. Students engaged in the elaboration process by exploring the video instructions provided by the VR system. When participants had difficulty continuing to perform the tasks, they were able to seek help by re-watching video instructions. Participants engaged in the elaboration process by paraphrasing and summarizing what the VR system instructed to do by means of videos. The screen recordings below belong to Erden's experience and display a common use of video instruction for elaboration. Erden activated the video instruction a second time to comprehend the fourth task and its requirements, as seen in the second image of Figure 36. This attempt was his use of help-seeking strategy when he could not proceed in the task. Then, he started to watch the video instruction carefully in the second image and continued his exploration of the video instruction as seen in the third image. Think aloud excerpt below shows his elaboration of the task by making a summary of what he heard and observed in the video. The video instruction provided by the VR system enabled her to engage in the elaboration process in sequence with the help-seeking strategy.

Figure 36. Screenshots from Erden’s experience in a temporal sequence

> “She says (the pedagogical agent) that hospitals’ number of beds is the determinant. 20 percent of infections require hospitalization.” (Think-aloud, Erden).

4.2.6 Instructional activities

Instructional activities refer to paper-based tasks designed to facilitate learning in the VR-based learning environment. The VR-based learning environment included pre-training materials and summarizing material in addition to virtual tasks (i.e., the VR learning environment). Table 15 displays sub-categories of instructional activities, their definitions and examples. In the following sections each sub-category and how they assisted students to utilize SRL processes will be explained.

4.2.6.1 Pre-training

The pre-training principle is that people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts. (Mayer & Pilegard, 2014). In this study, students were provided with the Turkish translations of key words, a summary of prior knowledge that students used to perform virtual tasks, and definitions of mathematical terms that students used in the virtual tasks.

Table 15. Sub-categories of Instructional Activities

Sub-Category	Definition	Example
Pre-Training	The pre-training principle is that people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts. (Mayer & Pilegard, 2014)	So, I didn't know what exponential function meant. I learned from those papers. For example, you gave examples and put questions underneath for me to solve. It also made me remember. I also learned the meaning of the graphics in English. I thought it was beautiful. It was very instructive for me. (Interview, Didem)
Summarizing	Concisely stating the main ideas from a lesson in one’s own words (Fiorella & Mayer, 2016)	It was good to finally have a summary written on a summary paper. Because, in my personal opinion, the more information is repeated, the more memorable it becomes. Everything remained in my mind. If you give it to me again right now, I can easily put everything on paper. (Interview, Fatih)

One of the functions of pre-training materials was to assist students in becoming aware of what the virtual tasks were about. For example, Zerrin's experience demonstrates that she initiated the virtual tasks with ease.

> “And I knew what I would encounter. I knew the subject was exponents. I knew it was a function. That's why I was more comfortable.” (Interview, Zerrin)

Since pre-training materials provided students with the definition of exponential functions, Zerrin was aware of the topic she would deal with in the virtual task. This would facilitate her task analysis processes due to her awareness of the focus point of virtual tasks.

The second contribution of pre-training materials was supporting students' prior knowledge that was used to proceed with the virtual tasks. Even if students studied the information provided to them in the pre-training material before, some of them forgot it, as stated in the following interview excerpt.

> “The first things I did definitely contributed to what happened in virtual reality. Because I had forgotten that general little piece of information, I couldn't remember it. The basic structure of the equation, for instance. “(Interview, Itır)

The pre-training materials included a basic summary of linear functions. This helped students remember the prior knowledge they needed for virtual tasks. Since students require prior knowledge for task analysis processes, the pre-training materials would facilitate their task analysis processes by providing the main prior knowledge they need for virtual tasks.

Another possible contribution of pre-training materials was supporting students' monitoring processes and making reaching task solutions easier in the virtual tasks. For instance, Zerrin’s interview excerpt below shows her use of pre-training material to understand task requirements and complete virtual tasks faster.

> “I could probably find it by reasoning. But there was a high probability that I would find it wrong. Therefore, it could take longer because I would not understand what it wanted from me. I could have made more mistakes.” (Interview, Zerrin)

Banu explained the contribution of the pre-training materials with an example from her experience in the VR learning environment.

> “Well, I will go through an example. It was directly increasing 5 times. The materials also said before that the exponent function is something like x to t.

> Numbers are used with their exponents. That's why I understood the issue directly." (Interview, Banu)

Since she explored the definition of the exponential function before the VR experience, she comprehended the task requirements and focused on exponential numbers in the virtual tasks.

> "Giving it has prepared a basis. If you hadn't given it, I would have had a hard time understanding the terms, and at least it was something like a training session. I didn't have anything related to functions in my mind at that moment. When I solved a few questions, it helped me with virtual reality as well." (Interview, Banu)

Banu's experience also showed that the key concepts presented to her in the pre-training facilitated her understanding of them in the virtual task. Moreover, she could apply in the VR learning environment what she explored in the pre-training session.

4.2.6.2 Summarizing

Summarizing is concisely stating the main ideas from a lesson in one's own words (Fiorella & Mayer, 2016). Students were provided with summarizing material at the end of virtual tasks to make a summary of what they had experienced in the virtual tasks. The main function of summarizing was to provide students with awareness about their learning. The following two interview excerpts show how summarizing contributed to students' learning processes in the VR-based learning environment.

> "I realised that I was learning the subject. I had no difficulty solving the questions. Actually, I learned the subject without realising it. I didn't feel like I was learning anything or having any responsibility while doing it. I was comfortable. I learned mathematics in a fun way. That's why I loved it." (Interview, Gülden)
>
> "I think it contributes. Because, as I said, while doing something in the game, it is a game. You're doing it to play games. Or you follow instructions. Sometimes you don't even realise you've learned something. Afterwards, after you exit the virtual reality, you become more aware of what you are doing, thanks to the activities you provide. Because you were just in the game. You followed the instructions given. You know, your goal is to follow the instructions and finish the game. Finally, oh, I learned these things by playing

this game and following the instructions. It gives you this awareness." (Interview, Aylin)

The common point that Gülden and Aylin stated was the feeling of being in a game while performing virtual learning tasks. Most of the participants expressed this point of view. Summarizing the material provided to them at the end of the VR experience assisted reflection on their learning. Students have a chance to develop a judgement regarding their learning at the end of the virtual tasks, thanks to making a summary of what they learned.

Another function of summarizing was to provide an opportunity to repeat what they experienced in the VR learning environment. The following two interview excerpts illustrate participants' common opinions about the contribution of the summarizing material on their learning.

> "It was good to finally have a summary written on a summary paper. Because, in my opinion, the more information is repeated, the more memorable it becomes. I remember everything. If you give it to me again right now, I can easily put everything on paper. (Interview, Fatih)
> It helped me not forget what I was doing in virtual reality. What I have learned has been reinforced again." (Interview, Didem)

Fatih and Didem underlined the benefit of repeating what they learned by means of summarizing material. They stated the summarizing material's contribution to the permanence of their learning. This situation contains a potential contribution to students' self-satisfaction about what they experienced in the VR learning environment, which can support students' further learning processes in similar contexts.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Overview of the study

In recent times, there has been a significant integration of VR technology in the fields of education across several application domains (Radianti et al., 2020). Self-regulated learning as a fundamental conceptual framework helps us comprehend the cognitive, motivational, and emotional components of the learning process (Panadero, 2017) in VR-based learning environments where different situations may possibly occur. On the one hand, these learning environments can enhance students' SRL by promoting a strong sense of social presence through meaningful interactions with pedagogical agents (Makransky & Petersen, 2021). On the other hand, students may face poorer learning outcomes in these learning environments due to higher cognitive load (Parong & Mayer, 2020) or hedonic aspects of VR, which may increase one's interest and enjoyment. They may also foster superficial learning strategies, which can subsequently diminish one's learning (Makransky et al., 2020), and a decline may occur in their self-regulated learning (Makransky et al., 2019). These two situations may occur and impact students' SRL in different ways, depending on the design and characteristics of the learning environment. It has been recommended to focus on the instructional design of the lesson in order to examine the educational effectiveness of VR-based learning environments by enabling students' self-regulation (Makransky & Petersen, 2021; Wu et al., 2020).

For this aim, a VR-based learning environment which included four learning materials and an immersive learning game, was provided to the students in this study. According to Mayer and Pilegard (2014) and Fiorella and Mayer (2016), respectively, the principles of pre-training and generative learning strategies guided the design of the learning materials. The selection of the VR learning environment, Pandemic by Prisms, was based on its focus on algebra, specifically exponential functions. In this study, traditional paper-based learning materials were integrated into a VR learning environment to offer students a more interactive, engaging, and effective approach to learning in the VR-based learning environment.

This instrumental case study was designed to investigate high school students' SRL processes as they engage in virtual tasks in the VR learning environment and to explore the features of the VR-based learning environment that are conducive to those SRL processes. In line with these purposes, the following research questions guided the study:

Research Question 1: What are high-school students' SRL processes in a VR learning environment?

Research Question 2: How is the VR-based learning environment conducive to students' SRL processes?

While the goal of the first research question was to reveal SRL processes that students utilize while carrying out virtual tasks, the aim was to examine underlying mechanisms that enable SRL processes to emerge in the VR learning environment for the second research question. Both self-reported (think-aloud protocols & interviews) and observational (screen recordings) data sources were utilized to answer the research questions. Think-aloud and screen recording data were gathered simultaneously while students were performing virtual tasks. In addition, a semi-structured interview was conducted with each student after the VR experience. The semi-structured interview consisted of seven open-ended questions and a stimulated recall part, which included the key moments of participants performance in the VR learning environment. Data obtained from interviews, think-aloud protocols, and screen recordings were analyzed using a deductive approach to answer the first research question, and an inductive approach was used to analyze the same data to answer the second research question. Task analysis, monitoring, and self-control strategies were identified as key SRL processes that students use while completing virtual tasks, as a general finding regarding the first research question. The VR-based learning environment was conducive to students' SRL by providing them with opportunities through interactions, assessment and feedback mechanisms, the feeling of agency, some visual and auditory elements, instructions in various formats, and traditional instructional activities. The interpretation of these findings will be shared in the following section.

5.2 Discussion of research findings

In this section of the chapter, the findings of the study will be summarized and discussed in light of existing theories and previous studies for both research questions.

5.2.1 SRL processes in the VR learning environment

Explaining how students learn in contexts in which they must regulate their own learning, such as when they are independently studying, is among the most difficult problems educational researchers face (Zimmerman & Moylan, 2009). Exploring how learning occurs is also one of the central questions that learning scientists are interested in (Fisher et al., 2018). VR has the potential to provide learners with an individualized context in which they can engage in self-regulated learning processes while practicing virtual tasks (Makransky & Petersen, 2021). In this respect, this dissertation sheds light on how learning occurs in a VR learning environment from the perspective of Zimmerman's (2000) cyclical model of self-regulated learning.

One of the key findings of this study was about the central role of task analysis processes while performing virtual tasks. Task analysis belongs to the forethought phase of Zimmerman's (2000) cyclical model of SRL, which means decomposing a learning task and its context into their components (Winne & Hadwin, 1998). Two ways in which students engaged in task analysis processes were through orientation and strategic planning as they practiced virtual tasks. The VR learning environment consisted of four virtual tasks, which also included four multiple-choice questions in total. Students were provided with instructions in multiple formats, such as written, auditory, or visual, at the beginning of each task. Prior to commencing their practice, the students' initial endeavor was to analyze the tasks. Put simply, their starting point for the virtual tasks was to comprehend the task and set an initial plan for the task solution. Students engaged in task analysis processes at the beginning of virtual tasks, which was crucial for self-regulation to take place (Panadero & Alonso-Tapia, 2014). Sonnenberg and Bannert (2015) demonstrated in their process model that task analysis is closely linked with other SRL processes in a hypermedia learning environment. This link was particularly evident for students who actively engaged in effective regulatory activities. Their study also displayed the most probable pattern of SRL processes, which started with task analysis. Furthermore, the results pertaining to task analysis processes align with the cyclical model of SRL, where the self-regulatory cycle commences with task analysis (Zimmerman & Moylan, 2009).

