THE RELATIONSHIP BETWEEN PERCEIVED AUTHENTICITY AND COGNITIVE ENGAGEMENT ACROSS FOUR LEARNING PHASES IN A MULTIMEDIA SCIENCE LEARNING ENVIRONMENT: USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS) MEASUREMENTS

by

HAOTIAN YANG

(Under the Direction of Ikseon Choi)

ABSTRACT

This study explores the relationship between perceived authenticity and cognitive engagement within authentic learning environments, a topic that has garnered increasing attention in educational research and practice. While previous studies have linked authenticity and engagement to improved academic outcomes, there remains a gap in understanding how specific dimensions of authenticity impact various aspects of learning engagement.

To address this gap, this research investigates learners' perceived authenticity, cognitive engagement, and their relationship across four distinct learning phases: reading, introductory video, virtual simulation, and debriefing. Employing a mixed-methods approach, the research combines functional near-infrared spectroscopy (fNIRS) to gather real-time physiological data with semi-structured interviews to capture participants' perceptions of authenticity and cognitive engagement. Three core research questions guided the study: (1) What are the levels of perceived authenticity across four learning phases? (2) What are the levels of cognitive engagement—both

perceived and physiological—across these phases? (3) What is the relationship between perceived authenticity and cognitive engagement?

The findings reveal significant findings in perceived authenticity and cognitive engagement. The virtual simulation phase, which incorporated all three dimensions of authentic learning, elicited the highest levels of both perceived and physiological engagement. The reading and debriefing phases also promoted higher engagement, though each emphasized different aspects of authentic learning. In contrast, the introductory video phase, perceived as the least authentic, generated the lowest engagement levels. Additionally, fNIRS measurements provided valuable information on cognitive engagement. Using Bland-Altman plots, the alignment analysis validated the congruence between participants' perceptions and physiological measurements, underscoring the reliability of combining both approaches to assess cognitive engagement comprehensively.

Kendall’s Tau correlation analysis showed strong positive relationships between perceived authenticity and both perceived and physiological cognitive engagement ($r(28) = 0.77$, $p = 0.001$; $r(38) = 0.76$, $p < 0.001$). These findings highlight the importance of integrating comprehensive authentic learning activities to enhance learning engagement. In conclusion, this study provides valuable insights into the complex relationship between authenticity and cognitive engagement, offering evidence-based recommendations for designing authentic learning environments that effectively enhance learners' cognitive engagement, ultimately leading to improved academic performance.

INDEX WORDS: Authentic Learning, Perceived Authenticity, Learning Engagement, Cognitive Engagement, Physiological Measurement, Functional Near-Infrared Spectroscopy (fNIRS), Case Study

THE RELATIONSHIP BETWEEN PERCEIVED AUTHENTICITY AND COGNITIVE ENGAGEMENT ACROSS FOUR LEARNING PHASES IN A MULTIMEDIA SCIENCE LEARNING ENVIRONMENT: USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS) MEASUREMENTS

by

HAOTIAN YANG

B.A., Communication University of China, China, 2008

M.A., Yunnan University of Finance and Economics, China, 2015

M.A., Old Dominion University, 2018

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2024

THE RELATIONSHIP BETWEEN PERCEIVED AUTHENTICITY AND COGNITIVE ENGAGEMENT ACROSS FOUR LEARNING PHASES IN A MULTIMEDIA SCIENCE LEARNING ENVIRONMENT: USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS) MEASUREMENTS

by

HAOTIAN YANG

Major Professor:	Ikseon Choi
Committee:	Ai-Chu Elisha Ding
	Amanda E. Ferster
	Richard L. Lamb

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
December 2024

DEDICATION

Viva La Vida

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to those who have supported me throughout my doctoral journey, making this dissertation possible.

First and foremost, I extend my heartfelt thanks to my family, whose unwavering support and encouragement carried me through the most stressful and challenging periods of the past few years. To my wife, your love, patience, and belief in me have been my constant source of strength. You are the reason I began this journey and the driving force behind my determination to see it through to the end. To my little daughter, thank you for bringing joy and happiness into my life during the difficult times—your laughter made every challenge a bit easier.

I am deeply grateful to my major professor, Dr. Choi, for his tireless guidance and support throughout these past two years. Without his mentorship, completing this dissertation would not have been possible. His insightful feedback, countless meetings, and willingness to push me beyond my limits have been invaluable and unrivaled. Dr. Choi's dedication to my development as a researcher helped me build a solid foundation that will benefit me throughout my career. I will always remember Dr. Choi's professionalism, commitment to excellence, and unwavering diligence.

I would express my special thanks to Dr. Lamb for introducing me to the use of physiological measurements in the field of instructional technology. His precise and constructive feedback significantly improved the quality and depth of this dissertation. Dr. Lamb opened new doors for me in an exciting and complex field, for which I am truly grateful.

I would also like to thank Dr. Ding, whose thoughtful questions and feedback shaped my dissertation from the very beginning. More importantly, Dr. Ding provided me with invaluable research opportunities that have greatly influenced this study and will continue to benefit me in the future.

My sincere thanks to Dr. Ferster for her expert opinions on quantitative methods and assessment development. Her insights not only enhanced my dissertation but will also guide my future research endeavors.

Lastly, I want to extend my appreciation to all the faculty and staff in the LDT program for their unwavering support throughout my academic journey. Special thanks to Dr. Lloyd Rieber, Dr. Rob Branch, Dr. Jill Stefaniak, Dr. Nancy Knapp, Ms. Gretchen Thomas, Ms. Tiffany Haag, Ms. Melanie Peiper, and Ms. Kremell Johnson. Your guidance, assistance, and encouragement have played an essential role in my growth as a scholar, and for that, I am sincerely thankful.

To all who have contributed to this journey, I am deeply grateful. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, research in the educational context has witnessed a growing interest that focused on learners' experiences within authentic learning environments that integrate elements such as real-world relevant content, in-depth exploration, and integrated assessment (Herrington et al., 2014). This growing interest particularly revolves around understanding the relationship between authenticity and learning engagement, especially in the context of emerging technologies and multimedia-based virtual labs (Lombardi & Oblinger, 2007; Newmann, 1996).

The widespread adoption of virtual science simulation platforms, such as PhET, Gizmos, Labster, and PraxiLabs, has established these tools as powerful assets in science education. These platforms enable students to engage in immersive learning experiences that have demonstrated promising results in enhancing learning outcomes (Banda & Nzabahimana, 2021; Makransky et al., 2019; Perkins, 2020). For example, PhET's interactive simulations and PraxiLabs' virtual laboratories have made science labs more accessible, improving students' understanding of scientific concepts and fostering the development of inquiry-based learning skills (Yassin, 2022). Such tools are revolutionizing the way science education is delivered by creating immersive, flexible, and effective learning environments.

However, the effectiveness of these virtual science learning systems heavily depends on the learner's engagement, which is significantly impacted by the learners' perception of the learning as relevant and immersive. This sense of authenticity plays a critical role in shaping the overall learning experience. While prior research has shown that authentic learning environments can lead to higher levels of engagement and ultimately result in improved academic performance and personal development (Fredricks et al., 2004; Herrington & Oliver, 2000), further exploration is needed to better understand how various dimensions of authenticity influence learning engagement, particularly in virtual science learning environments.

Authentic learning and learning engagement are both multidimensional constructs that encompass various aspects of the learning process (Reeves et al., 2002). Authentic learning refers to the learning environment that fosters a perception of authenticity by integrating real-world, problem-based learning experiences that reflect the complexities and challenges learners may encounter in their future professional lives (Herrington & Oliver, 2000). Learning engagement, on the other hand, is a construct encompassing behavioral, cognitive, social, and affective aspects of learners' involvement in learning (Fredricks et al., 2004). Together, these constructs have the potential to foster meaningful learning experiences and promote deep, sustained learner involvement (Herrington et al., 2014).

The growing interest in authenticity and engagement is driven by the recognition that traditional, teacher-centered approaches often fail to adequately prepare students for the complexities of the modern world (Savery, 2009). In contrast, authentic learning environments, which emphasize real-world problem-solving and promote learner autonomy, are associated with numerous benefits, including improved critical thinking skills, heightened engagement, and higher academic achievement (Herrington et al., 2014; Lombardi & Oblinger, 2007). In parallel, learning engagement has emerged as a critical factor in determining students' academic success, as engaged learners are more likely to persist in their studies and achieve higher levels of performance (Appleton et al., 2008; Kuh, 2009).

The interplay between authenticity and learning engagement is a crucial area of inquiry for educators, researchers, and policymakers seeking to enhance the learning experience and outcomes for diverse student populations (Lombardi & Oblinger, 2007; Newmann, 1996). By integrating authentic learning environments, educational stakeholders can better prepare learners to thrive in a world that is increasingly complex, interconnected, and dynamic (Herrington et al., 2014). Therefore, developing a comprehensive theoretical framework that systematically examines and conceptualizes the relationship between authenticity and learning engagement is essential for guiding the design, implementation, and evaluation of authentic learning environments.

1.2 Problem Statement

Although authenticity and learning engagement have received significant attention from researchers and practitioners alike, a salient knowledge gap remains about the complex interplay between specific elements of authenticity and the multiple dimensions of learning engagement (Reeves et al., 2002; Lombardi & Oblinger, 2007; Newmann, 1996). The literature concerning the sophisticated associations between discrete elements of authentic learning and the respective dimensions of learning engagement is limited. For instance, while the broader framework of authenticity has been correlated with academic achievements and enhanced critical thinking aptitudes (Lombardi & Oblinger, 2007; Herrington et al., 2014), an in-depth examination of which components of authenticity most potently influence specific dimensions of engagement remains absent.

This gap in academic discourse is particularly concerning given the escalating demands of modern education, which require not only the transmission of knowledge but also equipping learners with critical thinking skills, adaptability, and an autonomous mindset to navigate the complexities of a rapidly evolving world. (Savery, 2009; Kuh, 2009). Without a comprehensive understanding of the relationship between authentic learning elements and learning engagement, educators, policymakers, and instructional designers potentially lack crucial insights to improve pedagogical practices, thereby optimizing learning outcomes for diverse learner cohorts.

This study focuses on the relationship between cognitive engagement and learners' perceptions of authenticity. Cognitive engagement is arguably the most important dimension of learning engagement that is directly responsible for improved learning outcomes and plays a critical role in promoting learner persistence and reducing dropout rates (Fredricks et al., 2004; Appleton et al., 2008). It is uniquely influenced by all three dimensions of authentic learning—authentic content, learning activities, and outcome assessment—making it an ideal starting point for understanding how students internalize authentic learning experiences. Thus, exploring cognitive engagement provides a foundational lens for broader research into how authentic learning shapes overall learning engagement and fosters meaningful learning outcomes.

Accurate measurement of authenticity and learning engagement is crucial to explore the relationship. In the field of educational research, one of the main challenges in measuring learning engagement is the inherent subjectivity and potential bias associated with self-report measures (Schellens & Valcke, 2006). Students may not accurately report their level of engagement due to social desirability or misunderstanding survey questions. Additionally, researchers and practitioners may interpret the data differently, leading to inconsistencies in evaluating engagement levels (Fredricks et al., 2004). Moreover, these instruments capture the learner's perception at a single point during learning, potentially missing dynamic shifts in cognitive engagement as learning unfolds.

In response to the limitations of traditional engagement measures, researchers have begun exploring real-time physiological measures to assess engagement more objectively. These measures include functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), heart rate variability (HRV), Magnetic resonance imaging (MRI), and facial feature analysis techniques.

fNIRS offers a promising solution to these challenges. As a neuroimaging technique, fNIRS measures brain activity by detecting changes in blood oxygenation in the cortex, providing real-time data on cognitive processing (Cutini et al., 2011). While fMRI, another popular neuroimaging technique, provides greater spatial resolution, fNIRS offers unique advantages for educational research. Its non-invasiveness, relative tolerance to motion, and compatibility with natural learning environments make it particularly suitable for studying cognitive engagement in real-time, interactive settings (Ayaz et al., 2012). By detecting changes in oxygenated and deoxygenated hemoglobin concentrations in the brain, fNIRS can provide valuable insights into the neural mechanisms underlying learning and cognitive processes (Lamb & Etopio, 2019). Furthermore, integrating neuroimaging data from fNIRS and subjective measures, such as surveys and interviews, can yield a holistic understanding.

1.3 Purpose of the Study

In light of the above, this dissertation aims to investigate the relationships between perceived authenticity and learners' cognitive engagement level across four learning phases with different media—reading, introductory video, virtual simulation, and debriefing. The study utilizes fNIRS measurements to capture real-time cognitive responses alongside semi-structured interviews to gather insights on perceived authenticity and cognitive engagement. Specifically, the study seeks to address the following research questions:

1. What are the levels of authenticity students perceived according to four consecutive learning activities (reading, introductory video, virtual simulation, and debriefing)?
2. What are the levels of students' cognitive engagement across four learning activities (reading, introductory video, virtual simulation, and debriefing)?
   i. What are the levels of students' perceived cognitive engagement?
   ii. What are the levels of students' physiological cognitive engagement?
   iii. What similarity patterns emerge between students' perceived and physiological cognitive engagement?
3. What relationship patterns emerge between students' perceived authenticity and cognitive engagement?
   i. What relationship patterns emerge between students' perceived authenticity and perceived cognitive engagement?
   ii. What relationship patterns emerge between students' perceived authenticity and physiological cognitive engagement?