One of the most frequent codes that emerged in this study was orientation, and all participants engaged in the orientation process to ensure clarity regarding the task requirements, get a comprehensive understanding of the virtual materials offered, and clarify any uncertainties regarding multiple choice questions before commencing the solution. Bannert et al. (2013) reported successful students' use of forethought activities such as orientation prior to engaging with the content to be learned in hypermedia learning environments. Their findings showed the importance of students' initial attempts to engage in orientation processes at the beginning of the learning tasks. Even though orientation was not explicitly stated in the cyclical model of SRL, it was a part of the task analysis process that students used in this study. Prior research has identified orientation processes occurring at the onset of learning tasks in web-based learning environments (Lajoie et al., 2015) and hypermedia learning environments (Bannert et al., 2013; Engelmann & Bannert, 2019; Sonnenberg & Bannert, 2015). The similarity between the learning environments in the previous studies reporting the significance of orientation among SRL processes (e.g., Lajoie et al., 2015; Sonnenberg & Bannert, 2015) was the structured nature of the learning environments. Students were given previously designed learning tasks, and they were expected to proceed with the learning tasks by following certain instructions embedded in the tasks. Thus, in their initial encounter, the learning environment and the content of the learning tasks were unfamiliar and novel to the students. Students' active use of orientation at the beginning of learning tasks may be attributed to this factor. Upon encountering a learning task, students initially demonstrated an effort to figure out what was occurring in the learning environment. In brief, students took the first step to engage in the learning tasks by using the orientation process, which helped them understand the tasks and materials provided to them. Thus, findings of this study corroborated previous findings that orientation can be regarded as a considerable SRL process students employ at the onset of learning tasks in computer-based learning environments such as virtual reality.

A notable finding of this study about task analysis processes was the lack of goal setting in the VR learning environment. Since the frequency of students' efforts in setting goals was quite low, the goal setting code was not included in the final codebook concerning SRL processes in this study. The interviews included an explicit question about what the students' goals were in VR. Their common answer was to complete the tasks. Goal setting includes a commitment to achieve specific academic outcomes within a given timeframe (Zimmerman & Moylan, 2009), but students did not specify particular goals regarding their learning in the virtual tasks. Put simply, students had an intention to perform the virtual task successfully, but it did not lead them to set personal goals for completing the virtual tasks. Previous research carried out in hypermedia learning environments (e.g., Bannert et al., 2013; Engelmann & Bannert, 2019; Sonnenberg & Bannert, 2015) indicated rareness of students' goal setting while performing learning tasks. The nonexistence of goal setting in this study can be related to the highly structured nature of the virtual tasks, as they were in the hypermedia learning environments used in the previous research. In addition, students were provided with consecutive virtual tasks where they were not required to set any goals to proceed with the virtual tasks. It was sufficient for them to follow the system generated steps while performing the virtual tasks. Panadero and Alonso-Tapia (2014) discussed two key factors students can take into account while setting their goals: the assessment criteria and the level of performance they aspire to reach. While the assessment criteria serve as benchmarks against which performance will be evaluated, the level of performance means the degree of excellence the learner intends to reach. Students did not have any standards for assessment or performance before starting their experiences with the consecutive virtual tasks. A possible explanation for the scarcity of goal setting may be the lack of assessment or performance standards that could have been provided to or by the students. Panadero and Alonso-Tapia (2014) argued that if students are unaware of criteria about how the tasks will be assessed, they encounter greater challenges in setting suitable goals.

Certainly, the VR system included some criteria for assessing students' performance as they were carrying out the virtual tasks, but students were not informed about them before performing the virtual task, which could make goal setting difficult for students.

The findings of this study revealed students' frequent use of monitoring processes while carrying out the learning task in the VR learning environment. Monitoring is a SRL process that belongs to the performance phase of Zimmerman's (2000) cyclical model of SRL. Monitoring means engaging in informal mental tracking of one's performance, including the efficacy of one's learning processes in generating knowledge (Zimmerman & Moylan, 2009). Monitoring is an important SRL process for students to have control over the task's process because they acquire an extensive understanding of the sufficiency and quality of their work. This enables them to proceed if their work is accurate or make necessary modifications if it is not. Put simply, students assess their learning processes as they are performing learning tasks (Panadero & Alonso-Tapia, 2014). Hence, monitoring can be regarded as "self-assessment of the process" (Panadero & Alonso-Tapia, 2014, p. 455). In VR learning environments, due to their cognitively demanding nature, the learning processes of students may be impaired if they are unable to monitor and control their cognitive, metacognitive, emotional, and motivational processes (Makransky & Petersen, 2021). This may result in poorer learning outcomes. For instance, Lajoie et al. (2020) showed that high performers demonstrated monitoring processes more frequently when compared to low achievers in a hypermedia learning environment. Similarly, Winne and Azevedo (2014) argued the importance of monitoring processes for students to regulate their learning effectively. Specifically, it is crucial for students to be able to monitor their learning processes in the VR learning environment to take control of their own learning and complete the virtual task successfully. In this study, all participants engaged in monitoring processes to check their comprehension regarding the mathematical content presented to them, the VR system itself, task requirements, mathematical solutions and conjectures, errors they made, and the VR system's feedback. In brief, all participants engaged in the monitoring processes in a variety of ways while performing the virtual tasks. This finding is consistent with a recent study by Sobocinski et al. (2023) carried out in the same VR learning environment. They identified task understanding, prior knowledge, progress of the task, and content understanding as students' monitoring processes. Monitoring of task understanding, progress of the task, and content understanding were similar monitoring processes that were also identified in this research. Monitoring their actions and progress within the VR learning environment in a variety of ways could make students aware of their strengths and weaknesses. This awareness had the potential to enable them to regulate their learning effectively and make informed decisions about how to approach tasks. In addition, students could seek additional resources or guidance when needed, persist in solving challenges, and adjust their self-control strategies by continuously assessing their understanding and progress, thanks to the monitoring processes.

Makransky et al. (2020) asserted that fun aspects of VR may result in an increase in students' enjoyment and interest in the tasks. However, this might not result in desirable learning outcomes if students do not employ appropriate strategies in VR learning environments. In this study also, most of the students reported enjoyment and fun concerning the VR learning environment in the interviews. However, they also utilized many strategies to proceed with the virtual tasks. The most frequent codes that emerged in students' SRL processes were self-control strategies. The cyclical model of SRL (Zimmerman, 2000) represents a set of general task strategies such as self-instruction, environmental structuring, help seeking, etc. In addition to task general strategies, students can utilize task specific strategies, which refer to the development of a systematic approach to handling different aspects of a specific task (Zimmerman & Moylan, 2009). This study identified self-control strategies that students use in a VR learning environment, which is a remarkable finding. Zimmerman and Moylan (2009) reported that the list of strategies for self-control that they provided serves as an illustration of several self-regulatory strategies that have been used to improve students' acquisition of academic and non-academic skills. They underlined the importance of noting that the list is not comprehensive. Therefore, this study contributed to the list of self-control strategies by identifying a variety of self-control strategies, especially task specific ones. Self-instruction, environmental structuring, and help seeking are self-control strategies that students utilized to progress with the virtual tasks in this study. Zimmerman and Moylan (2009) stated them as task-general self-control strategies. Thus, students in the VR learning environment used three of the general self-control strategies included in the cyclical SRL model to complete the virtual tasks. Furthermore, this research specified ten additional self-control strategies that are task specific. Elaboration, reading, calculation, mental operations, task solution, searching, interacting with tables and graphs, drawing, trial and error, and observation-emulation are task-specific self-control strategies. The previous studies conducted in hypermedia learning environments (Azevedo et al., 2004; Greene & Azevedo, 2008; Sonnenberg & Bannert, 2015) identified elaboration, reading, searching, drawing, and trial and error as self-control strategies. However, in this study, students' experiences in the VR learning environment revealed the emergence of calculation, mental operations, task solutions, interacting with tables and graphs, trial and error, and observation-emulation as additional strategies. Additionally, the observation-emulation strategy was related to the social aspects of SRL. Zimmerman’s multi-level model (2013) explains how students’ social interactions encourage them to be self-regulated learners. Initially, the student examines a social model (the pedagogical agent in this study) and subsequently attempts to imitate the actions performed by the model in the given task (Zimmerman, 2013). In essence, the findings regarding the use of observation-emulation as a self-control strategy displayed social aspects of SRL in the VR learning environment.

The last phase of the cyclical model of SRL is self-reflection where students assess their own work and develop a rationale for their outcomes (Panadero & Alonso-Tapia, 2014). Students evaluate their performance on the task and make judgements about the reasons for their success or failure. These attributions elicit self-responses that have the potential to either favourably or adversely impact how students approach the task in subsequent performances (Panadero, 2017).

The results of this study did not include any SRL processes regarding the self-reflection phase of Zimmerman’s (2000) cyclical model of SRL. This can be regarded as a noteworthy finding of this study. In fact, the lack of self-reflection processes while students were performing the consecutive tasks in the VR learning environment was an expected result in this study. Panadero and Alonso-Tapia (2014) related the lack of students' reflection on their works to the lack of opportunities to do that. Prior to commencing the activity, the teacher may define the evaluation criteria with the students. This may enable the students to evaluate their own work with more precision and get a deeper understanding of how to fix their errors. However, on many occasions, students are unaware of these criteria, and so they delay their assessment of the quality of their work until their teachers provide them with a score for their performance. When students are unable to reflect on their work after receiving a score, they are unable to engage in self-reflection. Rather, they assess their success or failure solely based on the feedback they receive from their teachers (Panadero & Alonso-Tapia, 2014). A similar situation occurred while students were performing virtual tasks in this study. At the beginning of the VR experience, they were not provided any information about how their work would be assessed. Students proceed with the virtual task by following certain instructions provided by the VR system. They engaged in monitoring processes in various ways and aims, such as to understand the mathematical content, requirements of the VR system, and tasks, check their solutions, and detect their errors. They benefited from the VR system's feedback in the monitoring processes. Thus, the VR system decided the success or failure of the students in the virtual tasks in this study, and students engaged in monitoring processes considering the feedback provided to them. This was similar to Panadero and Alonso-Tapia's (2014) example where teachers decide students' performance level in a traditional learning environment. Thus, the VR environment did not provide students with many opportunities to self-reflect on their performance after completing the virtual tasks.

The paucity of self-reflection processes in the VR learning environment was an expected result in this study based on the recommendations of the previous studies. Previous research recommended summarizing as a generative learning strategy (Fiorella & Mayer, 2016), which can provide students with opportunities to reflect on their learning in VR learning environments (Parong & Mayer, 2018) and assess their performance (Anderson & Thiede, 2008). Thus, summarizing material was integrated into the VR-based learning environment in this study to facilitate students' self-reflections on their learning in the VR learning environment. Since the summarizing material was provided at the end of the VR experience, it did not directly contribute to students' self-reflection processes in the VR learning environment. However, some participants reported how making a summary enabled them to be aware of what they had done and learned in the VR learning environment in the interviews. Thus, the findings of this study showed that making a summary of what students performed in the virtual tasks gave some participants an opportunity to think and reflect on their learning in the VR learning environment. The summarizing activities they completed after the VR experience only served as a retrospective assessment of their learning processes.

5.2.2 Features that are conducive to students' SRL processes

This study investigated how environmental features of a VR-based learning environment induced particular SRL processes during the completion of virtual tasks. Thus, this study not only investigated students' SRL processes but also identified mechanisms that are conducive to students' use of those SRL processes in the VR learning environment. Interactions, assessment and feedback mechanism s, agency, visual and auditory elements, instructions, and instructional activities were specified as features of the VR-based learning environment that were conducive to SRL processes in virtual tasks.

These findings shed light on the contextual elements in the VR-based learning environment that are favorable for SRL processes. Even though Zimmerman (2000) did not directly include context in his cyclical phases model, he discusses the significance of contexts in his triadic and multilevel models (Zimmerman, 2000) for the use of SRL processes (Panadero, 2017). The triadic social cognitive model of SRL focuses on the interdependence of personal, behavioral, and environmental factors and explains the strategic adaptation of students to various environmental conditions by monitoring and controlling them in the learning process (Zimmerman, 2000). An ideal self-regulatory intervention would aim to address all three factors simultaneously to achieve a synergistic effect (Zimmerman, 2013). In this respect, this study explored students' SRL processes while performing the virtual tasks and related them to contextual elements that facilitated those SRL processes. In a nutshell, how specific environmental factors were conducive to particular self-regulation processes in the VR learning environment was identified in this study. Consequently, self-regulatory interventions can be informed by this research regarding the contextual factors that generate particular SRL processes in VR learning environments. In addition, Zimmerman (2013) underlined the importance of context provided to students for SRL processes to emerge in his multilevel model and discussed the value of context-specific information about students' use of SRL processes. When considered from this point of view, this study investigated specific contextual elements in a VR-based learning environment and explained how they are conducive to SRL processes while performing the virtual tasks.

In addition to Zimmerman's (2000) triadic and multilevel models of SRL, Panadero (2017) summarized the significance of context for Winne and Hadwin (1998), Pintrich (2000), and Efklides's (2011) models. Context is incorporated into the feedback loops in which students receive information from the context and modify their strategies; accordingly, it is therefore crucial for adapting to task demands. For instance, Winne and Hadwin (1998) specifically included task conditions such as resources, instructional cues, time, and social context in their model of SRL. The model explains how students generate standards by considering task conditions, which help them monitor and control their activities and use various strategies while performing tasks. Similarly, the findings of this study identified specific contextual elements (conditions) included in the VR-based learning environment, such as instructions that gave rise to SRL processes while performing the virtual tasks.

Context was also included in Pintrich's (2000) SRL model. Moreover, Pintrich's (2000) SRL definition explicitly emphasized the significance of the contextual elements for self-regulation. He defined SRL as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment." (Pintrich, 2000, p. 453). Pintrich argued that SRL processes "can mediate the relationships between individuals, the context, and their overall achievement" (Pintrich, 2000, p. 453). In addition, Pintrich (2000) stated that contextual factors, such as feedback mechanisms or autonomy levels, have the potential to either support or limit students' SRL processes. Put simply, a well-organized environment can minimize distractions, provide access to necessary resources, and facilitate students' ability to regulate their learning effectively. The findings of this research revealed contextual features in the VR learning environment and how they guided students' SRL processes to emerge while performing the virtual tasks.

Efklides's (2011) model of SRL focused on the task, which is embedded in a specific context such as a specific learning environment, and she argued that "self-regulation is always done in response to the task" (Efklides, 2011, p. 10). Thus, the relationship between contextual elements and students' SRL was discussed in her model of SRL. Feedback systems, task characteristics, complexity, and mode of presentation were stated as task features, and the model was "based on the idea that learning tasks can be objectively defined based on task features" (Efklides, 2011, p. 10). Taking this into account, this study focused on a specific learning environment and explored its features, which are conducive to students' SRL processes. Thus, this study attempted to reveal contextual elements regarding the VR-based learning environment, make clear definitions of them, and relate them to the particular SRL processes that students engage in during the virtual tasks. In brief, context is a significant variable in SRL across all of the models (Panadero, 2017), and this study identified contextual elements of the VR-based learning environment that are conducive to SRL processes.

Radianti et al. (2020) provided a comprehensive review of immersive VR applications in higher education and identified which design principles were included in immersive VR applications for higher education. They reported fifteen design principles that were used in the thirty-eight VR studies they analyzed. Five of those fifteen design principles were also identified in this study as features of the VR-based learning environment that are conducive to SRL processes. Basic interaction with objects, moving around, immediate feedback, knowledge tests, and instructions were identified by Radianti et al. (2020) as design principles that were used in VR studies. These five design principles show similarities with six of the features of the VR-based learning environment in this study that are conducive to SRL processes. For instance, “basic interaction with objects, moving around” was similar to three sub-categories emerged under the interactions category (i.e., manipulating the graph, relocating objects, and moving around) in this study. Basic interaction with objects means being able to interact with virtual objects in a variety of ways after selecting them (Radianti et al., 2020). Basic interaction with objects occurred in this study by means of manipulating the graph and relocating object features in the VR-based learning environment. Students were able to generate their own graphs, interact with them by zooming in and out, and change the positions of virtual objects in this study. In addition, moving around is about being free to independently investigate the VR learning environment. (Radianti et al., 2020). Moving around was also identified under the interactions category as a feature of the VR-based learning environment that gave rise to certain SRL processes in this study.

Immediate feedback and knowledge tests were also design principles stated by Radianti et al. (2020), and they occurred together under the same category in this research. Students can be informed through the immediate feedback whether or not the learning tasks were correctly completed, and students can assess their progress in learning by means of knowledge tests (Radianti et al., 2020). Similarly, the VR learning environment in this study provided students with assessment and feedback mechanisms by providing audio alerts about their answers and multiple-choice questions to evaluate students’ learning in the virtual tasks.

The last design principle that was similar to the features that were conducive to students’ SRL processes in this study was instructions, in which students are provided with a tutorial or instructions on how to utilize the VR system and complete the learning tasks. The instructions can be presented through text, audio, or a virtual agent (Radianti et al., 2020). Likewise, the VR learning environment provided students with instructions in text, video, and audio formats. In sum, even if the primary purpose of this study was not to explore the design principles used in the VR learning environment, the features that were conducive to SRL processes showed some similarities between five of the design principles stated by Radianti et al. (2020).

Lastly, a VR-based learning environment was constructed by adding some traditional learning materials to an already existing VR learning environment. These paper-based learning materials were developed based on the pre-training principle (Mayer & Pilegard, 2014) and generative learning strategies (Fiorella & Mayer, 2016). Previous studies showed the contribution of learning activities designed for pre-training and summarizing to students' learning. For instance, pre-training enabled students to show better learning outcomes in knowledge and transfer tests in Meyer et al.'s study (2019). They related these results to a decrease in cognitive load. Parong and Mayer's (2018) study showed the effect of adding the generative learning strategy of summarizing in an immersive VR condition. The group that experienced summarizing activity after the virtual tasks performed better in the posttest. This research explored a VR-based learning environment that included both pre-training and summarizing activities from the perspective of Zimmerman's (2000) cyclical model of self-regulated learning. Thus, the current study did not directly focus on learning outcomes measured by knowledge and transfer tests but instead investigated in what ways these instructional activities were conducive to SRL processes. For instance, pre-training materials included not only names and characteristics of key concepts as in the previous studies (e.g., Meyer et al., 2019) but also brief information about key points regarding prior knowledge they could require performing the virtual tasks. A positive correlation was found between students' prior knowledge and their use of planning and monitoring processes in hypermedia learning environments (Moss & Azavedo, 2008). Thus, in this study, it was conceptually expected that the pre-training material would support students' SRL processes by facilitating their prior knowledge activation. Students did not start the virtual task from scratch; they could place new information in context. Thus, the pre-training material enabled students to activate their prior knowledge at the beginning of the virtual tasks in this study. This was a consistent finding since the forethought phase of Zimmerman's (2000) cyclical model of SRL includes activation of appropriate prior knowledge at the beginning of tasks.

5.3 Implications for practice

The findings of this study have implications for teachers, researchers, instructional designers, and teacher educators. Firstly, immersive virtual reality applications with high-quality head-mounted displays (HMDs) in educational settings are quite new. Thus, many participants in this study experienced an immersive VR application for the first time. Parong and Mayer (2020) argued that the novelty of environments for students may cause poorer learning outcomes due to fewer cognitive resources for essential and generative processes because students who are not familiar with the VR learning environment and its equipment can use much of their cognitive resources for extraneous processing. Therefore, the first module of the Pandemic by Prisms was used to make students familiar with VR equipment such as controllers. Consequently, participants did not directly encounter the virtual tasks in the VR learning environment. They first performed a reasoning task in the first module of the Pandemic by Prisms and experienced the VR equipment. This helped them gain an understanding of the VR environment itself, and they had the opportunity to practice the VR equipment in a relatively easy reasoning task before performing virtual tasks about exponential functions in the second module of the game. Regarding this, the teachers should keep in mind the novelty of using high quality HMDs for students while integrating immersive VR applications into their courses. A session in which students can practice VR equipment in a similar immersive VR application may be helpful for students to overcome the novelty effect before carrying out the actual VR learning tasks. The second implication of this study for teachers is about the design of an immersive lesson. In this study, a set of traditional learning activities were included in the VR learning environment. Pre-training materials assisted students to activate their prior knowledge about the mathematical topics that were prerequisites for exponential numbers and outlined the key concepts and their features that will be presented in the VR learning environment. Pre-training can be a way of promoting students' SRL in the VR learning environment because it can reduce students' cognitive load (Meyer et al., 2019).

The findings of this study showed that students engaged in a variety of SRL processes while performing the virtual tasks. They did not have any difficulty remembering relevant prior knowledge or comprehending the key concepts in the VR learning environment. This can be related to the pre-training materials provided with them. In addition, the summarizing material was utilized at the end of the VR experience. Although this material did not directly influence students' VR experiences, it was encouraging them to reflect on their learning experience in the VR learning environment. Thus, at the end of the VR experience, students developed a sense of having gained knowledge, as many participants argued. To sum up, teachers can enrich the immersive lessons they plan with more traditional instructional activities, such as pre-training and summarizing, based on the findings of this study.

The study revealed a variety of SRL processes students engaged in while performing the virtual tasks. Self-regulation includes learners' actions and the covert processes that lead to those actions (Zimmerman, 2000). Thus, this study employed both self-reported and observational data sources to capture students' actions and covert processes. Self-reported data was collected through think-aloud protocols and interviews. While think-aloud data captured students' SRL processes as they were performing the virtual tasks simultaneously, interview data included their retrospective comments about their performance in the VR learning environment. In addition, students' screen recordings were recorded and analyzed as an observational data source simultaneously with think-aloud data. The findings showed that using different data collection methods helped capture more SRL processes in the VR learning environment. For example, students used environmental structuring as a strategy to control themselves in the VR learning environment. This was primarily determined by analyzing the data obtained from screen recordings. Then, interview data was used to confirm this result and gain a deeper understanding of students' experiences in the moments when they use environmental structuring as a self-control strategy. Thus, the use of more than one data collection method enabled the researcher to detect both students' overt actions and covert processes regarding their self-regulation. One of the implications of this study for researchers would be the benefit of using multiple data collection methods to capture students' SRL processes in VR learning environments.

In addition, one of the participants could not complete the VR experience due to discomfort she felt about her eyes. She was using contact lenses, and she mentioned having pain in her eyes. However, participants who were wearing eyeglasses did not tell the researcher about this kind of problem, and they completed the virtual tasks. Hence, a second implication for researchers would be to inform participants who have problems with their eyes to prefer eyeglasses instead of contact lenses while practicing immersive VR applications.

Thirdly, this study has implications for instructional designers. The findings of this study revealed that immersive VR applications may provide fruitful learning environments for students when suitable design principles are utilized in the design of the VR learning environment. The primary focus of this study was not on the design principles employed in the creation of Pandemic by Prisms. Nevertheless, the findings showed that some of the design principles used in immersive VR applications (as described by Radianti et al., 2020) are similar to some of the features that help students' SRL processes in the VR learning environment. This study revealed features that are conducive to the SRL process in the VR learning environment, which can inform instructional designers to integrate them in the design of similar environments in VR contexts. In conclusion, the features discovered in this study can be incorporated into the suggestions for the design of immersive VR applications. These features can support the design of learning environments that would assist students' engagement in SRL processes through virtual tasks.

Lastly, this study has implications for teacher educators. This study explored students' SRL processes in a VR learning environment and the mechanisms that were conducive to those SRL processes. It would be important for teachers to know how to integrate VR applications into their lessons in a way that they could support students' SRL processes. It is the responsibility of teacher educators to inform pre-service teachers about the SRL processes that students employ while learning in a VR learning environment and the features of it that give rise to students' SRL processes. This study offers teacher educators a prototype of a VR-based learning environment which can be utilized in teacher education to inform pre-service teachers about SRL processed that students may require and how to support them while performing the virtual tasks.

5.4 Limitations of the study

The population representativeness of the sample is one of the limitations of the current study. Since the language of the VR learning environment was English, participants were chosen from high school students proficient in English, with at least an intermediate level of proficiency in the language. Thus, the sample was purposefully selected from volunteer high school students in Istanbul. Consequently, the sample cannot be representative of the entire student population in Turkish high schools.

The VR learning environment used in this study was a pre-designed VR application. Thus, the results of this study show students' use of various SRL processes in this specific VR application. It would be possible to explore different SRL processes and environmental features that give rise to those SRL processes in other VR learning environments. Even if similar results could be expected in similar contexts, the results of this study cannot be generalized to other VR applications. This is an important limitation of this study.