1.4 Significance of the Study

The results of this study advance neuroscience research in the educational domain by offering a deeper understanding of the neural responses to various learning activities within authentic learning environments. By investigating these relationships, the study contributes to the development of evidence-based recommendations for educators and instructional designers, revealing how authentic learning elements enhance learning engagement. The findings expand knowledge in the field of instructional technology and catalyze the creation of transformative learning experiences that promote optimal learning outcomes. Insights derived from the empirical data will assist in shaping future pedagogical interventions and guiding the direction of subsequent research endeavors.

1.5 Definitions of Key Concepts

Authentic learning is a pedagogical approach that emphasizes the importance of integrating real-world contexts in the learning process, allowing learners to experience tasks resembling those encountered in daily life or professional settings (Herrington et al., 2014). Reeves, Herrington, and Oliver (2002) identified ten elements of authentic learning environments. These elements encompass real-world relevance, ill-defined problems, interdisciplinary perspectives, multiple sources and perspectives, collaboration, metacognition, sustained investigation, integrated assessment, polished products, and multiple interpretations and outcomes (Herrington et al., 2014; Lombardi & Oblinger, 2007; Reeves et al., 2002).

Incorporating authenticity into instructional technology involves designing learning environments that allow learners to engage in meaningful, real-world tasks supported by technology (Herrington et al., 2014). This can be achieved through the use of digital tools and resources that facilitate collaboration, problem-solving, and reflection, such as online discussion forums, multimedia case studies, and interactive simulations (Lombardi & Oblinger, 2007). Furthermore, researchers can leverage emerging technologies, such as artificial intelligence, virtual and augmented reality, to create immersive and authentic learning experiences that enable learners to explore complex, real-world situations in safe and controlled environments (Dunleavy et al., 2009).

By integrating strategies to enhance authenticity into the design process of technology-enhanced learning environments, educators and designers can foster a deeper understanding of the subject matter, facilitate meaningful interactions, and enhance learning engagement

(Herrington et al., 2014; Lombardi & Oblinger, 2007). Consequently, authentic learning has emerged as a promising approach that can contribute to better learning outcomes and prepare learners for success in their future personal, academic, and professional endeavors (Murphy et al., 2006).

Learning engagement, first conceptualized in the 1980s, represents learners' physical and psychological commitment to and exertion in the learning process (Finn, 1989; Zimmerman, 1990), emphasizing their pursuit of understanding, knowledge acquisition, and skill development. Finn (1989) offered a crucial perspective on learners' behavior, suggesting that participation was a key aspect of students' adaptation to the academic environment. In comparison, Zimmerman (1990) connected cognitive engagement to deeper understanding and better learning outcomes.

This foundational definition has since been elaborated and deepened by subsequent scholars. In the instructional technology field, learning engagement has been investigated through the lens of technology-enhanced learning environments, such as online courses, blended learning settings, and the use of digital tools and resources (Hew, 2016; Milligan et al., 2013). Researchers have sought to understand the role of instructional technology in supporting or hindering the four dimensions of engagement: behavioral, social, cognitive, and affective (Finn & Zimmer, 2012).

Behavioral engagement in instructional technology can be facilitated with digital tools and resources that promote active participation, timely feedback, and learner autonomy (Means et al., 2009). For example, learning management systems (LMS) and interactive multimedia can promote participation, while adaptive learning platforms can provide personalized feedback and support for learners (Aguilar et al., 2018).

Social engagement in technology-enhanced learning environments can be fostered through digital communication and collaboration tools, such as discussion forums, video conferencing, and social media (Kreijns et al., 2014). The integration of these tools can support learners in forming connections with their peers and instructors and engaging in meaningful and authentic discussions (Willms et al., 2009).

Cognitive engagement in instructional technology contexts can be enhanced using digital resources and instructional strategies that promote deep learning, critical thinking, and problem-solving (Paas & Sweller, 2012). Examples include online simulations, interactive multimedia, and game-based learning (Clark et al., 2016).

Instructional technology can influence affective engagement by creating a supportive digital learning environment (Willms et al., 2009). This can be achieved by ensuring the accessibility and usability of digital tools and resources, as well as by incorporating elements of choice, autonomy, and personal relevance into the learning experience (Park & Choi, 2009).

CHAPTER 2

LITERATURE REVIEW

This chapter is organized into three main sections. The first section explores the literature concerning authentic learning, exploring its theoretical foundations, elements, and significance in the educational context. Subsequently, the exploration shifts to learning engagement in the second section, encompassing a comprehensive review of divergent perspectives on the subject, its various dimensions, and its crucial role in shaping educational outcomes. Conclusively, the chapter articulates a conceptual framework that interlaces authenticity with learning engagement. This synthesis is sculpted based on the preceding literature insights and the discerned interrelationship between the two constructs.

2.1 Authentic Learning

Authentic learning is a pedagogical approach that emphasizes the significance of real-world contexts. It enables learners to experience tasks in the learning environment that closely resemble those they encounter in their daily lives or professional contexts (Herrington et al., 2014). Three major theoretical perspectives have influenced the concept of authentic learning: 1) Constructivism, 2) Sociocultural Theory, and 3) Situated Learning Theory.

2.1.1 Constructivism

Constructivism is a learning theory that posits that learners actively construct their own knowledge and understanding based on their experiences and interactions with the environment (Piaget, 1970). In constructivist learning environments, learners are encouraged to explore, inquire, and solve problems, thereby fostering the development of higher-order thinking skills and deep understanding (Jonassen, 1991).

Piaget's (1970) theory of cognitive development is a cornerstone of constructivism. It asserts that learners actively construct their knowledge through a process of assimilation and accommodation. Assimilation involves incorporating new experiences into existing cognitive structures, while accommodation entails modifying those structures to accommodate further information. According to Piaget, cognitive development progresses through a series of stages, each characterized by distinct mental structures and ways of thinking.

Piaget's theory underscores the importance of engaging learners in meaningful tasks and providing opportunities for them to interact with their environment. These interactions promote cognitive growth and the development of new mental structures by challenging learners to confront novel problems and situations (Piaget, 1970). Educators can stimulate learners' curiosity and facilitate the assimilation and accommodation processes that drive cognitive development by situating learning tasks in real-world contexts.

Constructivist learning environments that incorporate authenticity promote active learning, problem-solving, and reflection, enabling learners to construct their own understanding and knowledge (Jonassen, 1991). By situating learning tasks in real-world contexts and providing opportunities for exploration and inquiry, these environments support the development of higher-order thinking skills and foster deep learning (Herrington et al., 2014).

2.1.2 Sociocultural Theory

Sociocultural theory emphasizes the critical role of social interaction in human growth and cognitive development (Vygotsky, 1978). It posits that teaching and learning should be integrated with the society and culture in which they are situated (Erdogan, 2016). According to this perspective, knowledge is socially embedded, and learning occurs through a socially mediated collaborative process (Vygotsky, 1978).

Vygotsky (1978) argued that cognition should be understood in a social context, and human development should be viewed as the acquisition of culture. Social interaction is considered a critical component of the learning process, and the development of the mind would be impossible without this component (Cole & Wertsch, 1996). As a student-centered pedagogical method, the sociocultural approach often informs the design of authentic learning environments. Authenticity is built on learners' participation and interaction with peers and experts, making sociocultural theory an effective lens to understand the social dimension of authentic learning (Andersson & Andersson, 2005).

The critical concepts of sociocultural theory correspond with the content and strategy features of authentic learning. To facilitate cognitive development, learners must use mediatory tools to interact with peers, instructors, and the environment (Hall, 2007). These tools, which include language, symbols, and artifacts, enable learners to engage in meaningful communication and collaboration. In authentic learning environments, the use of mediatory tools facilitates learners' understanding and interpretation of the world, as cultural contexts and social experiences shape their perspectives (Vygotsky, 1978).

The learning environment and activities should be authentic to support cognitive development within a sociocultural framework (Hall, 2007). The learning environment should encompass individuals who naturally apply the knowledge, and the learning activities should be based on real-world scenarios. Lave and Wenger (1991) further developed the concept of authentic environments in their Situated Cognition theory, demonstrating that learning takes place most effectively in an authentic environment with authentic activities (Brown et al., 1989).

2.1.3 Situated Learning Theory

Authentic learning stems from situated learning theory that focuses on solving real-world problems in real-world contexts (Herrington et al., 2014). Developed by Lave and Wenger (1991) as a learning model in communities of practice, situated learning theory posits that learning is always situated (Saivyer & Greeno, 2009). The theory seeks to enable learners to apply their newly acquired knowledge and skills to real-life situations (Choi & Hannafin, 1995). It emphasizes the impact of context and culture on learning and cognition (Brown et al., 1989).

Situated learning theory identifies learning as a social phenomenon that emerges from everyday interactions (Henning, 2004). The traditional perspective views learning as a mental activity and considers highly decontextualized, abstract concepts as primary knowledge (Brown et al., 1989). In contrast, the situated perspective challenges the assumption that the cognitive process of learning is independent of contexts and interactions (Resnick et al., 1997). From a situated standpoint, a learning process based solely on accumulating information is considered ineffective since knowledge building is a social process established by interactions (Henning, 2004).

A key aspect of situated learning theory is the community of practice, which refers to a group of people working together on a similar or common task (Lave, 1988). A community of practice is constituted by three elements: a common domain, an interacting community, and a shared practice (Wenger, 1998). In these communities, knowledge is transferred during reciprocal interactions, and individuals undergo an identity transformation, transitioning from novice to expert. These transitions involve deeper participation in specific communities of practice.

In situated learning environments, learners engage in comprehensive learning processes, including identifying problems, collecting data, making hypotheses, proposing solutions, and analyzing outcomes (Henning, 2004). Collaboration is an inherent part of situated learning, as learners engage in highly interactive activities that collectively construct knowledge and skills with community members and share the responsibility of learning (Choi & Hannafin, 1995). Learning environments embodying the situated learning theory facilitate learners' engagement and help them acquire critical thinking and problem-solving skills. By allowing learners to engage in authentic tasks within real-world contexts, situated learning environments support the development of expertise and promote meaningful learning experiences.

In summary, the theoretical foundations of authenticity in learning environments are grounded in constructivism, sociocultural theory, and situated learning theory. These theories emphasize the importance of context, social interaction, and real-world problem-solving in the learning process. By integrating these theoretical foundations, educators can design authentic learning environments that foster more profound understanding, provide meaningful interactions, and improve engagement among learners. Such environments prepare learners for success in their future personal, academic, and professional endeavors by promoting the development of critical thinking, problem-solving, and collaboration skills.

2.1.4 Dimensions of Authentic Learning

Authentic learning is characterized as a multidimensional approach, incorporating various elements to create an immersive learning experience. Reeves, Herrington, and Oliver (2002) identified ten elements of authentic learning environments, which can be organized into three dimensions: authentic learning content, authentic learning activities, and authentic outcome assessment.

a. **Authentic Learning Content.** The content dimension of authentic learning environments encompasses the following four elements:

- Real-world relevance: Learning tasks should be grounded in real-world contexts that reflect the complexity and ambiguity of real-life situations, enabling learners to develop meaningful connections between their learning experiences and their daily lives or professional contexts (Herrington et al., 2014).
- Ill-defined problem: Authentic learning tasks should involve complex, ill-defined problems that require learners to engage in critical thinking, problem-solving, and decision-making skills, promoting the development of higher-order cognitive abilities (Reeves et al., 2002).
- Interdisciplinary perspective: Authentic learning tasks should incorporate multiple disciplines, reflecting the interconnected nature of real-world knowledge and skills, and fostering the development of versatile and adaptable learners (Lombardi & Oblinger, 2007).
- Multiple sources and perspectives: Learners should have access to diverse resources and perspectives, supporting the construction of knowledge and understanding through integrating and synthesizing varied information (Reeves et al., 2002).

b. **Authentic Learning Activities.** The activities dimension includes three elements that emphasize the processes learners engage in during authentic learning:

- Collaboration: Authentic learning tasks should involve collaboration among learners, fostering the development of essential teamwork, communication, and negotiation skills, as well as promoting the social construction of knowledge (Herrington et al., 2014).

- Metacognition: Learners should be encouraged to engage in metacognitive processes, such as reflection, self-assessment, and self-regulation, enabling them to monitor and improve their learning and develop lifelong learning habits (Lombardi & Oblinger, 2007).
- Sustained investigation: Authentic learning tasks should require sustained investigation, allowing learners to explore issues and concepts in depth over an extended period, promoting deep and meaningful learning experiences (Reeves et al., 2002).

c. **Authentic Outcome Assessment.** The final dimension of authentic learning environments focuses on assessing the outcomes of learning, incorporating the following three elements:

- Integrated assessment: Assessment strategies should be integrated into the learning process, providing ongoing feedback and opportunities for learners to demonstrate their understanding and skills, thereby fostering continuous improvement and growth (Herrington et al., 2014).
- Polished products: Learners should be encouraged to create polished, professional-quality products that demonstrate mastery of the learning objectives, reflecting the standards and expectations of real-world contexts (Lombardi & Oblinger, 2007).
- Multiple interpretations and outcomes: Authentic learning tasks should allow for multiple interpretations and outcomes, reflecting the complexity and diversity of

real-world situations and promoting the development of adaptable and flexible learners (Reeves et al., 2002).

2.1.5 Importance of Authentic Learning

Authentic learning is critical to preparing learners to thrive in the future technology-infused learning and workplace environment, as it enhances their engagement, critical thinking skills, and academic performance (Herrington et al., 2014; Lombardi & Oblinger, 2007). By offering students real-world, complex tasks that reflect their future personal and professional contexts, authentic learning promotes meaningful learning experiences and provides the following benefits:

a. **Learning Engagement.** Research has shown that authentic learning environments can foster learning engagement, as they provide relevant and relatable learning experiences that resonate with learners' interests and needs (Herrington et al., 2014; Lombardi & Oblinger, 2007). For instance, Murphy et al. (2006) found that curricula incorporating authentic learning features significantly improved high school female students' participation and learning in physics. Students engaged in authentic learning experiences are more likely to persist in their studies and achieve better learning outcomes (Herrington & Oliver, 2000).

b. **Development of Higher-Order Thinking Skills.** Authentic learning environments encourage learners to engage in critical thinking, problem-solving, and decision-making processes as they tackle complex, ill-defined problems that require interdisciplinary perspectives (Reeves et al., 2002; Lombardi & Oblinger, 2007). These higher-order thinking skills are essential for learners to navigate the complexities and uncertainties of the 21st century, as they foster cognitive flexibility, adaptability, and innovation (Herrington et al., 2014).

c. **Essential Interpersonal Skills.** Authentic learning environments emphasize collaboration and communication among learners as they work together to address real-world issues and challenges (Herrington et al., 2014). By fostering interpersonal skills such as teamwork and negotiation, authentic learning experiences prepare students for success in their future careers, where collaboration and communication are increasingly important in diverse, global work environments (Lombardi & Oblinger, 2007).

d. **Metacognition and Self-Regulation.** Authentic learning environments promote metacognitive processes, such as reflection, self-assessment, and self-regulation, enabling learners to monitor and improve their learning (Lombardi & Oblinger, 2007). Developing metacognitive skills is essential for lifelong learning, allowing learners to adapt and grow in response to new information and experiences (Herrington et al., 2014).

As research continues to highlight the benefits of authentic learning, its role in future education becomes increasingly indispensable. With the growing importance of authentic learning, there is a pressing need for further research and development in this area to better support learners and optimize their educational experiences.

2.2 Learning Engagement

Initially conceptualized in the 1980s, learning engagement denotes the physical and psychological investment learners allocate to the educational process, highlighting their endeavors toward understanding, knowledge acquisition, and skill development (Finn, 1989; Zimmerman, 1990). Various research approaches have contributed to understanding learning engagement. Finn's (1989) Participation-Identification Model emphasizes behavioral and emotional aspects, examining the impact of learners' attention, participation, and feelings of being valued members of the school community. Concurrently, Zimmerman (19) drew a direct correlation between cognitive engagement and learning outcomes characterized by a deeper understanding of the material. Furthermore, the self-system process model highlights intrapersonal dynamics, focusing on the fundamental needs for competence, autonomy, and relatedness (Connell, 1990). The results of subsequent research have demonstrated that learners exhibit higher engagement levels when these three elements are supported (Klem & Connell, 2004).

This foundational understanding of learning engagement has been substantially expanded and deepened by scholarly discourse in the succeeding years, incorporating a variety of perspectives and multidimensional analyses that unravel the intricacies of learner engagement from diverse angles. Consequently, six guiding principles were identified to foster learning engagement: offering voluntary choice to learners, involving students in policymaking, setting clear and consistent learning goals, maintaining small class sizes, fostering collaborative relationships between learners and instructors, and providing authentic curriculums (Newmann, 1992).

In the field of instructional technology, the study of learning engagement has often been contextualized within technology-enhanced learning environments, including online courses, blended learning modalities, and the utilization of digital tools and resources (Hew, 2016; Milligan et al., 2013). Initial research predominantly centered on the behavioral dimensions of engagement (Hew, 2016; Milligan et al., 2013). For instance, Xiong et al. (2015) postulated that engagement in Massive Open Online Courses (MOOCs) could be gauged through metrics such as the number of lectures attended, forum interactions, quizzes undertaken, and tasks accomplished. However, contemporary scholarship has expanded its scope to investigate the relationship between instructional technology and the different dimensions of engagement: behavioral, social, cognitive, and affective (Finn & Zimmer, 2012).

Considering concepts from different traditions, Axelson and Flick (2010) argue that learning engagement is a multidimensional construct requiring a broader perspective and that student satisfaction and successful completion of a course depend on it (Buelow et al., 2018; Robinson & Hullinger, 2008). However, a universally accepted definition remains elusive, with differences in perception between sociocultural theorists and cognitive and motivational psychologists (Nolen et al., 2011). While cognitive and motivational psychologists primarily conceptualize engagement as an individual characteristic or motivation outcome (Kindermann, 2007), sociocultural theorists view engagement as participation in communities of practice (Greeno, 1998).

2.2.1 Cognitive and Motivational Perspective

Cognitive and motivational psychologists posit that engagement is driven by internal factors such as cognitive processes, motivation, and self-regulation (Pintrich, 2003). From this perspective, engagement is considered a product of individual cognitive and motivational processes that can be influenced by interventions targeting specific cognitive or motivational factors (Zimmerman, 2008).

Cognitive and motivational psychologists primarily investigate the individual factors that contribute to learning engagement (Pintrich, 2003). Their research has shown that self-regulated learning strategies, goal orientation, and intrinsic motivation can positively impact engagement and learning outcomes (Zimmerman, 2008; Elliot et al., 2005). Additionally, interventions targeting these individual factors, such as promoting the growth mindset and fostering self-efficacy, have been shown to improve students' engagement (Dweck, 2006; Bandura et al., 1999).

The cognitive and motivational perspective on engagement provided a comprehensive understanding of the individual factors that influence learning engagement, which generated a wealth of empirical research documenting the relationships between various cognitive and motivational factors and learning engagement (Elliot et al., 2011; Dweck, 2006). However, this perspective tends to neglect the importance of group dynamics, cultural norms, and social interactions in shaping learning engagement (Johnson & Johnson, 2009). Therefore, the cognitive and motivational approach may not fully account for the complexity and diversity of real-world learning environments, which often involve multiple layers of social, cultural, and cognitive influences on engagement (Nolen et al., 2011).

2.2.2 Sociocultural Perspective

Sociocultural theories approach engagement as a component of social interaction and collaboration rather than solely focusing on task-based engagement (Nolen et al., 2011). Sociocultural theorists emphasize the role of social and cultural contexts in shaping learners' engagement and how learners actively construct knowledge through interaction with others (Vygotsky, 1978). According to this perspective, learning is inherently social, and engagement emerges from the collaborative nature of the learning process (Lave & Wenger, 1991).

The research in the sociocultural tradition primarily focuses on investigating how social interaction, collaboration, and cultural practices shape engagement in learning (Nolen et al., 2011). Their research often explores the influence of cultural, institutional, and interpersonal factors on learners' engagement, such as teacher-student relationships, classroom practices, and peer interactions (Rogoff, 1994).

The sociocultural perspective on engagement offers valuable insights into the social and contextual factors that influence learning engagement. By emphasizing the importance of collaboration and cultural context, this approach encourages the development of inclusive and responsive educational practices. However, the sociocultural perspective tends to overlook the role of individual cognitive and motivational factors in shaping engagement, which may limit its ability to address individual differences in learners' engagement (Kindermann, 2007).

Given the strengths and limitations of both sociocultural and cognitive/motivational perspectives on learning engagement, it is crucial to adopt a comprehensive approach that incorporates the merits of both frameworks. Therefore, learning engagement should be defined as a multidimensional construct involving behavioral, social, cognitive, and affective aspects (Axelson & Flick, 2010). In the authentic learning environment, each dimension plays a vital role in fostering a deep and meaningful learning experience.

2.2.3 Dimensions of Learning Engagement

Expanding upon the previously established definition and approaches to engagement, it becomes evident that learning engagement encompasses a more comprehensive range of elements beyond simply examining learners' internal factors, such as cognitive processes, or assessing behavioral factors from the instructor's perspective. Although learning engagement was suggested in several forms, different terms are used to describe them, such as academic, cognitive, intellectual, social, behavioral, emotional, etc. Four dimensions of engagement appear consistently in research: behavioral, social, cognitive, and affective (Finn & Zimmer, 2012).

a. **Behavioral Engagement.** This dimension refers to behaviors that directly connect to learning, such as participating in class, completing assignments, paying attention, and adhering to classroom rules. To enhance behavioral engagement, instructors should create activities that stimulate active involvement and connect to real-life situations (Herrington et al., 2014).

b. **Social Engagement.** Social engagement encompasses learners' interactions with instructors and peers (Willms et al., 2009). Creating collaboration opportunities, connecting with experts, and promoting dialogue and discussion can enhance learners' social presence and sense of belonging within the learning community. Incorporating multiple modes of communication and interaction, as suggested by Dixson (2010), can facilitate more engaging learning experiences.

c. **Cognitive Engagement.** This dimension involves learners' internal efforts to comprehend complex ideas and engage in higher-order thinking skills during the learning process (Willms et al., 2009; Parsons et al., 2006). Instructors can support cognitive engagement by employing inquiry-based, problem-based, and exploratory instructional practices. Authentic learning, which connects learning to real-world situations and problems, has been shown to increase cognitive engagement throughout the learning process (Newmann, 1992; Rotgans & Schmidt, 2011).

d. **Affective Engagement.** Affective engagement is characterized by learners' emotional responses and sense of involvement in learning as a worthwhile activity. Warm and supportive relationships between learners and teachers have significantly impacted affective engagement (Bergin & Bergin, 2009; Fredricks et al., 2004; Furrer & Skinner, 2003).

2.2.4 Importance of Learning Engagement

Learning engagement is widely acknowledged as one of the best indicators of learning outcomes and personal development (Carini et al., 2006). It is considered a significant factor contributing to academic success (Hew, 2016). Disengagement in learning can have severe consequences and maintaining learners' engagement is a critical component of high-quality digital-based education (Robinson & Hullinger, 2008).

According to the National Survey of Student Engagement (NSSE), numerous studies have demonstrated a positive relationship between engagement and learning persistence, as well as academic performance indicators, such as critical thinking and grades (Ewell, 2002; Hughes & Pace, 2003; Carini et al., 2006). NSSE identified five learning elements related to engagement: (1) level of academic challenge, (2) providing enriching learning experiences, (3) supportive learning environments, (4) meaningful interaction, and (5) active and collaborative learning activities (Kuh, 2005). The first two elements address learners' cognitive dimension of engagement, while the last three elements connect to learners' social dimension of engagement.

In the past two decades, learners have changed significantly due to a younger generation raised in a technology-rich environment. Digital technology is reshaping learning, and compared to previous generations, these learners appear to have different learning preferences, goals, and needs (Parsons & Taylor, 2011). Video games, social media, and alternative learning methods are becoming increasingly popular among learners (Gee & Hayes, 2011). Educational institutions and organizations are adopting digital-based learning due to compelling advantages such as expanded geographical reach, learner control, and cost-effectiveness. Consequently, innovative, technology-enabled platforms are being implemented to provide an increasing range of learning content (Hu & Hui, 2012).

However, the benefits of digital learning environments should not come at the expense of learning engagement. It has been reported that merely changing the knowledge delivery medium from in-person to digital methods, such as instructional video, can result in reduced learning engagement (Hu & Hui, 2012). According to research findings, instructor-centered approaches are inappropriate in an online environment (Sweany et al., 2020). The lack of interaction opportunities in teacher-led instruction interferes with learners' engagement (Sun et al., 2022), a major factor contributing to the high dropout rate in online courses (Willging & Johnson, 2009). The current generation of learners is more interested in hands-on, inquiry-based approaches to learning and less willing to absorb what is presented in front of them (Barnes et al., 2007).

With the increasing reliance on digital learning environments, it is essential to ensure that these new learning modes foster engagement rather than hinder it. Instructional design and assessment practices should incorporate the identified dimensions of engagement to accommodate the needs and preferences of today's learners.

2.2.5 Measurement Issue of Learning Engagement

a. Historical Evolution. The measurement of learning engagement has evolved over time. Historically, engagement was assessed through observational methods, including classroom observations and teacher evaluations (Bryk & Schneider, 2002). These methods provided valuable information on student behavior but were often subject to observer bias and lacked generalizability. In addition to observational methods, researchers utilized surveys and questionnaires to assess students' self-reported engagement levels (Fredricks et al., 2004).

These self-report measures allowed for a comprehensive understanding of student engagement, encompassing behavioral, social, cognitive, and affective dimensions. For instance, the National Survey of Student Engagement (NSSE) is a widely recognized and influential tool for measuring student engagement in higher education. NSSE was developed in 1999 by the Indiana University Center for Postsecondary Research. It has since been administered to millions of students across hundreds of universities and colleges in the United States and Canada (Kuh, 2001; Kuh et al., 2008). Despite the widespread use and acceptance of the NSSE, it has also faced criticism regarding its validity and reliability. Some critics argue that self-report measures, like the NSSE, are subject to various biases, such as social desirability and recall bias, which may affect the accuracy of the data collected (Schellens & Valcke, 2006).

b. Challenges and Limitations

- Subjectivity and Bias. One of the main challenges in measuring learning engagement is the inherent subjectivity and potential bias associated with self-report measures (Schellens & Valcke, 2006). Students may not accurately report their level of engagement due to social desirability or misunderstanding survey questions. Additionally, researchers and educators may interpret the data differently, leading to inconsistencies in evaluating engagement levels (Fredricks et al., 2004).
- Reliability and Validity Concerns. Another challenge in measuring learning engagement is the reliability and validity of the instruments used. Some engagement measures have not been thoroughly validated, and inconsistencies in the conceptualization of engagement make it difficult to establish a standard for measurement (Sinatra et al., 2015). Furthermore, the reliability of self-report measures can be questionable, as they are prone to fluctuations based on students' emotions or other contextual factors (Podsakoff et al., 2003).