5.5 Recommendations for future research

In this section, recommendations for future research will be discussed in terms of the use of multimodal data, measuring learning outcomes, participant selection, and learning environment design. In the field of learning sciences, there is a growing interest in collecting and analyzing multimodal data (Noroozi et al., 2019). The various multimodal data channels are classified as physiological, self-reported, and observational (Hadwin, 2020). This study investigated students' SRL processes by using self-reported and observational data sources. This provided me as a researcher with the opportunity to conduct a more detailed analysis and triangulate results by using three data sources (i.e., think-aloud protocols, interviews, and screen recordings). Researchers pointed out the potential benefits of using multimodal data sources to explore how individuals engage in SRL processes (e.g., Engelmann & Bannert, 2020; Greene et al., 2020; Järvelä et al., 2019; Taub et al., 2020). Researchers can gain a better understanding of learning experiences in computer-based learning environments by using multiple data channels that complement each other. Making better and more informed interpretations based on one data channel (e.g., physiological data) requires combining data coming from one data channel with data from other data channels (e.g., self-reported and observational data). In this way, researchers can cross-validate their measurements of complex constructs that are difficult to capture with a single data channel (Giannakos et al., 2019). For instance, Sobocinski et al. (2023) combined think-aloud protocols, bird's-eye view video recording, and physiological data in a VR learning environment. They reported an interaction between students' cognitive load, monitoring, and motion while learning in a VR learning environment. Future research can investigate the SRL processes of students in VR learning environments by combining think-aloud protocols, screen recordings, and interviews with additional data sources such as eye-tracking, electrodermal activity, or heart rate. This will allow for an examination of the interaction between these different data sources.

Mathematics is a crucial domain for SRL, as many students struggle with mathematics, and the proficient use of SRL processes can improve their learning outcomes (Schunk & Greene, 2018). This instrumental case study focused on exploring students' SRL processes in a VR learning environment. There was not a direct measure of students' learning outcomes from the mathematical knowledge they gained in this study. Future research can measure students' mathematical learning outcomes by means of retention or transfer tests and relate them to students' use of SRL processes in the VR learning environment.

The participants in this study were higher achievers. Therefore, the findings of this study display how high school students who were higher achievers utilized various SRL processes in the VR-based learning environment. Future research can focus on a heterogeneous group in terms of achievement level and compare how students from different achievement levels engage in SRL processes while performing the virtual task.

Lastly, the VR-based learning environment used in this study included four traditional learning materials. These materials were designed based on the pre-training principle (Mayer & Pilegard, 2014) and generative learning strategies (Fiorella & Mayer, 2016). Future research can use other instructional materials that can be integrated into immersive VR applications and explore how they facilitate students' SRL processes in the VR learning environment.

APPENDIX A

VR MODULE 1 OF PANDEMIC BY PRISMS

The VR environment that was selected for this study is Pandemic by Prisms developed by Prisms of Reality company. Pandemic by prisms is a publicly available VR environment which can be run by Oculus Quest. Pandemic by Prisms aims at teaching exponential functions in the context of the real-world problem of the 2020 global pandemic. This VR application was selected for this study for three reasons. Firstly, the mathematical content of the VR application was suitable to the curricular objectives of high-school mathematics. Exponential functions and their graphical representations were the focus of Pandemic by Prisms, and these were appropriate for Turkish high school mathematics curriculum. Secondly, Pandemic by Prisms provide students a highly immersive VR experience where students can feel a high level of presence and agency in the virtual world. Thirdly, Pandemic by Prisms provides students with a navigable interface. It was easy to use for students with a user-friendly interface which was simple to use with clear directions in the application.

VR Module 1 is the first context that students will experience in the VR environment. The first aim of this module is to familiarize participants with the VR environment and the HMD equipment. VR Module 1 will be used as a training task in this study to lessen the novelty effect. The novelty of students in the VR environment was claimed as a possible reason for poorer learning outcomes due to fewer cognitive resources for essential and generative processes because students who are not familiar with the VR environment and its equipment can use much of their cognitive resources for extraneous processing (Parong & Mayer, 2020).

VR Module 1 introduces the global pandemic with a simulation that can be manipulated by the users to observe the effects of interventions such as wearing masks and social distancing. This module also includes some embedded tools that guide users in the VR environment. For instance, users can interact with a watch to use a pen, make calculations, and delete what is written. In addition, users can interact with a pedagogical agent whenever they need help. They can watch and rewatch videos, which helps users sustain the task. For instance, Figure 37 represents a scene from the VR Module 1 where the participant learns how to use a pen in the VR environment by watching a video and listening to a pedagogical agent. In summary, users are expected to be familiar with the VR environment and equipment by the agency of VR Module 1 before performing the actual learning task in VR Module 2.

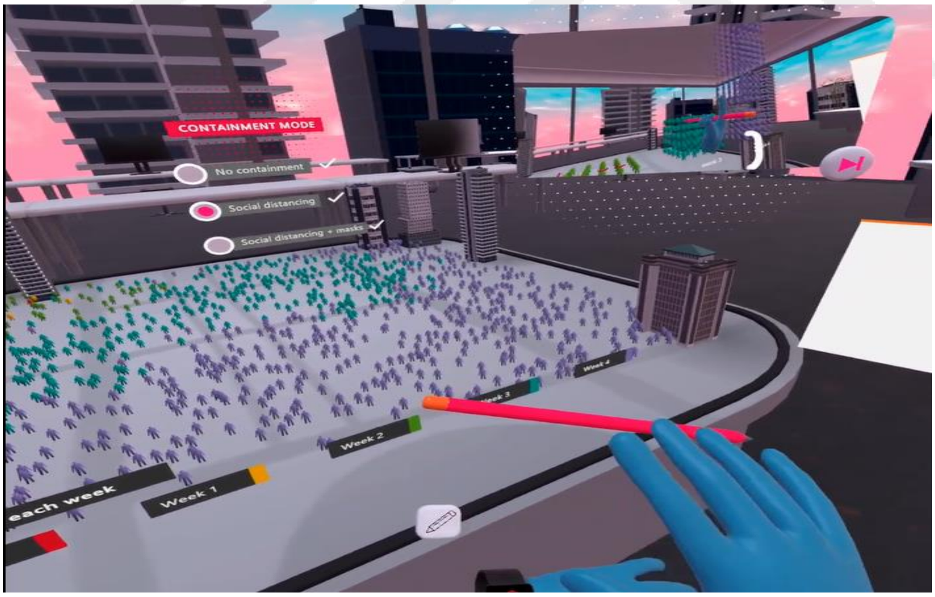


Figure 37. A screenshot from VR module 1

APPENDIX B

VR MODULE 2 OF PANDEMIC BY PRISMS

VR Module 2 is the second context that students will experience in the VR environment. There are three curricular objectives of the Turkish high school mathematics curriculum (MEB, 2018) that VR Module 2 includes.

1. Students will be able to explain exponential function.
2. Students will be able to calculate solution sets of exponential equations.
3. Students will be able to use exponential functions to model real life situations.

While the first curricular objective is an understanding level outcome, the second and third ones are applying level outcomes based on the revised version of Bloom's taxonomy (Anderson et al., 2001). The first curricular objective is about constructing meaning from experience with exponential functions in VR. The second and third curricular objectives aim at implementing new information and procedures about exponential functions in particular situations.

The aim of VR Module 2 is to provide activities for the students to achieve these curricular objectives. Students will experience exponential functions in a real-life situation. VR Module 2 provides a learning environment where students will be able to explore exponential functions and their properties. In the first task, students will observe an interactive bar graph, which is the representation of exponential growth. They will be expected to fill out a table based on their observations, and they will answer a multiple-choice question related to the interactive bar graph. In the second task, students will experience a graphical representation of exponential growth. They will try to write an exponential function. They will also fill out a table and answer two multiple-choice questions to successfully complete the task. Students will be guided by a pedagogical agent in VR Module 2. They will be free to seek help whenever they cannot proceed with the tasks. As in VR Module 1, this module also includes embedded tools such as a pedagogical agent, a pen, a calculator, and video simulators that will support students' learning in the VR environment.

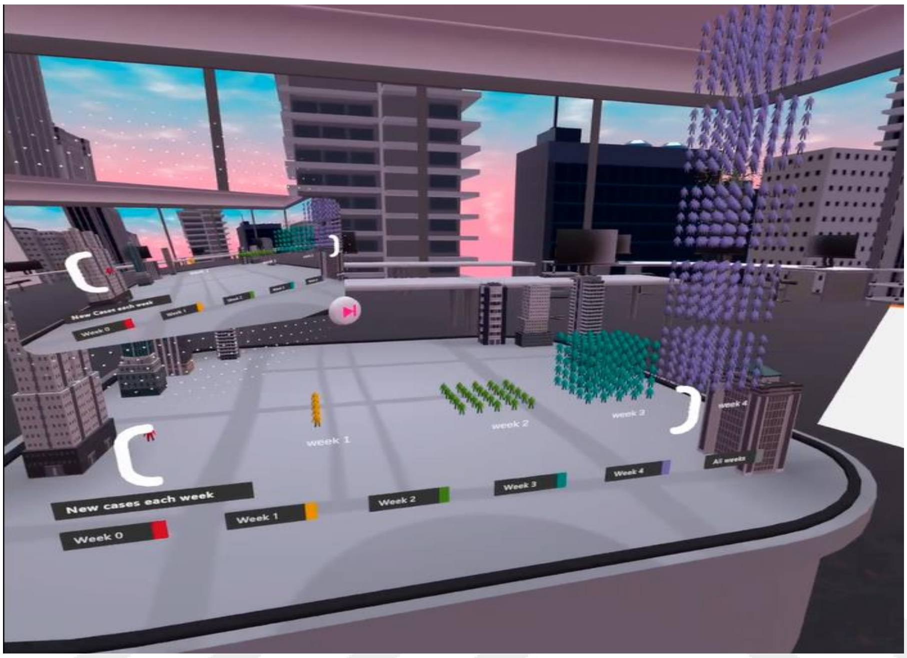


Figure 38. A screenshot from the first task of VR module 2

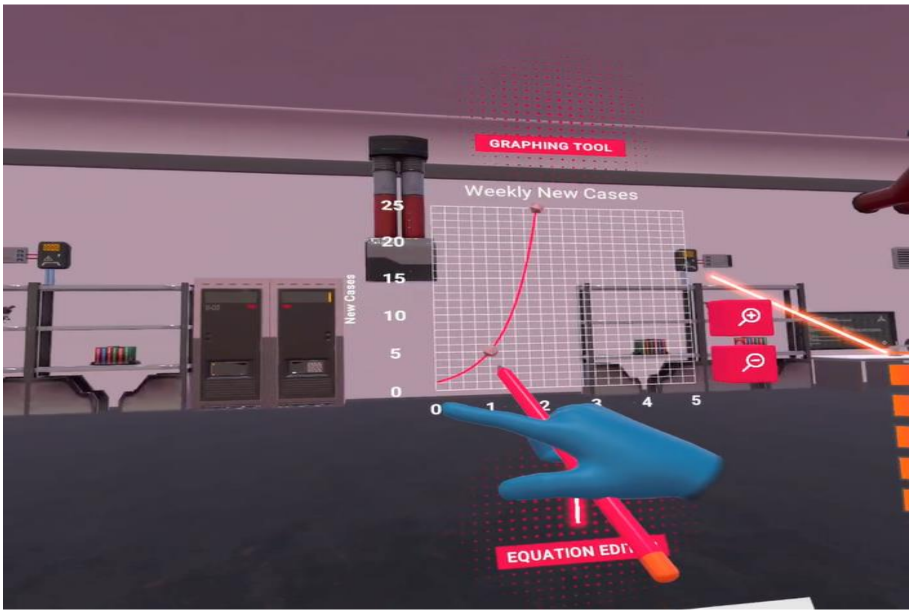


Figure 39. A screenshot from the second task of VR Module 2

APPENDIX C

PRIOR KNOWLEDGE ACTIVATION MATERIAL

The aim of this material is to support students' activation of prior knowledge related to exponential functions. Students with adequate prior knowledge can guide their own learning (Kirschner et al., 2006). Vrieling et al. (2010) identified prior knowledge activation as one of the significant SRL aspects of a learning task. In addition, students' working memory load may increase in complex learning environments, which may diminish learning according to cognitive load theory (Sweller et al., 2011). Kirschner et al. (2006) claimed that students with lower prior knowledge in complex learning environments where students are free to explore cannot integrate new information due to a lack of appropriate schemas. Guided instruction was suggested to be a way of supporting students to activate their prior knowledge by Kirschner et al. (2006). Thus, in this study, a material was designed as a part of the VR-based learning environment to activate students' prior knowledge with regard to exponential functions.