In order to overcome the challenges and limitations of the traditional engagement measurement approaches, researchers have started to employ physiological measures that allow for real-time assessments of engagement during learning activities. These methods include functional near-infrared spectroscopy (fNIRS), which tracks brain activity related to cognitive engagement by measuring changes in oxygenated and deoxygenated hemoglobin in the prefrontal cortex (Peck et al., 2013; Ferrari & Quaresima, 2012). Similarly, electroencephalography (EEG) offers insights into neural activation patterns, making it useful for assessing cognitive workload and attention during learning tasks (Hsieh & Ranganath, 2014).

In addition to brain-based measurements, heart rate variability (HRV) has been employed to assess emotional and stress-related engagement, as fluctuations in heart rate can reflect autonomic nervous system responses linked to emotional arousal and cognitive effort (Porges, 2007). Functional magnetic resonance imaging (fMRI), although less frequently used in classroom settings due to its logistical constraints, has also provided in-depth insights into neural mechanisms underlying learning and engagement (Logothetis, 2008).

Lastly, facial feature analysis techniques, such as eye tracking and facial expression monitoring, allow for the assessment of cognitive engagement by monitoring students' gaze patterns, attention shifts, and emotional responses to learning stimuli (van Gog & Scheiter, 2010). These technologies help in tracking where students focus their attention and how they react emotionally to learning tasks, offering a detailed view of engagement that is difficult to capture through self-reported measures alone (Hutt et al., 2017).

As technology advances, the measurement of learning engagement will likely continue to incorporate physiological measurements like fNIRS. These measurement techniques offer promising avenues for assessing learning engagement from a physiological perspective, thus addressing the limitations of traditional methods.

2.2.6 Functional Near-Infrared Spectroscopy (fNIRS) in Educational Research

fNIRS is a noninvasive neuroimaging technique that has gained increasing attention in educational research over the past few decades. fNIRS employs near-infrared light to measure changes in the concentrations of oxygenated and deoxygenated hemoglobin within the cerebral cortex, reflecting neural activity and providing valuable insights into cognitive processes (Ferrari & Quaresima, 2012). Compared to other neuroimaging techniques, such as fMRI and EEG, fNIRS offers several advantages, including greater tolerance to motion artifacts, relatively lower cost, and ease of use in more ecologically valid settings (Scholkmann et al., 2014). This makes fNIRS particularly suitable for investigating cognitive processes in educational contexts (Baker et al., 2017).

fNIRS is based on the principle that neural activity leads to increased local blood flow and oxygen consumption in the brain, a phenomenon known as neurovascular coupling (Attwell et al., 2010). By monitoring changes in the absorption of near-infrared light by oxygenated and deoxygenated hemoglobin, fNIRS can indirectly measure the underlying neural activity (Boas et al., 2014). This is achieved by using light-emitting diodes (LEDs) to transmit near-infrared light through the scalp and skull into the cortex and photodetectors to measure the amount of light scattered and absorbed by the brain tissue (Pinti et al., 2018). By employing various algorithms and signal-processing techniques, researchers can obtain estimates of the relative changes in the concentrations of oxygenated and deoxygenated hemoglobin, which are assumed to reflect task-related neural activity (Huppert et al., 2009).

In recent years, fNIRS has been employed in various educational research contexts to investigate cognitive processes underlying learning, memory, problem-solving, and decision-making (Cutini & Brigadoi, 2014). For instance, Soltanlou et al. (2018) investigated brain activation related to cognitive development, focusing on tasks such as mathematics and language skills, demonstrating that fNIRS effectively capture cognitive processing in ecologically valid settings. In addition, Lamb et al. (2022) explored the real-time prediction of science student learning outcomes using machine learning classification of hemodynamics during VR, video, and no-content sessions. The study found that fNIRS-derived hemodynamic data could accurately predict learning outcomes, demonstrating the potential of fNIRS in conjunction with machine learning techniques for predicting and monitoring student performance in real-time.

Moreover, fNIRS has been applied to investigate the effects of various instructional strategies on neural activity and learning outcomes (Baker et al., 2017). Balardin et al. (2017) used fNIRS to explore the ability of fNIRS to examine neural correlates of cognitive processes in unconstrained environments and found fNIRS is feasible to monitor hemodynamic changes in natural settings. In another study, Lamb et al. (2018) conducted a study comparing the effectiveness of virtual reality (VR) and hands-on activities in science education using fNIRS. Their findings suggested that the VR intervention increased activation in the prefrontal cortex (PFC). This study highlights the potential of fNIRS in examining the cognitive impact of emerging educational technologies, such as VR, on student learning outcomes.

By measuring neural activity in the prefrontal cortex, which is associated with higher-order cognitive functions such as attention, working memory, and executive control (Miller & Cohen, 2001), fNIRS has been employed to investigate the neural responses that correlate to cognitive tasks in various learning contexts (Cutini & Brigadoi, 2014). One area where fNIRS has been applied to study cognitive processes is the investigation of cognitive load, which refers to the mental effort required to process and manage information during learning (Sweller, 2011). By examining the relationship between prefrontal cortex activity and cognitive load, fNIRS studies have provided insights into the neural basis of cognitive overload and its impact on learning outcomes (Liu et al., 2012). For example, Simon et al. (2022) used fNIRS to demonstrate that increased prefrontal cortex activation was associated with a higher cognitive load during a mathematics learning task. This suggests that neural activity could be a potential marker of cognitive engagement in learning contexts.

Another application of fNIRS is to study cognitive processes involved in critical thinking tasks. By examining changes in prefrontal cortex activation during critical thinking tasks, fNIRS research has provided insights into the neural mechanisms underlying cognitive dynamics and the development of higher-order thinking skills (Lamb & Etopio, 2019). For instance, Fishburn et al. (2014) employed fNIRS to investigate the neural correlates of cognitive engagement during a complex problem-solving task, revealing that increased prefrontal cortex activation was associated with higher levels of cognitive engagement and better task performance.

Despite the promising applications of fNIRS in educational research, several challenges must be addressed to fully exploit its potential. These challenges include methodological issues such as the limited spatial resolution and penetration depth of fNIRS (Pinti et al., 2018), as well as the need for standardized protocols and analysis techniques to ensure the comparability and reliability of findings across studies (Yücel et al., 2021). Additionally, the interpretation of fNIRS data can be confounded by factors such as systemic physiological changes, motion artifacts, and individual differences in the anatomical and vascular structure of the cortex (Tachtsidis & Scholkmann, 2016). Therefore, combining fNIRS with other traditional measurement techniques such as surveys, interviews, and observation recording analysis can provide complementary insights regarding the dynamics of cognitive processes in educational settings.

2.3 Conceptual Framework: Relationship between Authenticity and Learning Engagement

2.3.1 Overview

Drawing on the established understanding of authentic learning theory and learning engagement, this section presents a conceptual framework to explore the relationship between authenticity and learning engagement. The framework seeks to provide a comprehensive structure for investigating how the dimensions of authenticity, as outlined in the authentic learning theory, interact with the dimensions of learning engagement, including behavioral, social, cognitive, and affective aspects.

By integrating the elements of authentic learning and the dimensions of learning engagement, the framework aims to identify the key factors that contribute to enhanced learning experiences and, ultimately, to a deeper understanding of the relationship between authenticity and engagement. The framework comprises two main components: (1) authentic learning context, which includes the learning content, learning activities, and outcome assessment; (2) learning engagement dimensions, including behavioral engagement, social engagement, cognitive engagement, and affective engagement. These components are closely interconnected, with the authentic learning context serving as the foundation for fostering engagement. The dynamic interaction between the dimensions of authenticity and learning engagement enhances the overall learning experience, leading to improved outcomes such as academic performance, heightened interest, and personal development (Fredricks et al., 2004; Herrington & Oliver, 2000).

Through the examination of the complex interplay between authentic learning and engagement, the framework seeks to provide valuable insights for educators, researchers, and policymakers in designing and implementing effective authentic learning environments that support meaningful and impactful educational outcomes.

2.3.2 A Conceptual Framework for Authenticity and Learning Engagement

Based on the literature review and the identified relationship between authenticity and learning engagement, the conceptual framework for this study will outline the specific dimensions of authentic learning and their impact on various aspects of learning engagement.

The conceptual framework (Figure 1) illustrates the interplay between authentic learning dimensions and learning engagement dimensions. It posits that the dimensions of authentic learning – authentic learning content, authentic learning activities, and authentic outcome assessment – influence the dimensions of learning engagement – behavioral, social, cognitive, and affective.

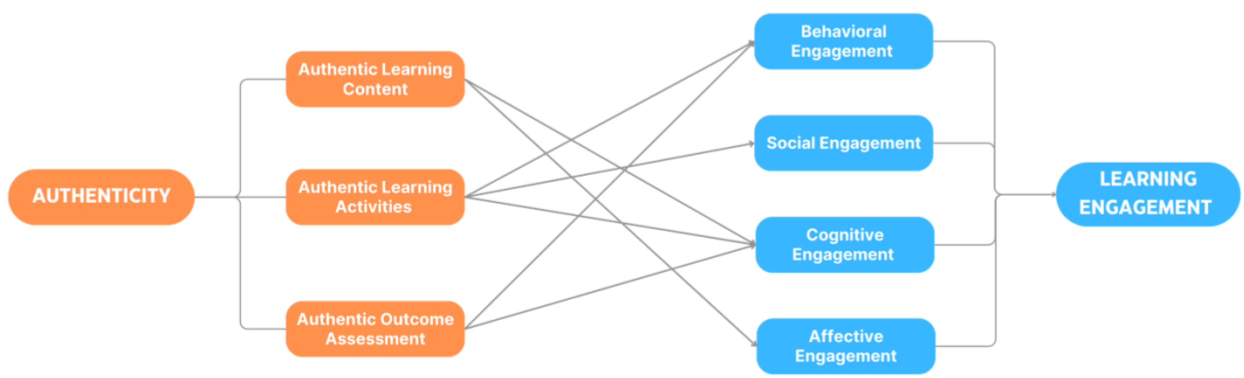


Figure 1

Conceptual Framework of Authenticity and Learning Engagement

As these dimensions of authentic learning are implemented in the learning environment, they have the potential to impact the different dimensions of learning engagement. Drawing from the literature review and the definition ns provided earlier, the following assumptions can be made regarding the impact of specific authentic learning dimensions on different aspects of learning engagement:

a. **The impact of Authentic Learning Content:**

- It can be assumed that when learning content is relevant to real-world contexts, learners will experience increased cognitive engagement as they strive to apply the acquired knowledge and skills to actual situations (Lombardi & Oblinger, 2007). Furthermore, affective engagement may be positively influenced as learners find more meaning and value in the learning process, motivating them to invest more effort (Herrington & Oliver, 2000).
- Presenting learners with ill-defined problems that require critical thinking and problem-solving skills may lead to higher cognitive engagement as they are challenged to analyze, evaluate, and synthesize information (Jonassen, 1997).
- Integrating interdisciplinary perspectives into the learning content can promote cognitive engagement by encouraging learners to make connections between different subject areas and develop a more comprehensive understanding of the topic (Herrington et al., 2014).

b. **The Impact of Authentic Learning Activities:**

- It can be assumed that social and behavioral engagement is promoted when learners work together in a collaborative setting (Johnson & Johnson, 1989). Collaboration can foster a sense of belonging and support, encouraging learners to participate actively and invest effort in the learning process (Fredricks et al., 2004).

- Providing opportunities for self-assessment and reflection on the learning process can enhance cognitive engagement and self-regulation (Dewey, 2022). It is assumed that when learners are encouraged to think critically about their learning strategies and progress, they will be more likely to engage in deep learning and develop metacognitive skills that support lifelong learning (Pintrich, 2003).
- It is assumed that learners will be more likely to remain engaged in the learning process when immersed in long-term investigations that encourage critical thinking and sustained attention (Hmelo-Silver et al., 2007).

c. The impact of Authentic Outcome Assessment:

- Implementing authentic assessment tasks that mirror real-life tasks and challenges may enhance cognitive and behavioral engagement by connecting learners' efforts to meaningful outcomes (Gulikers et al., 2004). It can be assumed that when assessment aligns with real-world expectations, learners will be more motivated to produce high-quality work demonstrating their knowledge and skills (Wiggins, 1998).

Specifically, this study explores the relationship between cognitive engagement and learners' perceptions of authenticity. Cognitive engagement stands out as a critical dimension of learning engagement due to its direct impact on learners' processing, comprehension, and application of knowledge, making it arguably the most essential component for achieving meaningful learning outcomes (Fredricks et al., 2004). It reflects the depth of mental effort learners invest in understanding and integrating complex information (Fredricks et al., 2004). Studies suggest that cognitive engagement is an effective predictor of academic success and an essential factor in students' persistence, as it encourages them to see learning as a valuable and goal-oriented activity (Appleton et al., 2008).