Five curricular objectives were identified as essential prior knowledge for learning exponential functions from the Turkish high school curriculum (MEB, 2018).

1. Students will be able to solve equations containing exponential expressions (9th grade).
2. Students will be able to solve problems related to functions (10th grade).
3. Students will be able to draw graphs of functions (10th grade).
4. Students will be able to interpret graphs of functions (10th grade).

5. Students will be able to construct graphical representations of real-life situations that can be expressed with linear functions (10th grade)

This material includes learning tasks related to each curricular objective. For instance, for the first learning objective, students will be informed about what an exponential number is and its special features. Then, they will be provided with worked examples about the integer power of a real number. Subsequently, they will exercise their options based on these calculations.

In a nutshell, this material will be designed to activate students' prior knowledge about exponential functions. It is expected to decrease students' working memory capacity by enabling them to reach required prior knowledge easily as they learn exponential functions in the VR environment. The Turkish version of the material is presented below.

Sanal gerçeklik ortamında deneyimleyeceğiniz matematik etkinliğine ön bilgi sağlayacak bazı kavramlar, bunların açıklamaları ve/veya örnekleri aşağıda verilmiştir. Lütfen bu etkinliği inceleyiniz. Bu çalışma için maksimum 10 dakikanız olacaktır.

1) Üslü İfadeler

Tanım:

$a \in R \; ve \; n \in Z^{+}$olmak üzere a^{n} ifadesine üslü ifade adı verilir. a^{n} ifadesinde a

sayısına taban , n ye ise üs veya kuvvet denir.

a^{n}= a.a.a.a….a olarak hesaplanır.

Örnek: Aşağıda bazı üslü ifadeler ve değerleri verilmiştir. Bunları inceleyiniz.

3^{0} = 1

3^{1} = 3

3^{2} = 3.3 = 9

3^{3} = 3.3.3 = 27

2) Fonksiyon
Tanım:

f, A dan B ye bir bağıntı olsun. Eğer

1. Her x ∈ A için (x,y) ∈ f olacak şekilde bir y ∈ B var ve

2. (x,y_1) ∈ f ve (x, y_2) ∈ f olduğunda y_1 = y_2 oluyorsa f bağıntısına

A dan B ye bir fonksiyon denir.

A dan B ye tanımlanan f fonksiyonu $f: A \rightarrow B$ şeklinde gösterilir.

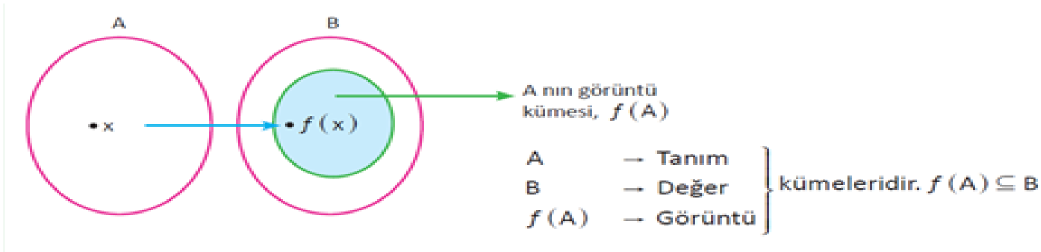
$(x, y) \in f \Rightarrow y = f(x)$ şeklinde yazılır.

Bu gösterimde x bağımsız değişken, y bağımlı değişken olarak adlandırılır.

$f: A \rightarrow B$ gösteriminde A kümesine fonksiyonun tanım kümesi, B kümesine fonksiyonun değer kümesi adı verilir.

A kümesinin elemanlarının, f fonksiyonuyla B kümesinde eşleştiği elemanlardan oluşan kümeye fonksiyonun görüntü kümesi denir ve $f\ (A)$ ile gösterilir.

Fonksiyonun tanımını açıklayan aşağıdaki şekli inceleyiniz.



3) Doğrusal Fonksiyon (Linear Function)
Tanım:

$f: R \rightarrow R$ ve a, b ∈ R olmak üzere

f (x) = ax + b biçimindeki fonksiyonlara doğrusal fonksiyon denir.

Bu fonksiyonların görüntü kümeleri analitik düzlemde doğru belirtir.

Örnek: Aşağıda verilen soruyu ve çözümünü inceleyiniz.

$f: R \rightarrow R$ doğrusal bir fonksiyon olmak üzere,

$f(3) = 15$

$f(5) = 23$ olduğuna göre $f(9)$ değerini bulunuz.

Çözüm:

$f(3) = 3a + b = 15$

$f(5) = 5a + b = 23$ bulunur. Bulunan denklem sistemi, yok etme yöntemiyle çözüldüğünde

–1 / 3a + b = 15

5a + b = 23

+

2a = 8

a = 4 ve b = 3 olur.

Yani $f(x) = 4x + 3$ olur.

$f(9) = 4.9 + 3 = 39$ olur.

Örnek (Sıra Sizde): Aşağıda verilen soruyu çözünüz.

$f: R \rightarrow R$ doğrusal bir fonksiyon olmak üzere,

$f(1) = 5$

$f(2) = 8$ olduğuna göre $f(5)$ değerini bulunuz.

Çözüm:

Örnek (Sıra Sizde): Aşağıda verilen soruyu çözünüz.

$f: R \rightarrow R$, f (x) = (a - b - 5)x^3 + (a + b + 1) x^2 + ax + b fonksiyonu doğrusal fonksiyon olduğuna göre f (2) değerini bulunuz.

4) Doğrusal Fonksiyonun Grafiği

Tanım:

$f: A \rightarrow B, y = f(x)$ fonksiyonuna ait bütün noktaların dik koordinat sisteminde gösterilmesiyle oluşan noktalar kümesine f fonksiyonunun grafiği denir.

Bilgi:

Doğrusal fonksiyonun grafiği çizilirken tanım kümesinin elemanları yatay eksende, değer kümesinin elemanları ise düşey eksende gösterilir.

$f: R \rightarrow R$, f (x) = ax + b içimindeki doğrusal fonksiyonların grafikleri çizilirken en az iki x

değeri için f (x) değerleri bulunur. Bulunan (x, f (x)) noktaları, dik koordinat sisteminde

işaretlenir. Bu noktaların birleştirilmesiyle oluşan doğru f fonksiyonunun grafiğidir.

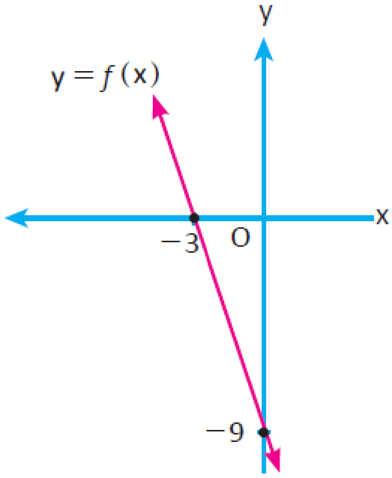
Örnek: Aşağıda verilen soruyu ve çözümünü inceleyiniz.

$f: R \rightarrow R$ olmak üzere, f (x) = -3x - 9 fonksiyonunun grafiğini çiziniz.

Çözüm:

x	0	–3
f (x)	–9	0

(0, –9) ve (–3, 0) noktaları dik koordinat sisteminde gösterilir. Ve doğrusal fonksiyonun grafiği çizilir.



Örnek (Sıra Sizde): Aşağıda verilen soruyu çözünüz.

$f: R \to R$ olmak üzere, $f(x) = \frac{2}{3}x - 4$ fonksiyonunun grafiğini çiziniz.

APPENDIX D

PRE-TRAINING MATERIALS

Two materials were designed based on the pre-training principle, which suggests that "people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts" (Mayer & Pilegard, p. 316, 2014). Supporting students with pre-training material before the VR experience increased their learning outcomes, according to Meyer et al.'s (2019) study. Thus, pre-training can promote learning in the VR environment because it reduces students' cognitive load (Meyer et al., 2019). The aim of pre-training materials is to present crucial words and concepts that are relevant for learning exponential functions before students attend VR Module 2 in pursuance of the pre-training principle. Students will be provided with the key concepts that they will encounter in VR Module 2. Some characteristics of those terms will also be introduced to the students. The Turkish version of the materials is presented below.

İngilizce Kavramların Türkçeleri (Pre-Training Material 1)

<u>Matematiksel Terimler</u>

Linear Function: Doğrusal Fonksiyon

Exponential Function: Üstel Fonksiyon

Exponential Growth: Üstel Büyümeye

Graph of the Exponential Function: Üstel Fonksiyonun Grafiği

Steeper Curve: Daha Dik Eğri

Shallower Curve: Daha Sığ Eğri

Left Shifted Curve: Sola Kaydırılmış Eğri

Right Shifted Curve: Sağa Kaydırılmış Eğri

Power: Üs

Base: Taban

Equation: Denklem

Factor: Çarpan

Multiplicative Relationship: Çarpımsal İlişki

<u>Tıbbi Terimler</u>

No Precautions: Önlem Yok

Social Distancing: Sosyal Mesafe

Containment: Sınırlama

Case: Vaka

Infection: Enfeksiyon & Hastalık & Bulaşma

Hospitalization: Hastaneye Yatma

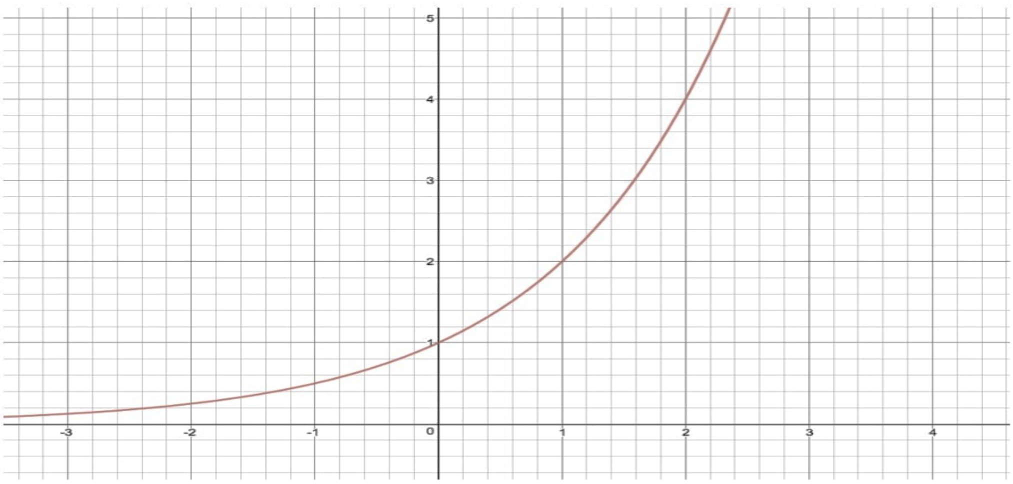
Pre-Training Material 2

Aşağıda sanal gerçeklik ortamında karşılaşacağınız belirli kavramlar, bu kavramlarla ilgili kısa açıklamalar ve/veya örnekler verilmiştir. Sanal gerçeklik ortamında bu kavramların İngilizceleri ile karşılaşacağınız için her kavramın yanına İngilizce karşılıkları da eklenmiştir. Bu kavramları inceleyiniz. Bu etkinlik için maksimum beş dakika süreniz olacaktır.

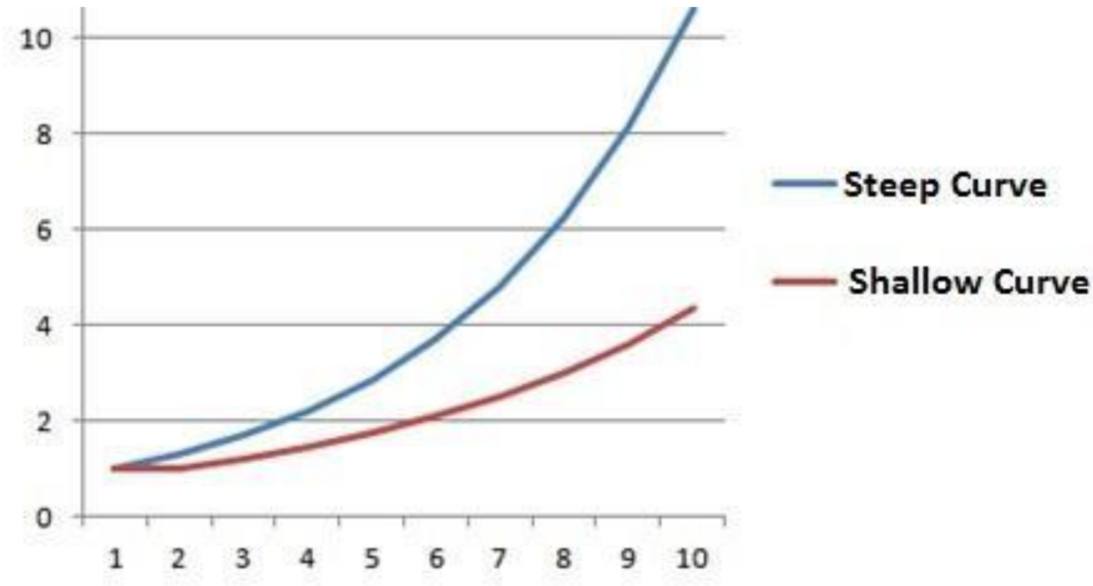
Üstel Fonksiyon (Exponential Function)

a, 1 den farklı pozitif bir reel sayı olsun. $f: R \rightarrow R^{+}, f\ (x) = \ a^{x}$ şeklinde tanımlanan fonksiyona üstel fonksiyon denir. Burada a sayısı üstel fonksiyonun tabanı ve x üs olarak adlandırılır.

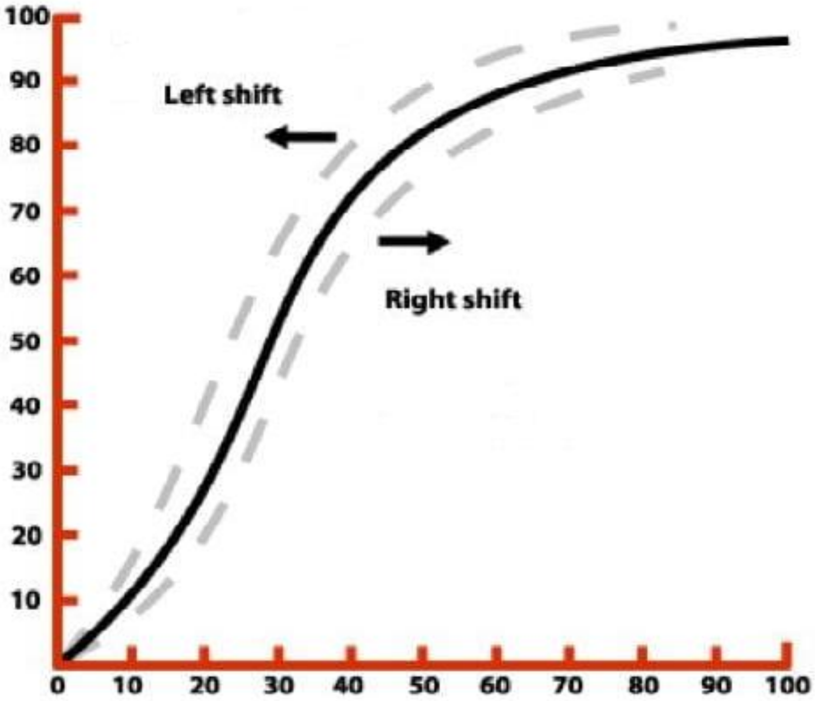
Üstel Fonksiyonun Grafiği (Graph of the Exponential Function)



Steeper and Shallower Curves:



Left and Right Shifted Curves:



APPENDIX E

SUMMARIZING MATERIAL

The purpose of this material is to provide students with a summary context for reflecting on what they have learned in VR Module 2. Summarizing involves selecting the most relevant information, organizing it, and integrating it with prior knowledge (Fiorella & Mayer, 2016), and it is one method of organizing instruction to facilitate SRL processes (Ley & Young, 2001). According to Anderson and Thiede (2008), summarizing contributes to students' metacognitive knowledge because it is a fruitful way of assessing students' own learning. In addition, summarizing as a generative learning strategy (Fiorella & Mayer, 2016) allows students to reflect on the learning material, which promotes deeper learning and SRL in VR environments (Parong & Mayer, 2018). Thus, this material contains a series of summarizing tasks that allow students to reflect on what they have learned in VR Module 2. In line with curricular objectives instructed in VR Module 2, the summarizing material was designed according to the tasks in VR Module 2.

Firstly, the summarizing material includes some prompts to guide and organize the summarizing. Students are required to

- construct a table with two variables which have an exponential relationship
- write the function of that relation
- draw the graph of that function
- state the difference between a linear function and an exponential function

Secondly, some tasks were designed to summarize graphical representations of exponential functions. In VR Module 2, students could observe an exponential function related to the number of patients in a pandemic and guess what happens in the different situations such as no containment, wearing mask, or wearing masks +

social distancing. Therefore, in the second task students were prompted to draw three exponential functions for each real-life situation. The Turkish version of the material is presented below.

Summarizing Material

Bu etkinlikte sanal gerçeklik ortamında deneyimlediğiniz "üstel fonksiyon (exponential function)" konusunu özetlemeniz hedeflenmektedir. Aşağıdaki yönergeleri takip ederek konuyu özetleyebilirsiniz.

1) Bir virüsün 0. haftada 1 kişi ile başlayıp sonraki her hafta üstel büyümeye (exponential growth) uygun şeklinde yayıldığını hayal ediniz. Aşağıdaki model şablonu size yardımcı olmak için hazırlanmıştır. 0. haftada enfekte olmuş bir kişi modellenmiştir. Bu modeli sonraki haftalardaki enfekte olan kişi sayısı (yeni vaka sayısı) üstel büyümeye uygun olacak şekilde devam ettiriniz.

0. Hafta | 1. Hafta | 2. Hafta | 3.Hafta

2) Yukarıda oluşturduğunuz modele uygun olarak aşağıdaki tabloyu doldurunuz.

Hafta	Yeni Vaka Sayısı
0	1
1	
2	
3	
4	
5	

3) 6. Haftadaki yeni vaka sayısı 5. haftadaki yeni vaka sayısı ile kıyaslandığında nasıl bir artış olur? Açıklayınız ve 6. haftadaki yeni vaka sayısını hesaplayınız.

4) 2. Soruda oluşturduğunuz tabloya bir sütun daha ilave ediniz. Yeni vaka sayısının üslü sayı olarak gösteriniz.

Hafta	Yeni Vaka Sayısı	Yeni Vaka Sayısı (Üslü Gösterim)
0	1	
1		
2		
3		
4		
5		

5) Yeni vaka sayısını üstel (exponential) bir fonksiyon olarak ifade ediniz.

f (t) =

6) 5. soruda yazdığınız üstel fonksiyonun grafiksel gösterimini yapınız.

7) Maskenin ve sosyal mesafenin virüsün yayılma hızını azalttığı bilinmektedir. 6. Soruda çizilen grafik virüsün ortalama şartlar altındaki yayılımını göstermektedir. Buna göre, insanların maske ve sosyal mesafe kurallarına hiç uymamaları durumunda 6. soruda çizmiş olduğunuz grafikte nasıl bir değişim olacağını gösterebilir misiniz?

8) Maskenin ve sosyal mesafenin virüsün yayılma hızını azalttığı bilinmektedir. 6. Soruda çizilen grafik virüsün ortalama şartlar altındaki yayılımını göstermektedir. Buna göre, insanların maske ve sosyal mesafe kurallarına sıkı sıkıya uymaları durumunda 6. soruda çizmiş olduğunuz grafikte nasıl bir değişim olacağını gösterebilir misiniz?

8) Doğrusal (lineer) fonksiyon ile üstel (exponential) fonksiyonu karşılaştırınız. Bunun için aşağıdaki tabloları tamamlayabilir ve tablolara uygun fonksiyonları yazabilirsiniz.

Hafta	Yeni Vaka Sayısı
1	5
2	10
3	15
4	20

f (t) =

Hafta	Yeni Vaka Sayısı
1	5
2	25
3	125
4	625

f (t) =

APPENDIX F

SELF-CONTROL STRATEGIES: THEIR DESCRIPTIONS AND EXAMPLES

Sub-Category	Definition	Example
Elaboration	Deeper processing such as Paraphrasing, connecting, inferring (Sonnenberg & Bannert, 2015), summarizing and interpreting	It explains the relationship between linear function and exponential function. While it increases by adding in the linear function, it increases by multiplying in the exponential function. (He summarizes what is explained audibly and visually in the virtual reality environment with his own words.) (Think-aloud, Aziz)
Reading	Re-reading out loud at text (Sonnenberg & Bannert, 2015; Greene & Azevedo, 2008)	She says to me. How many people are in the hospital every week? (She reads the question for the second time.) (Think-aloud, Itır)
Environmental Structuring	Changing the position of the tablet or deleting what is written for “increasing the effectiveness of one’s immediate environment” (Zimmerman & Moylan, 2009)	I'll take this. Okay here. Ok. (She changed the location of the tablet twice, bringing it to the most suitable position for writing on the table.) (Think-aloud, Itır)
Calculation	Carrying out task related calculations by calculator or pen	That means. Let's do our operation. 3000 if twenty percent. Since one hundred percent is a

		multiple of five, it is 5000. When the total number of patients reaches 15000 people, it means we have reached the limit. We do our multiplication immediately. If the fifth week is 3125, the sixth week is 15625, which is five times that. (He performs operations by writing on the virtual reality environment with a pen) (Think-aloud, Aziz)
Mental Operation	Carrying out task related calculations mentally	Now I proceed by dividing by 5. Because he said 20%. That's why I wrote it by multiplying it by 5. Now I proceed by dividing by 5. 5 became 1. 25 became 5. 125 will become 25. I could not write. From now on, 625 will be 125. Then yes. (She fills the table by performing mental operations.) (Think-aloud, Aylin)
Task Solution	Solving task related questions	That's why I take 5 as a base. I also take the number of weeks as the power. I put 5 t in the square. (Think-aloud, Aziz)
Searching	Searching the VR environment to proceed	Now I'm looking for a place where I can see the numerical values. (Continues to search by moving in the virtual reality environment) (Think-aloud, Itır)

Self-instruction	"Overt or covert descriptions of how to proceed as one executes a task, such as self-questioning as one reads textual material" (Zimmerman & Moylan, 2009, p. 302)	Ok. I don't know where to use the number of inpatients he gave me, but right now I will calculate twenty percent of the given numbers. (Think-aloud, Itır)
Help-seeking	"Soliciting assistance when learning or performing" (Zimmerman & Moylan, 2009, p.303)	Right now, I have to write my cases week by week. But I want to watch the video again. Because I didn't understand where to write the exponents. (Think-aloud, Itır)
Interacting with Tables and Graphs	Interacting with tables and graphs to solve a problem or understand the task.	Right now, I'm seeing how many people have been infected over the weeks. Although it infected only one person at first, five people in the first week, then twenty-five people. After that, it continues exponentially. (Think-aloud, Aziz)
Drawing	Drawing a graph to assist learning	Now I'm going to the graph. I still can't draw the graph. Hmm, I drew it. Ok. Here. Now, I said 5 in the first week. I'm marking 1 out of 5. I draw graphs for myself. In the third week. Pardon. I said 25 in the second week. Now I'm drawing 25 in the second week. Hmm,

		my graph will be like this. Ok. (Think-aloud, Itır)
Trial-Error	Trying, making errors and trying again to solve a problem or understand the task	I'm trying again. This time, I'll try the cube. I'm writing 5 again. (While trying to write an exponential function suitable for the model given in the table) (Think-aloud, Aziz)
Observation-Emulation	“Vicarious induction of a skill from a proficient model and imitative performance of a general pattern or style of a model's skills by social assistance” (Zimmerman, 2000, p.29)	“To do this, grap your tablet and press the mode button to access all of the equation tiles. Each equation tile represents a different function type. Grap an equation tile using the trigger and drop it into the equation editor.” (Instructions of the pedagogical agent). The participant observed the video instruction and replicated the movements of the pedagogical agent. (Screen Recording, Itır)

APPENDIX G

INTERVIEW QUESTIONS

1) What have you enjoyed the most and the least in the VR task?

2) What goals did you set for yourself at the onset of this task?

3) Have you used any particular strategy to enhance your learning during the task? Can you give an example?

4) Did you check your progress while you were working on the VR task? How?

5) How did you help yourself to learn/understand during the task?

6) What aspects of VR did you find challenging and why?