Additionally, cognitive engagement is uniquely influenced by all three dimensions of authentic learning: authentic content, authentic learning activities, and authentic outcome assessment, according to the conceptual framework. Focusing on cognitive engagement aligns with the study's objective to understand how learners' engagement levels are influenced by the authenticity of their learning experiences. Authentic learning environments that incorporate complex, ill-defined problems and real-world relevance are known to stimulate cognitive processes by challenging students to apply critical thinking and problem-solving skills (Lombardi & Oblinger, 2007). Analyzing cognitive engagement in this context provides a clear understanding of how authenticity promotes learners' ability to focus, persist, and invest mental effort in meaningful tasks, ultimately leading to improved learning outcomes (Reeve & Tseng, 2011). Therefore, investigating the relationship between cognitive engagement and learners' perceptions of authenticity serves as an ideal starting point for exploring the broader, complex relationship between learning engagement and authentic learning.

Moreover, this study employs a dual approach to assess cognitive engagement by combining semi-structured interviews with fNIRS measures. The OBELAB NIRSIT LITE system used in this study is designed to measure hemodynamic responses in the prefrontal cortex, a brain region associated with higher-order cognitive functions such as attention, working memory, and problem-solving (Fishburn et al., 2014). The physiological data allows for real-time monitoring of cognitive processes as participants engage in different learning tasks, offering insights into the depth of their cognitive engagement. By combining self-reported perceptions with physiological assessments, the study captures cognitive engagement from two different dimensions. Triangulating the results from these two methods enhances the accuracy of the findings and provides a more robust, quantifiable basis for examining the impact of authentic learning on engagement.

In summary, cognitive engagement connects to all three dimensions of authenticity, and its measurable nature makes it a valuable focal point for examining how authentic learning environments affect learners' overall engagement during the learning process. By starting with cognitive engagement, this study establishes a foundation for broader explorations of how authentic learning shapes learning engagement. As a result, this conceptual framework can be further expanded and refined based on future research findings and the growing understanding of authentic learning and learning engagement. It is crucial to continue examining this complex interplay to optimize learning experiences and promote learner's success.

CHAPTER 3

METHODOLOGY

This chapter outlines the research methodology used to investigate the relationship between perceived authenticity and cognitive engagement across four learning phases: reading, introductory video, virtual simulation, and debriefing. The virtual simulation was delivered through the PhET science simulation platform. The chapter provides a detailed description of the research design, participants, materials, instruments, data collection procedures, and data analysis strategies.

The primary aim of this study is to explore how authentic learning experiences impact learners' cognitive engagement, both perceived and physiological. To capture these dynamics, a mixed-methods case study approach was employed. Semi-structured interviews were conducted to gather qualitative data on learners' perceptions of authenticity and cognitive engagement. Additionally, fNIRS technology was used to collect real-time data on learners' physiological cognitive engagement during the learning module.

fNIRS is a non-invasive neuroimaging technique that tracks cerebral hemodynamic changes, allowing for real-time monitoring of brain activity during cognitive tasks (Ayaz et al., 2012). By detecting changes in oxygenated and deoxygenated hemoglobin concentrations, fNIRS provides valuable insights into the neural mechanisms underlying learning and cognitive processes (Lamb & Etopio, 2019).

The study was conducted in May 2024 at a middle school in the southeastern United States, and the research protocol was approved by the Institutional Review Board (IRB) at the

University of Georgia, Athens. Through a combination of self-reported data and physiological measurements, this research aims to reveal the connections between task-related authenticity and learners' cognitive engagement across different learning activities.

By examining both learners' perceptions and their neural signatures during the learning process, this study provides a detailed investigation of how authenticity influences cognitive engagement. Specifically, the study seeks to address the following research questions:

1. What are the levels of authenticity students perceived according to different consecutive learning activities?
2. What are the levels of students' cognitive engagement according to different consecutive learning activities, and what is the general relationship between perceived and physiological cognitive engagement?
3. What relationship patterns emerge between students' perceived authenticity and cognitive engagement?
    a. What relationship patterns emerge between students' perceived authenticity and perceived cognitive engagement?
    b. What relationship patterns emerge between students' perceived authenticity and physiological cognitive engagement?

3.1 Research Design

3.1.1 Case Study Approach

This study employs a mixed-methods case study design to investigate the impact of authenticity on learners' cognitive engagement. As described by Yin (2003), a case study involves an empirical investigation of a contemporary phenomenon within its real-life context, particularly when the boundaries between the phenomenon and context are not clearly defined.

Similarly, Simons (2009) describes a case study as an in-depth exploration from multiple perspectives of the complexity and uniqueness of a specific project, policy, institution, program, or system in a real-life context. Generally, a qualitative case study involves an in-depth analysis of one or a few instances of a phenomenon (Creswell & Creswell, 2018).

3.1.2 Multiple-Case Study Design

This study expanded the traditional boundaries of the case study to integrate a mixed-methods design and incorporated a multiple-case study setting. A multiple-case study involves the detailed examination of several interconnected cases, allowing for the investigation of differences from both within-case and cross-case analysis, thus providing a thorough understanding of the inquiry (Baxter & Jack, 2008; Yin, 2003). While a single case study focuses on understanding one specific, often unique or critical case, a multiple-case study broadens the scope to encompass several cases, resulting in a more robust and generalized understanding of the research question (Baxter & Jack, 2008). Researchers can explore the nuances and complexities of each case in the multiple-case study, facilitating a comparative analysis that highlights similarities and differences among them (Stake, 1995). This approach is particularly useful for developing a comprehensive understanding of phenomena by leveraging insights from multiple instances.

To analyze the fNIRS data collected during the consecutive learning activities within each case, repeated measures ANOVA (Analysis of Variance) was employed. Repeated measures ANOVA is a statistical technique that is particularly well-suited for analyzing data where multiple measurements are taken from the same subjects under different conditions or over time (Keselman et al., 2001). One of the key advantages of using repeated measures ANOVA is its ability to control for individual differences among participants, which increases the statistical power of the analysis (Keselman et al., 2001; Field, 2013). In the context of fNIRS studies, repeated measures ANOVA is often used to analyze hemodynamic responses across different conditions or time points to determine whether there are statistically significant differences in brain activity (Pinti et al., 2018). By applying repeated measures ANOVA in this study, it was possible to explore how participants' physiological cognitive engagement varied across the four different phases of the learning module (Reading, Introductory Video, Virtual Simulation, and Debriefing).

In this study, ten middle school students engaged in four different learning activities that held different dimensions of authenticity, including reading, introductory video, virtual simulation, and debriefing. The goal was to gain deep insights into the relationships and dynamics between authentic learning and cognitive engagement. The qualitative data is obtained through semi-structured interviews, while the quantitative data is generated by fNIRS measurements. For the first research question, data is gathered through interviews conducted at the end of the session. The second question utilizes data from both the fNIRS equipment and interviews to explore cognitive engagement levels. For the third question, a mixed-method case study approach combines qualitative and quantitative data. The triangulation of data through this mixed-method approach is anticipated to foster a holistic perspective, providing a comprehensive understanding of how authenticity impacts cognitive engagement in a virtual science learning environment.

3.1.3 Unit of analysis

Qualitative and quantitative data collection and analysis were combined within a case study framework. Individual participants served as the unit of analysis, with each participant's experiences and responses treated as the data of a single case. The mixed-method multiple-case study approach enables the integration of quantitative and qualitative data at the case level. This approach is grounded in case study research principles, emphasizing the depth of understanding (Yin, 2009).

This research design integrates qualitative data with fNIRS data to offer a detailed and comprehensive understanding of how various learning activities within a multimedia-based virtual science learning environment impact cognitive engagement. This approach facilitates a thorough analysis of the relationship between cognitive engagement and perceived authenticity in educational settings, contributing valuable insights to understanding the interplay between these two constructs.

3.2 Participants

This study recruited ten eighth-grade students, aged 13 to 14, from a middle school in the Southern United States. Both female and male students were invited to participate voluntarily. To minimize confounding variables such as reading level or prior knowledge of the subject matter, all participants were selected from the eighth grade. Additionally, their prior knowledge levels were assessed through questions included in the semi-structured interview. Two weeks prior to the commencement of the onsite research, the student assent forms, and parent permission forms were distributed through a school administration member. These documents provided detailed information about the study's objectives, the procedures to be employed, potential risks and benefits, and the participants' unequivocal right to withdraw at any time. Enrollment in the study was conditioned upon the receipt of both signed assent and permission forms. The Institutional Review Board (IRB) of the University of Georgia in Athens, Georgia, granted approval for the research protocol, ensuring adherence to ethical standards in the treatment of study participants.

3.3 Materials

The physics of balance was used as the subject of the learning module in this study. Participants engaged in a complete science class module, including a reading activity, an introductory video, a virtual science simulation, and a debriefing session.

3.3.1 Reading Material

The two-page reading material, "The Physics Behind a Seesaw," was selected for the reading activity. It has approximately 2000 words and three illustrative images. The document begins with a historical anecdote about the origin of the seesaw, illustrating its real-world relevance and cultural significance. This narrative sets a tangible context, making the physics concepts of balance more relatable and accessible for students. By linking the seesaw, a familiar playground equipment, to its practical uses and origins, the material directly connects classroom learning with real-world phenomena.

The document demonstrated how formulas can be applied to solve real-world problems, thus bridging the gap between theoretical knowledge and practical application. This relevance helps students appreciate the application of physics in daily life, thereby fostering a deeper understanding and retention of the learned concepts. Additionally, the material leverages diagrams and quotes from physicists to illustrate the concept of balance. By using multiple sources—historical anecdotes, expert opinions, and visual aids—the document provides a diverse range of perspectives that enrich students’ understanding.

3.3.2 Introductory Video for Using Simulation Platform

Following the reading activity, the researcher introduced a brief video tutorial designed to familiarize students with the "Balancing Act" science simulation from PhET. This video serves as a primer, guiding students on how to navigate and utilize the simulation they will engage with in the subsequent phase of the science learning module. Notably, the video focuses solely on the operational aspects of the simulation without exploring the underlying scientific concepts.

3.3.3 Virtual Simulation

For the virtual science simulation, the virtual science simulation "Balancing Act" from PhET was selected for this study. The simulation is designed to reinforce the concepts introduced in the reading material and extend them into a dynamic, hands-on learning experience. In this simulation, students interact directly with various objects, position them at different distances from the fulcrum, and observe the effects in real time.

This active manipulation of elements mimics real-life scenarios where students must apply their understanding of balance and leverage to solve progressively challenging problems. These tasks require the application of formulas to calculate the weights of various objects and determine their optimal placement on the seesaw to achieve balance. The direct application of theoretical knowledge makes the abstract principles of physics tangible in everyday situations, thus aligning well with the principles of authentic learning environments.

3.3.4 Debriefing

The debriefing session at the conclusion of the science learning module exemplifies the elements of metacognition and integrated assessment, which are central to authentic learning. During this session, participants engaged in a reflective process where they articulated the knowledge they had acquired, thereby fostering metacognitive awareness. This reflection served as an integrated form of assessment, enabling students to evaluate their understanding and the strategies they employed during the learning activities.

3.4 Instrument

In this study, two primary instruments were utilized: semi-structured interviews and fNIRS measurements. These tools were selected to provide a comprehensive analysis of the participants' perceived experiences regarding authenticity and cognitive engagement, as well as their real-time physiological responses throughout the learning module. This dual approach ensures a robust and comprehensive understanding of how authenticity impacts learning engagement.

3.4.1 Semi-Structured Interview

The semi-structured interview was designed to examine the dimensions of authenticity in learning and the elements of cognitive engagement. Comprising 15 questions, the interview protocol was carefully crafted to align with the science learning module employed in this study (detailed in Appendix C). The questions aimed to thoroughly investigate the three dimensions of authenticity defined by the conceptual framework: Authentic Learning Content, Authentic Learning Activities, and Authentic Outcome Assessment. For instance, to assess real-world relevance, participants were asked, "Which activity in this session do you feel is closely related to a real-world situation?" Similarly, to explore the concept of ill-defined problems, participants were prompted with, "Was there any moment during this session that you felt the problem you needed to solve didn't have a clear answer?"

Additionally, the interview sought to assess four key elements of cognitive engagement: Attention, Effort, Connections to Previous Knowledge, and Persistence (Willms et al., 2009; Herrington et al., 2014). For example, to examine the connections to previous knowledge, participants were asked, "When we were learning today, how often did you think about things you already knew?"

The interview offered the researcher valuable insights into the participants' perceptions of the learning activities' authenticity and their cognitive engagement. The semi-structured nature of the interview allowed for flexibility in probing further based on the participants' responses, providing richer, more detailed data. This method is well-supported in qualitative research for its ability to elicit in-depth insights and facilitate a deeper understanding of participants' perspectives (Creswell & Poth, 2016).

3.4.2 fNIRS Measurements

This study employed the fNIRS technique to measure relative changes in oxygenated (HbO) and deoxygenated (HbR) hemoglobin concentrations in the brain, which serve as indicators of neural activity (Ayaz et al., 2012; Lamb & Etopio, 2019). The OBELAB NIRSIT LITE fNIRS system utilized in this study is designed to measure changes in cerebral blood oxygenation by emitting near-infrared light at two specific wavelengths, 780 nm and 850 nm, into the cerebral cortex. This device uses LED light with an output of 1 mW or less, ensuring it is safe for human use. Additionally, the system offers a high temporal resolution with an 8.33Hz sampling rate, enabling precise monitoring of hemodynamic responses during the learning activities. The device was positioned on the participants' foreheads to monitor activity in the prefrontal cortex, an area associated with higher-order cognitive functions (Cutini & Brigadoi, 2014). Hemodynamic responses were recorded continuously throughout the reading, introductory video, virtual simulation, and debriefing phases, capturing real-time data on cognitive engagement during these activities.