7) What do you think about the tasks that you completed before and after the VR task? Did they contribute to your learning? If so, how?

APPENDIX H

ETHICAL APPROVAL FROM BOĞAZİÇİ UNIVERSITY

Evrak Tarih ve Sayısı: 26.03.2022-59472

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ
SOSYAL VE BEŞERİ BİLİMLER YÜKSEK LİSANS VE DOKTORA TEZLERİ ETİK İNCELEME KOMİSYONU
TOPLANTI KARAR TUTANAĞI

Toplantı Sayısı	:	29
Toplantı Tarihi	:	24.03.2022
Toplantı Saati	:	10:00
Toplantı Yeri	:	Zoom Sanal Toplantı
Bulunanlar	:	Prof. Dr. Ebru Kaya, Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen
Bulunmayanlar	:	

Nazmi Erdoğan
Öğrenme Bilimleri

Sayın Araştırmacı,
"Lise Öğrencilerinin Sanal Gerçeklik Temelli Harmanlanmış Öğrenme Ortamındaki Öz-Düzenlemeli Öğrenmelerinin Desteklenmesi" başlıklı projeniz ile ilgili olarak yaptığınız SBB-EAK 2022/23 sayılı başvuru komisyonumuz tarafından 24 Mart 2022 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya çevrimiçi olarak katılımı ve oybirliği ile alınmıştır. COVID-19 önlemleri kapsamında kurul üyelerinden ıslak imza alınamadığı için bu onay mektubu üye ve raportör olarak Yasemin Sohtorik İlkmen tarafından bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Dr. Öğr. Üyesi Yasemin
SOHTORİK İLKMEN
ÜYE

e-imzalıdır
Dr. Öğr. ÜyesiYasemin Sohtorik
İlkmen
Öğretim Üyesi
Raportör

SOBETİK 29 24.03.2022

Bu belge, güvenli elektronik imza ile imzalanmıştır.

APPENDIX I

ETHICAL APPROVAL FROM MINISTRY OF NATIONAL EDUCATION

T.C.
İSTANBUL VALİLİĞİ
İl Millî Eğitim Müdürlüğü

GÜNLÜDÜR

Sayı : E-59090411-44-50548526 27.05.2022

Konu : Anket ve Araştırma İzni (Nazmi ERDOĞAN)

BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜNE
(Sosyal Bilimler Enstitüsü Müdürlüğü)

İlgi : a) Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 21.02.2020 tarihli ve 2020/2 sayılı genelgesi.
b) Valilik Makamının 25.05.2022 tarihli ve 50347906 sayılı oluru.

Valilik Makamının Anket ve Araştırma İzni konulu ilgi (b) oluru ve kullanılması uygun görülen ölçme araçlarının Müdürlüğümüzce mühürlenen örnekleri ekte gönderilmiştir.

İlgi (a) genelgenin 28. maddesinde; "Araştırma uygulama izni alan kamu kurum ve kuruluşları, uluslararası kuruluşlar, üniversiteler, sivil toplum kuruluşları ve araştırmacılar tamamladıkları bilimsel araştırma ile ilgili sonuç raporlarını, izni aldıkları ilgili birime çalışma bitiminden itibaren 30 gün içerisinde göndereceklerdir." ifadesi yer almaktadır.

Olur gereğince işlem yapılması ve araştırma sonuç raporunun ekte sunulan örneğe göre Müdürlüğümüz Strateji Geliştirme Şubesine gönderilmesi hususlarında gereğini arz ederim.

Abdurrahman ENSARİ
İl Millî Eğitim Müdürü a.
Şube Müdürü

Ek:
1- Valilik Oluru (1 Sayfa)
2- Rapor Örneği
3- Ölçekler

REFERENCES

Anderson, M. C. M., & Thiede, K. W. (2008). Why do delayed summaries improve metacomprehension? *Acta Psychologica*, *128*, 110–118. https://doi.org/10.1016/j.actpsy.2007.10.006

Antoniou, P. E., Arfaras, G., Pandria, N., Athanasiou, A., Ntakakis, G., Babatsikos, E., Nigdelis, V., & Bamidis, P. (2020). Biosensor real-time affective analytics in virtual and mixed reality medical education serious games: Cohort study. *JMIR Serious Games*, *8*(3). https://doi.org/10.2196/17823

Azevedo, R. (2015). Defining and measuring engagement and learning in science: Conceptual, theoretical, methodological, and analytical issues. *Educational Psychologist*, *50*(1), 84–94. https://doi.org/10.1080/00461520.2015.1004069

Azevedo, R. (2020). Reflections on the field of metacognition: Issues, challenges, and opportunities. *Metacognition and Learning, 15*, 91-98.

Azevedo, R., Cromley, J., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology*, *29*, 344–370. https://doi.org/10.1016/j.cedpsych.2003.09.002

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall Inc.

Bandura, A. (1997). *Self-Efficacy: The exercise of control*. New York, NY: W. H. Freeman.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report, 13,* 544-559.

Bloom, B. S. (1953). Thought processes in lectures and discussions. *The Journal of General Education*, *7*(3), 160–169. http://www.jstor.org/stable/27795429

Buttussi, F., & Chittaro, L. (2018). Effects of different types of virtual reality display on presence and learning in a safety training scenario. *IEEE Transactions on Visualization and Computer Graphics*, *24*(2), 1063–1076. https://doi.org/10.1109/TVCG.2017.2653117

Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2015). A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments. *Psychophysiology, 49*, 1017–1034.

Chen, Y., & Hsu, C. (2020). Self-regulated mobile game-based English learning in a virtual reality environment. *Computers & Education, 154*. https://doi.org/10.1016/j.compedu.2020.103910

Cleary, T. J., Callan, G. L., Malatesta, J., & Adams, T. (2015). Examining the level of convergence among self-regulated learning microanalytic processes, achievement, and a self-report questionnaire. *Journal of Psychoeducational Assessment*, *33*(5), 439–450.

Cummings, J. J., & Bailenson, J. N. (2015). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media Psychology*, *19*(2), 272–309. https://doi.org/10.1080/15213269.2015.1015740

Collins, J., Regenbrecht, H., Langlotz, T., Can, Y. S., Ersoy, C., & Butson, R. (2019). Measuring cognitive load and insight: A methodology exemplified in a virtual reality learning context. In *Proceedings of the IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 351–362). https://doi.org/10.1109/ISMAR.2019.00033

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research,* (4th ed.). Boston, MA: Pearson.

Creswell, J. W. (2013). *Qualitative inquiry & research design* (3rd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage.

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. BMC Medical Research Methodology, 11(1), 100. https://doi.org/10.1186/1471-2288-11-100

De Jong, F., Kollöffel, B., van der Meijden, H., Staarman, J. K., & Janssen, J. (2005). Regulative processes in individual, 3D and computer supported cooperative learning contexts. *Computers in Human Behavior*, *21*(4), 645–670.

Dignath, C., & Büttner, G. (2018). Teachers' direct and indirect promotion of self-regulated learning in primary and secondary school mathematics classes–insights from video-based classroom observations and teacher interviews. *Metacognition and Learning*, *13*(2), 127–157.

Dindar, M., Malmberg, J., Järvelä, S., Haataja, E., & Kirschner, P. A. (2019). Matching self-reports with electrodermal activity data: Investigating temporal changes in self-regulated learning. *Education and Information Technologies, 25*, 1785–180.

Efklides, A. (2011). Interactions of metacognition with motivation and affect in self-regulated learning: The MASRL model. *Educational Psychology, 46*(1), 6–25. https://doi.org/10.1080/00461520.2011.538645

Eisenberg, M., & Pares, N. (2014). Tangible and full-body interfaces in learning. In R. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 339–357). Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.021

Engelmann, K., & Bannert, M. (2020). Analyzing temporal data for understanding the learning process induced by metacognitive prompts. *Learning and Instruction*. Advance online publication. https://doi.org/10.1016/j.learninstruc.2020.101233

Erlandson, D. A., Harris, E. L., Skipper, B. L., & Allen, S. D. (1993). *Doing naturalistic inquiry: A guide to methods*. Sage Publications, Inc.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191. https://doi.org/10.3758/bf03193146

Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). SAGE Publications.

Fiorella, L., & Mayer, R. E. (2016). Eight ways to promote generative learning. *Educational Psychology Review*, *28*(4), 717–741. https://doi.org/10.1007/s10648-015-9348-9

Fischer, F., Hmelo-Silver, C. E., Goldman, S. R., & Reimann, P. (2018) (Eds.). *International handbook of the learning sciences*. New York: Routledge. Taylor & Francis.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education* (8th ed.). New York: Mc Graw HIll.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In *The International Scientific Conference eLearning and Software for Education* (Vol. 1, p. 133). "Carol I" National Defence University.

Giannakos, M.N.; Sharma, K.; Pappas, I.O.; Kostakos, V.; Velloso, E. (2019). Multimodal data as a means to understand the learning experience. *International Journal of Information Management*, *48*, 108–119.

Glaser, B. G. & Strauss, A. L. (1967). *The Discovery of grounded theory. Strategies for qualitative research*. Chicago: Aldine.

Graesser, A. C., Hu, X., & Sottilare, R. (2018). Intelligent tutoring systems. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 246–255). New York: Routledge.

Greene, J. A., Deekens, V. M., Copeland, D. Z., & Yu, S. (2018). Capturing and modeling self-regulated learning using think-aloud protocols. In D. H. Schunk & J. A. Greene (Eds.), *Handbook of self-regulation of learning and performance* (2nd ed.). New York: Routledge.

Greene, J., Plumley, R., Urban, C., Bernacki, M., Gates, K., Hogan, K., Demetriou, C., & Panter, A. (2020). Modeling temporal self-regulatory processing in a higher education biology course. *Learning and Instruction*, *72*, 101201. https://doi.org/10.1016/j.learninstruc.2020.101201

Greene, J. A., Robertson, J., & Costa, L. J. C. (2011). Assessing self-regulated learning using think aloud methods. In B. J. Zimmerman & D. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 313-328). New York, NY: Routledge.

Greeno, J. G., & Engeström, Y. (2014). Learning in activity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd edition ed., pp. 128-147). Cambridge University Press.

Hadwin, A. (2020). Commentary and future directions: What can multimodal data reveal about temporal and adaptive processes in self-regulated learning? *Learning and Instruction*. Advance online publication. https://doi.org/10.1016/j.learninstruc.2020.101214

Hadwin, A., Järvelä, S., & Miller, M. (2018). Self-regulation, co-regulation, and shared regulation in collaborative learning environments. In D. H. Schunk & J. A. Greene (Eds.), *Handbook of self-regulation of learning and performance* (2nd ed.). New York: Routledge.

Harley, J. M., Bouchet, F., Hussain, M. S., Azevedo, R., & Calvo, R. (2015). A multi-componential analysis of emotions during complex learning with an intelligent multi-agent system. *Computers in Human Behavior, 48*, 615–625. https://doi.org/10.1016/j.chb.2015.01.034

Hitchcock, G., & Hughes, D. (1995). *Research and the teacher : a qualitative introduction to school-based research* (2nd ed.). Routledge.

Horvers, A.; Tombeng, N.; Bosse, T.; Lazonder, A.W.; Molenaar, I (2021). Detecting emotions through electrodermal activity in learning contexts: A systematic review. *Sensors*, *21*, 7869. https://doi.org/10.3390/s21237869

Järvelä, S., Hadwin, A.F. Malmberg, J. & Miller. M. (2018). Contemporary perspectives of regulated learning in collaboration. In F. Fischer, C.E. Hmelo-Silver, Reimann, P. & S. R. Goldman (Eds.). *International handbook of the learning sciences* (pp. 127–136). New York, NY: Routledge. Taylor & Francis.

Järvelä, S., Malmberg, J., Haataja, E., Sobocinski, M., & Kirschner, P. (2020). What multimodal data can tell us about students’ regulation of their learning process? *Learning and Instruction*. Advance online publication. https://doi.org/10.1016/j.learninstruc.2020.101214

Järvelä, S., Järvenoja, H. & Malmberg, J. (2019). Capturing the dynamic and cyclical nature of regulation: Methodological Progress in understanding socially shared regulation in learning. *International Journal of Computer-Supported Collaborative Learning. 14*, 425–441.

Jong, T. (2010). Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science*, *38*, 105-134. https://doi.org/10.1007/S11251-009-9110-0.

Joo, Y. J., Bong, M., & Choi, H. J. (2000). Self-efficacy for self-regulated learning, academic self-efficacy and internet self-efficacy in web-based instruction. *Educational Technology Research and Development*, *48*(2), 5–17.

Kafai, Y. B., & Dede, C. (2014). Learning in virtual worlds. In K. R. Sawyer (Ed.), The *Cambridge handbook of the learning sciences* (2nd ed., pp. 522–542). New York, NY: Cambridge University Press.

Kirschner, P., Clark, R., & Sweller, J. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Klingenberg, S., Jørgensen, M., Dandanell, G., Skriver, K., Mottelson, A., & Makransky, G. (2020). Investigating the effect of teaching as a general learning strategy when learning through desktop and immersive VR: A media and methods experiment. *British Journal of Educational Technology*, *51*, 1-24.

Kvale, S. and Brinkmann, S. (2015) *Interviews: Learning the craft of qualitative research interviewing.* 3rd Edition, Sage Publications, Thousand Oaks, CA.

Lajoie, S. P., Lee, L., Poitras, E., Bassiri, M., Kazemitabar, M., Cruz-Panesso, I., Hmelo-Silver, C., Wisemand, J., Chane, L., & Lu, J. (2015). The role of regulation in medical student learning in small groups: Regulating oneself and others' learning and emotions. *Computers in Human Behavior*, *52*, 601–616. doi:10.1016/j.chb.2014.11.073

Lajoie, S., Zheng, J., Li, S., Jarrell, A., & Gube, M. (2020). Examining the interplay of affect and self-regulation in the context of clinical reasoning. *Learning and Instruction*. Advance online publication. https://doi.org/10.1016/j.learninstruc.2020.101224

Latham, G. P., & Locke, E. A. (1991). Self-regulation through goal setting. *Organizational Behavior and Human Decision Processes*, *50*(2), 212–247.

Liu, R.; Stamper, J.; Davenport, J. (2018). A novel method for the in-depth multimodal analysis of student learning trajectories in intelligent tutoring systems. *Journal of Learning Analytics*, *5*, 41–54.

Ley, K., & Young, D. B. (2001). Instructional principles for self-regulation. *Educational Technology Research and Development*, *49*(2), 93–103. https://doi.org/10.1007/BF02504930

Lyle, J. (2003). Stimulated recall: a report on its use in naturalistic research. *British Educational Research Journal*, *29*, 861-878. https://doi.org/10.1080/0141192032000137349.

Makransky, G., Andreasen, N. K., Baceviciute, S., & Mayer, R. E. (2020). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *Journal of Educational Psychology*. Advance online publication. https://doi.org/10.1037/edu0000473

Makransky, G., Lilleholt, L., & Aaby, A. (2017). Development and validation of the multimodal presence scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. *Computers in Human Behavior*, *72*, 276–285. https://doi.org/10.1016/j.chb.2017.02.066.

Makransky, G., & Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. *Computers & Education*, *134*, 15–30. https://doi.org/10.1016/j.compedu.2019.02.002

Makransky, G., & Petersen, G. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review*, *33*(2), 291–316. https://doi.org/10.1007/s10648-020-09586-2

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, *60*, 225–236. https://doi.org/10.1016/j.learninstruc.2017.12.007

Malmberg, J., Järvelä, S., Holappa, J., Haataja, E., Huang, X., & Siipo, A. (2019). Going beyond what is visible: What multichannel data can reveal about interaction in the context of collaborative learning? *Computers in Human Behavior*, *96*, 235–245.

Mayer, R. E., & Pilegard, C. (2014). Principles for managing essential processing in multimedia learning: Segmenting, pre-training, and modality principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 316–344). New York, NY: Cambridge University Press. http://dx.doi.org/10.1017/CBO9781139547369.016

McCombs, B. (1989). Self-regulated learning and academic achievement: A phenomenological view. In *Advances in self-regulation of learning and performance* (pp. 177–195). Springer. https://doi.org/10.1007/978-1-4612-3618-4_3

Means, B., Peters, V., & Zheng, Y. (2014). *Lessons from five years of funding digital courseware: Postsecondary success portfolio review, full report.* Menlo Park, CA: SRI Education.

Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). San Francisco, CA: Jossey Bass.

Meyer, O. A., Omdahl, M. K., & Makransky, G. (2019). Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. *Computers & Education, 137*, 19–30. https://doi.org/10.1016/j.compedu.2019.103603

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

Miles, M.B., Huberman, A.M. and Saldana, J. (2014). *Qualitative data analysis: A methods sourcebook.* Sage, London.

Mills, S., & Noyes, J. (1999). Virtual reality: an overview of user-related design issues. *Interacting With Computers*, *11*(4), 375–386. https://doi.org/10.1016/s0953-5438(98)00057-5

Milli Eğitim Bakanlığı Talim ve Terbiye Kurulu Başkanlığı (MEBTTKB). (2018). Ortaöğretim Matematik dersi öğretim programı. Ankara: MEB.

Moos, D. C., & Azevedo, R. (2008). Self-regulated learning with hypermedia: The role of prior domain knowledge. *Contemporary Educational Psychology*, *33*(2), 270–298. https://doi.org/10.1016/j.cedpsych.2007.03.001

Mu, S.; Cui, M.; Huang, X. (2020). Multimodal data fusion in learning analytics: A systematic review. *Sensors. 20*, 6856. https://doi.org/10.3390/s20236856

Noroozi, O., Alikhani, I., Järvelä, S., Kirschner, P. A., Juuso, I., & Seppänen, T. (2018). Multimodal data to design visual learning analytics for understanding regulation of learning. *Computers in Human Behavior*, *100*, 298-304.

Palumbo, R. V., Marraccini, M. E., Weyandt, L. L., Wilder-Smith, O., McGee, H. A., Liu, S., & Goodwin, M. S. (2017). Interpersonal autonomic physiology: A systematic review of the literature. *Personality and Social Psychology Review, 21*(2), 99–141. https://doi.org/10.1177/1088868316628405

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology*, *8*, 422.

Panadero, E., & Alonso-Tapia, J. (2014). How do students self-regulate? Review of Zimmerman's cyclical model of self-regulated learning. *Anales de Psicología*, *30*(2), 450–462.

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology, 110*(6), 785–797. https://doi.org/10.1037/edu0000241.

Parong, J., & Mayer, R. E. (2020). Cognitive and affective processes for learning science in immersive virtual reality. *Journal of Computer Assisted Learning*, *37* (1), 1-16. https://doi.org/10.1111/jcal.12482.

Patrick, H., & Middleton, M. (2002). Turning the kaleidoscope: What we see when self-regulated learning is viewed with a qualitative lens. *Educational Psychologist*, *37*, 27 - 39. https://doi.org/10.1207/S15326985EP3701_4.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts & P. R. Pintrich (Eds.), *Handbook of self-regulation* (pp. 491–501). New York: Academic.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers and Education*, *147*. https://doi.org/10.1016/j.compedu.2019.103778.

Reiser, B., & Tabak, I. (2014). Scaffolding. In R. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (Cambridge Handbooks in Psychology, pp. 44-62). Cambridge: Cambridge University Press. doi:10.1017/CBO9781139519526.005

Sawyer, R., Smith, A., Rowe, J., Azevedo, R., & Lester, J. (2017). Is more agency better? The impact of student agency on game-based learning. In E. André, R. Baker, X. Hu, M. Rodrigo, & B. du Boulay (Eds.), *Artificial intelligence in education: AIED 2017. Lecture notes in computer science* (Vol. 10331, pp. 275–283). Springer. https://doi.org/10.1007/978-3-319-61425-0_28

Sawyer, R. K. (2014). Introduction the new science of learning. In Sawyer, R. K. (Ed.), *The Cambridge handbook of the learning sciences*, (2nd ed., pp. 1–18). New York: Cambridge University Press. doi:10.1017/CBO9781139519526

Sawyer, R. K. (2014). Conclusion: The future of learning: Grounding educational innovation in the learning sciences. In Sawyer, R. K. (Ed.), *The Cambridge handbook of the learning scienc*es, (2nd ed., pp. 726–746). New York: Cambridge University Press. doi:10.1017/CBO9781139519526

Schunk, D. H. (1982). Verbal self-regulation as a facilitator of children's achievement and self-efficacy. *Human Learning*, *1*, 265–277.

Schunk, D. H. (2012). Social cognitive theory. In K. R. Harris, S. Graham, & T. Urdan (Eds.), *APA educational psychology handbook*. Vol. 1: Theories constructs, and critical Issues (pp. 101–123). Washington, DC: American Psychological Association.

Schunk, D. H., & Greene, J. A. (2018). Historical, contemporary, and future perspectives on self-regulated learning and performance. In D. H. Schunk & J. A. Greene (Eds.), *Handbook of self-regulation of learning and performance* (2nd ed., pp. 1–15). Routledge/Taylor & Francis Group. https://doi.org/10.4324/9781315697048-1

Sonnenberg, C., & Bannert, M. (2015). Discovering the effects of metacognitive prompts on the sequential structure of SRL-processes using process mining techniques. *Journal of Learning Analytics*, *2*(1), 72–100. 10.18608/jla.2015.21.5

Stake, R. E. (2005). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (3rd ed., pp. 443–466). Sage Publications.

Sweller, J., Merrienboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*, 251-296. https://doi.org/10.1023/A:1022193728205.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer.

Taub, M., Azevedo, R., Rajendran, R., Cloude, E., Biswas, G., Price, M. (2020). How are students' emotions related to the accuracy of cognitive and metacognitive processes during learning with an intelligent tutoring system? *Learning and Instruction*, *72*, https://doi.org/10.1016/j.learninstruc.2019.04.001.

Veenman, M. V. (2005). The assessment of metacognitive skills: What can be learned from multi-method designs? In C. Artelt & B. Moschner (Eds.), *Lernstrategien und Metakognition: Implikationen für Forschung und Praxis* (pp. 77–99). Berlin: Waxmann.

Villanueva, I., Campbell, B. D., Raikes, A. C., Jones, S. H., & Putney, L. G. (2018). A multimodal exploration of engineering students' emotions and electrodermal activity in design activities. *Journal of Engineering Education, 107*(3), 414–441.

Vrieling, E. & Bastiaens, T. & Stijnen, S. (2010). Process-oriented design principles for promoting self-regulated learning in primary teacher education. *International Journal of Educational Research, 49*, 141-150. 10.1016/j.ijer.2011.01.001.

Winne, P., & Azevedo, R. (2014). Metacognition. In R. Sawyer (Ed.*), The Cambridge handbook of the learning sciences* (Cambridge Handbooks in Psychology, pp. 63-87). Cambridge: Cambridge University Press.

Winne, P. H. (2017). Cognition and metacognition within self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulation of learning and performance* (pp. 52–64). London: Routledge.

Winne, P. (2014). Issues in researching self-regulated learning as patterns of events. *Metacognition and Learning, 9*, 229-237. https://doi.org/10.1007/S11409-014-9113-3.

Winne, P. H. & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Metacognition in educational theory and practice*. Hillsdale, NJ: Lawrence Erlbaum Associates

Witmer, B., & Singer, G. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225–240. doi: https://doi.org/10.1162/105474698565686.

Wu, B., Yu, X., & Gu, X. (2020). Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis. *British Journal of Educational Technology.*, *51*(6), 1991–2005. https://doi.org/10.1111/bjet.13023

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Thousand Oaks, CA: Sage.

Zimmerman, B. J. (2013). From cognitive modelling to self-regulation: A social cognitive career path. *Educational Psychologist*, *48*(3), 135-147. doi: 10.1080/00461520.2013.794676

Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-40). San Diego, California: Academic Press.

Zimmerman, B. J. (2008). Goal setting: A key proactive source of academic self-regulation. In D. H. Schunk & B. J. Zimmerman (Eds.), *Motivation and self-regulated learning. Theory, research and applications* (pp. 267-295). New York: Lawrence Erlbaum Associates.

Zimmerman, B. J., & Campillo, M. (2003). Motivating self-regulated problem solvers. In J. E. Davidson & R. J. Sternberg (Eds.), *The nature of problem solving* (pp. 233-262). New York: Cambridge University Press.

Zimmerman, B. J., & Moylan, A. R. (2009). Self-regulation: Where metacognition and motivation intersect. In D. J. Hacker, J. Dunlosky & A. C. Graesser (Eds.), *Handbook of metacognition in education* (pp. 299-315). New York: Routledge.