Given that each phase within the learning module spans several minutes, significant fluctuations in hemodynamic responses are expected. The fNIRS device provides real-time, continuous data on brain activity, offering valuable insights into the cognitive processes underlying learning (Ayaz et al., 2012). This technique complements self-reported data by enabling another perspective to understand the impact of authentic learning activities on cognitive engagement.

3.5 Data Collection

3.5.1 Overall Procedure

The study involves middle school students participating in a complete science module that consists of a sequence of distinct learning activities: reading (3 minutes), introductory video (1 minute), virtual simulation (5 minutes), and a debriefing session (1 minute). Following the debriefing, each participant engaged in a semi-structured interview. The entire duration of the study for each participant was approximately 25 to 30 minutes.

- fNIRS Equipment and Video Recording Setup: Each session will be conducted with one researcher and one student. The fNIRS probe was attached to the forehead of the participants to measure the oxygen saturation in the prefrontal cortex area, which has been linked to cognitive activity. Simultaneously, the learning process was video recorded. The video recording equipment was positioned at the back of the room to get a broad overview of the learning environment while ensuring that students' faces were not recorded, thereby maintaining their privacy. The video captured the participants' interactions and activities without interfering with the learning process or the fNIRS data collection.
- Synchronization of fNIRS Data and Video Recordings: The fNIRS data and video recordings were synchronized for data process and analysis. This synchronization allows researchers to accurately mark the onset and duration of different learning activities

within the fNIRS data. This step is crucial for aligning hemodynamic responses with specific learning tasks and interactions observed in the videos.

- Learning Activities: During the science learning module, students engaged in a series of learning activities, including three consecutive activities: Reading, Introductory Video, and Virtual Simulation. Both the fNIRS data and video recordings captured these activities, providing a dual-perspective view of the learning process.
- Debriefing and Semi-Structured Interview: After the virtual simulation, a debriefing session followed by a semi-structured interview was conducted to capture the students' immediate reflections and feedback on their learning experiences. This interview aimed to gather participants' perspectives on the authenticity and cognitive engagement associated with the three learning activities within the science learning module.
- Post-Experiment baseline: Following the interview, students engaged in a five-minute relaxation period to establish the post-experiment baseline. As their brain activity returned to the resting state, the data collection process was concluded.
- Data Integration and Analysis: Integrating fNIRS data with synchronized video recordings provided a comprehensive understanding of cognitive engagement across different learning activities.
- Verification and Validation: The combination of fNIRS data with interview data served as a methodological triangulation, enhancing the validity and reliability of the findings. The video recordings assisted in verifying the accuracy of the fNIRS data analysis, ensuring that the hemodynamic responses were correctly attributed to the corresponding learning activities. The insights from the interview allow the researcher to interpret the hemodynamic response analysis results from the participants' perspectives, enhancing the

understanding of changes in cognitive engagement and its relationship with the perceived authenticity of the learning experience.

3.5.2 Procedure for fNIRS Data Collection

The total duration of the study for each participant is approximately twenty-five to thirty minutes. The fNIRS device was carefully positioned on the participant's foreheads upon their arrival, ensuring optimal placement of optodes for accurate data collection from prefrontal cortex areas. Participants engaged in the following activities:

i. The participant first relaxed for three minutes to establish a pre-experiment baseline. This phase is crucial for ensuring that the fNIRS device records a stable baseline of brain activity before the commencement of learning activities.

ii. The researcher provided a two-page reading material for the participant to read for three minutes, offering the foundational knowledge for the subsequent virtual simulation.

iii. The participant watched a 1-minute introductory video to learn how to use the virtual science simulation.

iv. The participant engaged in a hands-on, interactive science simulation for five minutes.

v. Participated in a seven to ten minutes debriefing and interview activity to reflect and share the learning experiences.

vi. The participant relaxed for 5 minutes to establish a post-experiment baseline.

The researcher monitored and marked the data collected by fNIRS optodes during the science class module. The entire session was recorded to facilitate qualitative data analysis and to assist in the preprocessing of fNIRS data, enabling precise marker adjustments for each block.

3.5.3 Procedure for Semi-Structured Interview Data Collection

Upon completing the virtual science simulation, participants took part in a session that encompassed a debriefing and a semi-structured interview. Initially, participants reflected on and articulated their understanding of the knowledge gained from the previous activities. Following this reflection, the researcher conducted interviews to investigate participants' overall experiences with the various learning activities, their perceptions of authenticity, and their views on cognitive engagement.

The students will be introduced to the purpose and format of the semi-structured interview. They will be informed about the confidentiality of their responses and assured that there are no right or wrong answers. The importance of each participant's honest reflections will be emphasized. With participants' consent, the interviews were audio-recorded to ensure accuracy in data transcription. Additionally, the interviewer took notes to capture non-verbal cues and the dynamics of the group interaction.

3.6 Data Analysis

A data mapping procedure was implemented to align the semi-structured interview data and the physiological data. The video recording of the learning session for each participant was combined with the corresponding fNIRS brain map replay generated by fNIRS monitor software NIRSIT SCAN and edited into a single picture-in-picture video format. The screenshot of the video clip is shown in Figure 2. A six-second delay was added to the fNIRS brain map replay to synchronize it with the session video recording, accommodating the lag in hemodynamic responses (Pinti et al., 2020). This step ensures that the two datasets are accurately aligned and correspond to the same timeframes and activities: reading, introductory video, virtual science simulation, and debriefing.

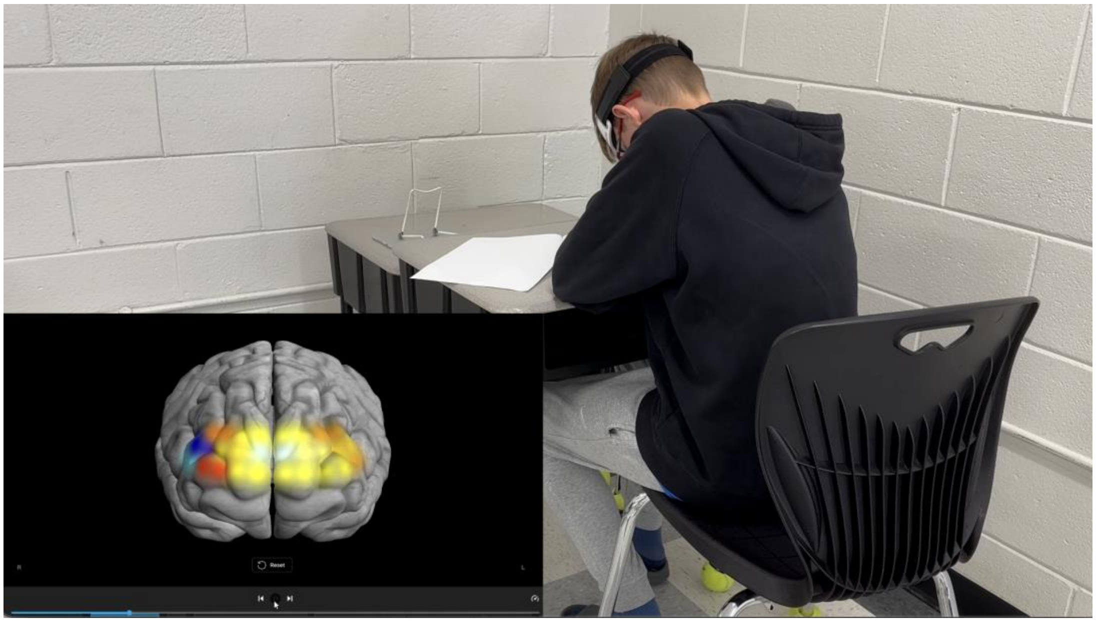


Figure 2

Screenshot of the Synchronized Video

The data from the synchronized picture-in-picture video clips and the semi-structured interview were used to assess the levels of authenticity and cognitive engagement students perceived across different learning activities. Based on the frequency of mentions in the interview responses, perceived authenticity and perceived cognitive engagement were categorized into four levels (e.g., high, moderate to high, moderate, and low).

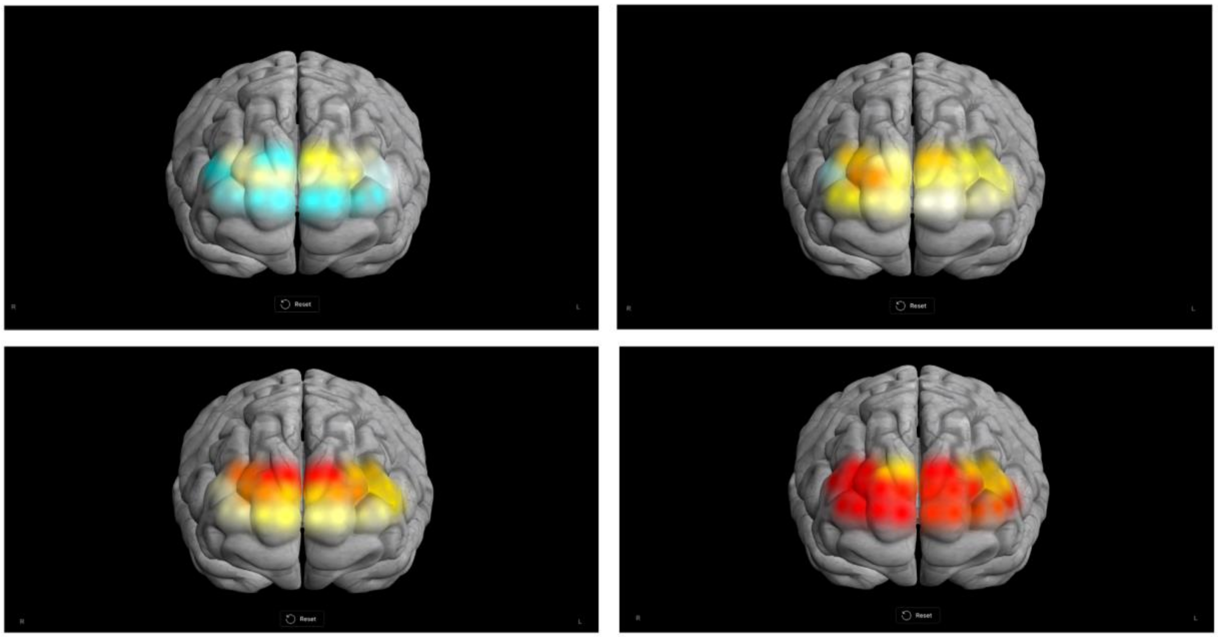
Quantitative data captured by the fNIRS device provided real-time information regarding the psychological cognitive engagement of each participant during various learning activities. Statistical analyses, including repeated measures ANOVA, were employed to compare the differences in hemodynamic responses across different phases of the learning module. This analysis facilitated a detailed examination of the cognitive engagement patterns of the participants.

To investigate the relationships between perceived authenticity and cognitive engagement, comprehensive profiles for each participant were developed, incorporating both interview responses and fNIRS data. The themes from the interview data and the patterns from the fNIRS data were integrated for each case to explore how participants' perceptions of authenticity and cognitive engagement (from the interviews) relate to their physiological responses (from the fNIRS data).

3.6.1 Analyzing the Synchronized Video Clips.

The picture-in-picture video analysis was designed to identify significant fluctuations in brain activity during different learning activities. A comprehensive log detailing observed brain activity patterns and corresponding events was created. The researcher annotated transitions between activities with precise timestamps and noted observed brain activity levels along with potential indicators of cognitive engagement. Through a thorough review and detailed descriptions, specific events or actions coinciding with peaks or changes in brain activity were identified, enabling a deeper examination of the engagement dynamics during the study.

The approximate brain activity levels are inferred from the color spectrum displayed in the fNIRS brain map replay, while the precise hemodynamic values are detailed in the fNIRS analysis section. Figure 3 comprises four screenshots from the fNIRS brain map replay, each illustrating different levels of brain activity in the prefrontal cortex. The upper left image displays a low brain activity level with the monitored prefrontal cortex predominantly in blue color. The upper right image shows a medium level of brain activity, characterized by primarily yellow hues in the prefrontal cortex section. The lower left image, representing a medium to high brain activity level, features a blend of yellow, orange, and red in the prefrontal cortex. Lastly, the lower right image indicates a high brain activity level and exhibits a dominant orange and red color combination and a significant red ratio in the prefrontal cortex area.



Note: The upper left image: low brain activity level. The upper right image: medium brain activity level. The lower left image: medium to high brain activity level. The lower right image: high brain activity level.

Figure 3

Brain Activity Level

3.6.2 Analyzing the Semi-Structured Interview.

The interview data was transcribed verbatim, ensuring accuracy and maintaining the essence of participants’ responses (Braun & Clarke, 2006). The transcriptions underwent multiple readings to fully capture the content and context (Smith & Larkin, 2009). All identifiable information will be replaced to maintain participant confidentiality.

a. The coding protocol for Interview Data. The coding protocol is carefully structured to dissect the relationship between authenticity and cognitive engagement during various learning activities. This protocol consists of two primary constructs: Authenticity and Cognitive Engagement, each divided into several dimensions according to the conceptual framework and the learning material of this study.

The first construct, Authenticity, is dissected into three dimensions according to the conceptual framework:

i. **Authentic Learning Content**

- ***Real World Relevance*** - This dimension is assessed through two codes:
  - Relate: This code is used when participants indicate that the learning activity is closely connected to real-world situations.
  - Apply: This code applies when participants express that the knowledge gained could be utilized in real-life contexts.
- ***Ill-defined Problem*** - Encapsulated by the code "Challenge," which is applied when participants describe encountering problems that are complex and lack clear, definitive answers.

ii. **Authentic Learning Activity**

- ***Sustained Investigation*** - Represented by the code "Keep," indicating tasks that require prolonged exploration to reach a resolution.

iii. **Authentic Outcome Assessment**

- ***Multiple Interpretations and Outcomes*** - Covered by the code "Methods," used when students employ various approaches to solve learning tasks, showcasing the complex nature of real-world problems.

The second construct, Cognitive Engagement, is segmented into four categories, each critical to understanding the depth of participant involvement:

i. **Attention** - Analyzed through two codes: "Focus" and "Active/Passive." Focus indicates the intensity of participants' concentration during learning activities. Active/Passive distinguishes whether participants were actively engaging with the material or passively receiving information.

ii. **Effort** - Defined by the code "Difficulty," which assesses the exertion required to grasp complex ideas or resolve challenging problems.

iii. **Previous Knowledge** - Captured by the code "Connect," examines if participants link new information in the learning module to their existing knowledge base.

iv. **Persistence** - Encapsulated by the code "Continue," this reflects the extent to which the educational content motivates learners to sustain their exploration and learning.

b. Classification Criteria for Interview Data. Each code from the above coding protocol represents a distinct element of authentic learning or cognitive engagement. To quantify the levels of perceived authenticity and cognitive engagement for each learning phase, a structured classification system was established based on the frequency of each phase mentioned in the participants' interview responses. The criteria are outlined in Table 1.

Table 1

Classification Criteria for Interview

Code		Classification Criteria	
Perceived Authenticity	Perceived Cognitive Engagement	Level	Frequency
Real World Relevance	Attention	Low	Mentioned in 0 codes
Ill-defined Problem	Effort	Moderate	Mentioned in 1 code
Sustained Investigation	Previous Knowledge	Moderate to High	Mentioned in 2 codes.
Multiple Interpretations and Outcomes	Persistence	High	Mentioned in more than 3 codes.

For example, if a participant referenced only the "Real World Relevance" code for the reading phase in the perceived authenticity section of the interview, the participant's perceived authenticity level for the reading phase would be categorized as "Moderate." Similarly, if the virtual simulation phase is referenced in three codes—such as “Attention,” “Effort,” and “Persistence”—within the interview’s perceived cognitive engagement section, the participant’s perceived cognitive engagement level for the simulation phase is categorized as "High." Participants had the flexibility to associate multiple learning phases to each code if they felt it reflected their experience. For instance, if a participant believed that both the reading and simulation phases incorporated real-world relevance as an element of authentic learning, they could reference both phases in that code in their interview response.

3.6.3 Preprocessing the fNIRS Data.

Preprocessing the fNIRS data in this study involved several steps, such as synchronization, signal quality check, filtering, and motion artifact removal, to ensure the accurate interpretation of neurocognitive data (Ayaz et al., 2012).

The synchronization process involves aligning the fNIRS data with the exact timing of each learning activity. The timing of the start and end of each activity is marked to a precision of 0.12 seconds since the OBELAB NIRSIT LITE device used in this study has an 8.33Hz sampling rate. Given the hemodynamic response delay in the human brain, a 6-second offset correction is applied to the fNIRS data. This adjustment accounts for the physiological delay between neural activation and the resultant hemodynamic changes detectable by the fNIRS sensors (Lamb & Etopio, 2019).

This study employed the NIRSIT Quest software, provided with the equipment, to preprocess the fNIRS data. Appendix E presented the advanced options of the preprocessing function in the NIRSIT Quest software. Signal quality was assessed using the signal-to-noise ratio (SNR) with a threshold of < 20 dB. Channels failing to meet this SNR threshold were excluded from further analysis (Yücel et al., 2021). The preprocessing stage incorporated advanced signal processing techniques to mitigate noise and confounding factors, such as light source instability, electronic noise, and physiological artifacts stemming from gross movements, respiration, and heart pulsations (Yücel et al., 2021). These steps were crucial for accurately isolating cerebral hemodynamic responses from extraneous physiological and movement-related artifacts (Pinti et al., 2020; Scholkmann et al., 2014).

This study selected the Temporal Derivative Distribution Repair (TDDR) method to correct motion artifacts in the fNIRS data, as motion artifacts can significantly distort the recorded signals (Scholkmann et al., 2010). TDDR is a widely used approach for addressing such artifacts (Fishburn et al., 2019). The method leverages temporal derivatives of the fNIRS signal to identify and correct discontinuities caused by motion (Fishburn et al., 2019). As a non-parametric method, TDDR requires minimal assumptions about the data and is highly effective at detecting and correcting brief yet substantial motion-related disruptions, making it a robust choice for this study (Fishburn et al., 2019).

The Butterworth bandpass filter with low and high cut-off frequency is employed in the digital filtering process (Scholkmann et al., 2014). The low cut-off frequency is set at 0.01Hz to isolate brain activity-related signals by removing slower oscillations. The high cut-off frequency is set at 0.1 Hz to eliminate high-frequency noise such as heartbeat, breathing cycle, and other psychological noise (Vitorio et al., 2017). The choice of the Butterworth filter is due to its flat frequency response in the passband, ensuring minimal distortion of the hemodynamic signal (Cooper et al., 2012).

3.6.4 Analyzing the individual fNIRS Data.

Once the preprocessing step was completed, a repeated measures ANOVA was performed on each participant's data. In repeated measures ANOVA, the same participant or experimental units are measured multiple times under different conditions or at different points in time (Field, 2013). It is a common statistical technique in fNIRS studies for analyzing within-subject variations in hemodynamic responses across different conditions or time points (Tak & Ye, 2014). This method is particularly effective for fNIRS data, as it accommodates the nature of fNIRS data and enables the examination of temporal trends in brain activity, especially in cognitive studies that require tracking changes in cognitive process across multiple tasks or phases (Mirelman et al., 2014; Tak & Ye, 2014). By applying repeated measures ANOVA, researchers can evaluate condition-specific effects, yielding robust insights into cognitive processes across different experimental conditions (Mirelman et al., 2014).

In this study, hemodynamic response values are reported in micromolar units (μM). The significance level for repeated measures ANOVA is set at $\alpha = 0.05$. To ensure equal sample sizes, the learning phases were segmented into one-minute blocks, with each fNIRS channel recording 506 samples per block (one minute). As the study does not focus on brain activation in specific areas, each block's data from all fifteen channels was aggregated into a single column in the datasheet. As a result, each participant's data consists of ten columns, each has 7590 samples, representing one block during the learning module. Within-case repeated measures ANOVA analysis compares the hemodynamic response levels of each block for each participant across different learning phases, including Reading, Introductory Video, Virtual Simulation, and Debriefing. The analysis provides a preliminary overview of the trends and fluctuations in each participant's hemodynamic responses throughout the learning module, assisting in the identification of any potential anomalies in the physiological data. The steps of the analysis process are outlined as follows:

a. **Export Data**: Export the fNIRS data from 15 channels for each 1-minute block.
b. **Aggregate Data**: Aggregate the 15-channel data from each block into a single column in the datasheet for each participant.
c. **Organize Data**: Organize block columns by activity phase:
    - 3 columns for Reading
    - 1 column for Introductory Video
    - 5 columns for Virtual Simulation
    - 1 column for Debriefing
d. **Statistical Analysis**: Calculate descriptive statistics and conduct repeated measures ANOVA to compare hemodynamic response levels across different learning phases.

3.6.5 Convert the physiological hemodynamic response level to a 4-point scale variable.

To evaluate the alignment or discrepancy between perceived and physiological measures of cognitive engagement, as well as the relationship between authenticity and physiological cognitive engagement, the continuous fNIRS data for each phase or key segments identified as authentic by the participants were transformed into a 4-point scale variable. This conversion process involved three steps. First, the average hemodynamic response level for each block, alongside the mean hemodynamic response level of the entire learning module, was calculated. Second, the standard deviation of each participant's hemodynamic response levels was computed. Third, using the calculated mean and the standard deviation, the physiological data were categorized into four levels to correspond with the categories used for perceived authenticity and cognitive engagement. The specific criteria were as follows:

- **Low (1 point):** Hemodynamic response values that were lower than the overall mean hemodynamic response value minus one standard deviation were categorized as low physiological cognitive engagement.
- **Moderate (2 points):** Hemodynamic response values that fell below the mean but within one standard deviation were categorized as moderate physiological cognitive engagement.
- **Moderate to High (3 points):** Hemodynamic response values that exceeded the mean but below the mean plus one standard deviation were considered moderate to high level of physiological cognitive engagement.
- **High (4 points):** Hemodynamic response values that were higher than the mean value plus one standard deviation were classified as high physiological cognitive engagement.

Table 2

4-Point Scale Physiological Cognitive Engagement

Physiological Cognitive Engagement		
Level	Criteria	Score
Low	Hemodynamic Value < Mean - Standard Deviation	1
Moderate	Mean - Standard Deviation < Hemodynamic Value < Mean	2
Moderate to High	Mean + Standard Deviation > Hemodynamic Value > Mean	3
High	Hemodynamic Value > Mean + Standard Deviation	4

Table 2 summarizes the classification criteria. This approach enables a consistent comparison between self-reported (perceived) engagement and physiological (hemodynamic response) engagement, allowing for the identification of similarities or discrepancies across participants and phases of the learning module. The 4-point scale physiological engagement also facilitated the calculation of the correlation between authenticity and physiological cognitive engagement, allowing for the analysis needed to address Research Question 3.

This structured approach ensures that each participant's responses are analyzed with consistency and rigor, allowing for a detailed and comparative assessment of how each dimension of authenticity and cognitive engagement is experienced across different learning activities.

3.6.6 Standardization and Cross-Case Analysis.

The hemodynamic data was standardized in preparation for the cross-case analyses since the raw data are relative values that cannot be directly compared across subjects (Ichikawa et al., 2014). Z-score transformation is applied to each participant's hemodynamic data to normalize responses with respect to their baseline measurements. The Z-score transformation is an important step due to individual differences in baseline hemodynamic responses, which can vary widely due to physiological characteristics such as skull thickness and skin blood flow (Huppert et al., 2009). This process involves converting the raw hemodynamic measurements into standardized scores, facilitating comparisons across different subjects and conditions (Ichikawa et al., 2014).

A Z-score indicates the number of standard deviations a data point is from the mean. In fNIRS data, it shows the deviation of hemodynamic responses from a baseline condition for each participant (Ichikawa et al., 2014). To reduce the complexity of the data, the mean hemodynamic value of each channel within each learning phase for each participant was calculated to conduct the Z-score transformation. (Lamb & Etopio, 2019). The Z-score transformation formula for fNIRS data is:$ZO_2HB = \frac{O_2HB - MO_2Hb_i}{SDO_2Hb}$, where O_2HB is the mean value of hemodynamic response of each channel during each learning phase, MO_2Hb_i is the mean baseline hemodynamic response, and SDO_2Hb is the standard deviation of the baseline hemodynamic response (Ichikawa et al., 2014; Lamb & Etopio, 2019). This transformation normalizes the data, reduces the impact of individual physiological variations, and ensures that observed variations of hemodynamic responses are due to learning activities rather than inherent physiological differences (Plichta et al., 2007; Ichikawa et al., 2014).

Post-transformation, hemodynamic responses for each task can be compared directly, highlighting changes in brain activity due to learning activities. Descriptive statistics and Analysis of Variance (ANOVA) were conducted. These standardized values become the behavioral dependent variables of interest in the analysis, facilitating the assessment of differences in physiological cognitive engagement of all participants across all learning activities.

3.6.7 Synthesizing within-case and cross-case analyses.

The final step involves synthesizing the findings from both within-case and cross-case analyses. A comparative analysis is conducted across different cases to identify overarching patterns, similarities, and variations in how authenticity and cognitive engagement are perceived and physiologically experienced. This cross-case analysis is vital for understanding the broader implications of the findings (Baxter & Jack, 2008).

CHAPTER 4

RESULTS

This chapter presents the findings derived from the comprehensive case analysis designed to address the research questions concerning student experiences across a sequence of different learning phases. These phases include a 3-minute reading session to cover fundamental concepts, a 1-minute introductory video serving as a tutorial for the virtual simulation, a 5-minute virtual simulation where students apply their knowledge to solve problems, and a 1-minute debriefing session designed to articulate and consolidate their understanding. It provides an in-depth examination of the data collected from ten middle school students to assess the interplay between cognitive engagement and authenticity.

The study was structured around three principal research questions. The first research question examines the levels of authenticity perceived by students during each distinct learning activity, as assessed through semi-structured interviews. The second research question focuses on the levels of cognitive engagement experienced by students across these activities. It evaluates the similarity between perceived cognitive engagement as reported in the interview and psychological cognitive engagement as indicated by fNIRS data. The third research question explores the patterns of relationship between students' perceived authenticity and their cognitive engagement, both perceived and physiologically measured.

This study included ten eighth-grade middle school students to minimize variations in reading ability and prior knowledge levels. Data collection took place in an unoccupied classroom within their school, ensuring the learning activities occurred in a familiar and controlled environment. This setting was chosen to enhance comfort and reduce external variables that could potentially influence the students' performance and engagement.

In this study, a mixed-methods case analysis approach was employed within a multiple-case study framework, treating each participant's experiences and responses as individual cases. Detailed descriptions were developed for each participant using synchronized picture-in-picture video clips, which constituted a critical component of the data evaluation process. These videos were meticulously analyzed in conjunction with corresponding fNIRS brain map replays, a method essential for visualizing physiological responses during various learning activities. Fluctuations in brain activity were systematically documented for each activity. Following the within-case analysis, a synthesis of qualitative and quantitative data was conducted, resulting in comprehensive reports that included both within-case and cross-case findings. These findings integrated insights from semi-structured interviews and neurophysiological measurements, thereby enhancing the depth and breadth of the analysis.

4.1 Case Analysis Results

This section outlines the individual experiences and responses of the participants, exploring their perceived levels of authenticity (according to the interview responses) and cognitive engagement (based on the interview responses and fNIRS measurements) across different learning activities. Descriptive analysis is the primary approach for the qualitative section of the within-case analysis. This includes detailed observations of the synchronized picture-in-picture video clips and participants' perceptions as conveyed in semi-structured interviews. This qualitative analysis is supplemented by a quantitative analysis of individual fNIRS data through repeated measures ANOVA. The case of Participant 01 is presented in detail as a representative example, illustrating the analytic techniques and the interplay of qualitative insights with quantitative data. The within-case analysis results for other participants are available in Appendix D. Subsequent subsections summarize the key findings from all participants, providing a comprehensive view of the individual experiences and setting the stage for a broader cross-case analysis.

Following the descriptive analysis of the synchronized video clips, the next step involves analyzing the semi-structured interview responses. Upon completing the debriefing session, participants answered a series of questions that addressed their perceptions of authenticity and cognitive engagement during various learning activities.

The third step of the data analysis process involves performing repeated measures ANOVA on the individual fNIRS data. This analysis compares hemodynamic response levels across the four different phases of the study for each participant: Reading, Introductory Video, Virtual Simulation, and Debriefing. To ensure equal sample sizes, the learning activities were segmented into one-minute blocks. This method allows for a detailed examination of physiological cognitive engagement and its changing trends, as measured by hemodynamic response levels, across different learning activities.

The final step of the data analysis process involves a cross-case fNIRS data analysis using descriptive statistics and Analysis of Variance (ANOVA). Standardized hemodynamic values, obtained through Z-score transformation, serve as the behavioral dependent variables of interest. This approach enables a comprehensive assessment of physiological cognitive engagement across all learning phases for all participants, facilitating direct comparisons into engagement patterns throughout the study.

4.1.1 Within-case analysis for Participant 01

The within-case analysis for Participant 01 includes a descriptive analysis of the synchronized video clip showcasing student activities alongside fNIRS brain map replay, an analysis of interview responses, and the application of repeated measures ANOVA to the fNIRS data.

a. Descriptive Analysis of the Synchronized Video Clip.

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

  Participant 01, fitted with an fNIRS device, began the data collection with a 3-minute relaxation phase to establish a pre-experiment baseline. The participant sat quietly in a chair without external stimuli during this phase.

- ***Reading Material Phase (0:03:20 - 0:06:19):***

  Following the baseline phase, Participant 01 engaged with the reading material for 3 minutes. The fNIRS brain map indicated a moderate activity level at the beginning. From 0:03:52, increased brain activity was noted, particularly with a high level of hemodynamic response in the lower section of the left prefrontal lobe and the higher section of the right prefrontal lobe.

  The participant started to read the second page at 0:04:01. The brain activity increased compared to the first page according to the fNIRS brain map. The brain activity peaked from 0:05:24 to 0:05:38, coinciding with the participant’s focus on an equation used to calculate the balance of a seesaw. No distractions were recorded during this phase. The phase concluded at 0:06:20.

- ***Introductory Video Phase (0:06:54 - 0:07:53):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated that lower to moderate levels of brain activity.

- ***Virtual Science Simulation Phase (0:08:03 - 0:13:02):***

Participant 01 then engaged with the virtual science simulation for 5 minutes. The detailed time and attempt data are summarized in Table 3.

Table 3

Participant 01 Virtual Simulation Outcome

Problem	Problem Type	Time (s)	Attempt 1	Attempt 2
1	Object Balancing	7	Correct	
2	Multiple Choice	9	Correct	
3	Object Balancing	28	Incorrect	Correct
4	Object Balancing	12	Correct	
5	Multiple Choice	5	Correct	
6	Object Balancing	53	Correct	
7	Multiple Choice	9	Correct	
8	Object Balancing	10	Correct	
9	Object Balancing	8	Correct	
10	Multiple Choice	16	Correct	
11	Object Balancing	13	Correct	
12	Object Balancing	15	Correct	
13	Object Balancing	14	Correct	
14	Object Balancing	20	Correct	
15	Multiple Choice	14	Incorrect	Incorrect
16	Object Balancing	8	Correct	
17	Multiple Choice	11	Correct	
18	Object Balancing	21	Correct	
19	Object Balancing	8	Incorrect	

The participant spent 16 seconds solving the first two problems with moderate brain activity, predominantly in the higher section of the right prefrontal lobe. The third problem required two attempts: the first was incorrect, and the second was correct, taking 28 seconds. This problem-solving effort significantly increased brain activity in both the left and right prefrontal lobes. Subsequent problems were solved more quickly, with brain activity fluctuating accordingly. A high level of hemodynamic response was observed consistently from problems 6 to 19 as the problem difficulty increased.

- ***Debriefing (0:13:15 - 0:14:15):***

During the debriefing session, the participant shared the experience and insights gained from the learning activities, with brain activity increasing from moderate to high within the first 14 seconds. The debriefing activity concluded approximately one minute after the phase began.

b. Interview Analysis.

- ***Interview (0:14:18 - 0:20:10):***

Following the debriefing session, the researcher started the interview with Participant 01. The participant reported that the virtual simulation was more interesting, while the reading material provided more useful information for learning (Excerpt 1, line 1 to 2). The participant expressed an interest in games and reading in daily life and highlighted the real-world relevance of the virtual simulation (Excerpt 1, line 3 to 4). He noted no major challenges during the module (Excerpt 1, line 5). Still, he found the problem involving balancing several items on a seesaw required extra effort and additional attempts, indicating sustained investigation (Excerpt 1, line 6 to 7). For

Participant 01, the reading phase is the most focused activity, while the introductive video is the least interesting activity. The participant connected previous knowledge to the simulation and found the second page of the reading material particularly useful in learning the topic (see Excerpt 1, line 8). The coding protocol for the interview is shown in Table 4.

Table 4

Interview Data Coding Protocol and Results for Participant 01

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation/Reading
		Apply	The knowledge can be used in real life.	Simulation
	Ill-defined Problem	Challenge	The problems are challenging and do not have a clear answer.	n/a
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	n/a
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Reading
		Active /Passive	Whether the learners are actively learning or passively receiving the information.	Video (Passive activity)
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve difficult problems.	n/a
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Reading

Excerpt 1.	Perceived authenticity and cognitive engagement of Participant 01
1	The game (simulation) is more engaging, but I feel like the passage got
2	the information across quicker than the game.
3	I can manipulate the real objects on the seesaw and I think I can use the
4	knowledge in real life if I need to balance something.
5	They are relatively easy (to solve).
6	It was more interesting when I need to balance multiple objects instead
7	of two. Sometimes it took more than one try.
8	The second page of the article is pretty interesting.

- ***Post-Experiment Baseline (0:20:15 - 0:25:18):***

After the completion of the interview, the participant entered a 5-minute rest phase to establish a post-experiment baseline, concluding the fNIRS data collection at 0:25:18.

c. Repeated Measures ANOVA for fNIRS Data.

As indicators of brain activity, the hemodynamic responses of Participant 01 captured by the fNIRS device were recorded continuously throughout the learning module. In the within-case quantitative data analysis section for Participant 01, the data is utilized to assess the participant's physiological cognitive engagement. The analysis aims to compare hemodynamic values across various phases: Reading, Introductory Video, Virtual Simulation, and Debriefing. A repeated measures ANOVA was conducted with a significance level set at $\alpha = 0.05$. The learning activities are segmented into one-minute blocks to achieve equal sample sizes. The mean and standard deviation for hemodynamic values across each learning activity are summarized in Table 5.

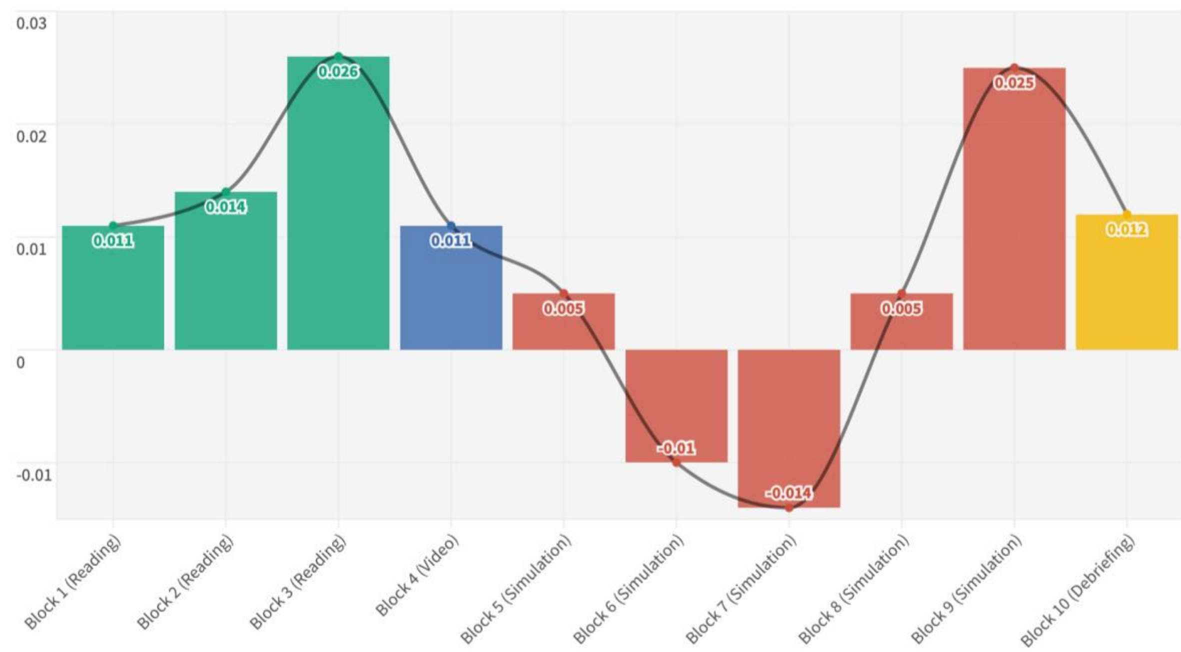
Table 5

fNIRS Data Descriptive Statistics for Participant 01

Activity Hemodynamic Level (μM)	*M*	*SD*
Reading 1 (μM)	0.011	0.066
Reading 2 (μM)	0.014	0.073
Reading 3 (μM)	0.026	0.101
Video 1 (μM)	0.011	0.105
Simulation 1 (μM)	0.005	0.077
Simulation 2 (μM)	-0.010	0.082
Simulation 3 (μM)	-0.014	0.050
Simulation 4 (μM)	0.005	0.086
Simulation 5 (μM)	0.025	0.077
Debriefing 1 (μM)	0.012	0.115

The multivariate test results showed a significant effect of learning activity on hemodynamic values, Pillai's Trace = 0.385, $F(15, 7560) = 314.891$, $p < .001$, partial $\eta^2 = 0.385$. The repeated measures ANOVA revealed a significant main effect of learning activity on hemodynamic values, $F(7.762, 58791.068) = 168.403$, $p < .001$, partial $\eta^2 = 0.022$. This indicates that hemodynamic response levels significantly differed across the learning activities.

Figure 4 illustrates the mean hemodynamic response levels for each learning phase of Participant 01. The blocks are color-coded for clarity: green represents the reading phase, blue is the introductory video phase, red is the virtual simulation phase, and yellow is the debriefing phase. A connecting line across all blocks depicts the trend of Participant 01's physiological cognitive engagement throughout the learning module.



Note: The blocks of the reading phase are in green color, the block of the video phase is in blue color, the blocks of the simulation phase are in red color, and the block of the debriefing phase is in yellow color.

Figure 4

Mean Hemodynamic Response Level for Participant 01

d. Case Summary for Participant 01.

Qualitative insights from the picture-in-picture video and semi-structured interview are combined with the quantitative results from fNIRS data to address the research questions and explore the relationship between perceived authenticity, cognitive engagement, and physiological responses during different science learning activities.

Participant 01's case analysis illustrates a robust connection between perceived authenticity, cognitive engagement, and physiological responses. The findings indicate that learning activities perceived as authentic and relevant to real life are associated with higher levels of physiological engagement, as measured by fNIRS. This relationship becomes more pronounced when examining the qualitative results and physiological responses within smaller segments of the learning process. For instance, the participant found the second page of the reading material particularly beneficial and perceived the challenging problems in the simulation as applicable to real-world scenarios. Both instances coincided with peak hemodynamic response levels from the fNIRS data, underscoring the strong correlation between perceived authenticity and cognitive engagement.

Additionally, there was an inconsistency between perceived and physiological cognitive engagement during the virtual simulation. While Participant 01 perceived only moderate cognitive engagement during the simulation phase, the fNIRS data indicated a high level of physiological engagement. However, the physiological data is closely aligned with the perceived authenticity level. The participant found the tasks toward the end of the virtual simulation as highly authentic. Correspondingly, the fNIRS data recorded high hemodynamic response levels in the last block of this phase, demonstrating the relationship between perceived authenticity and physiological engagement.

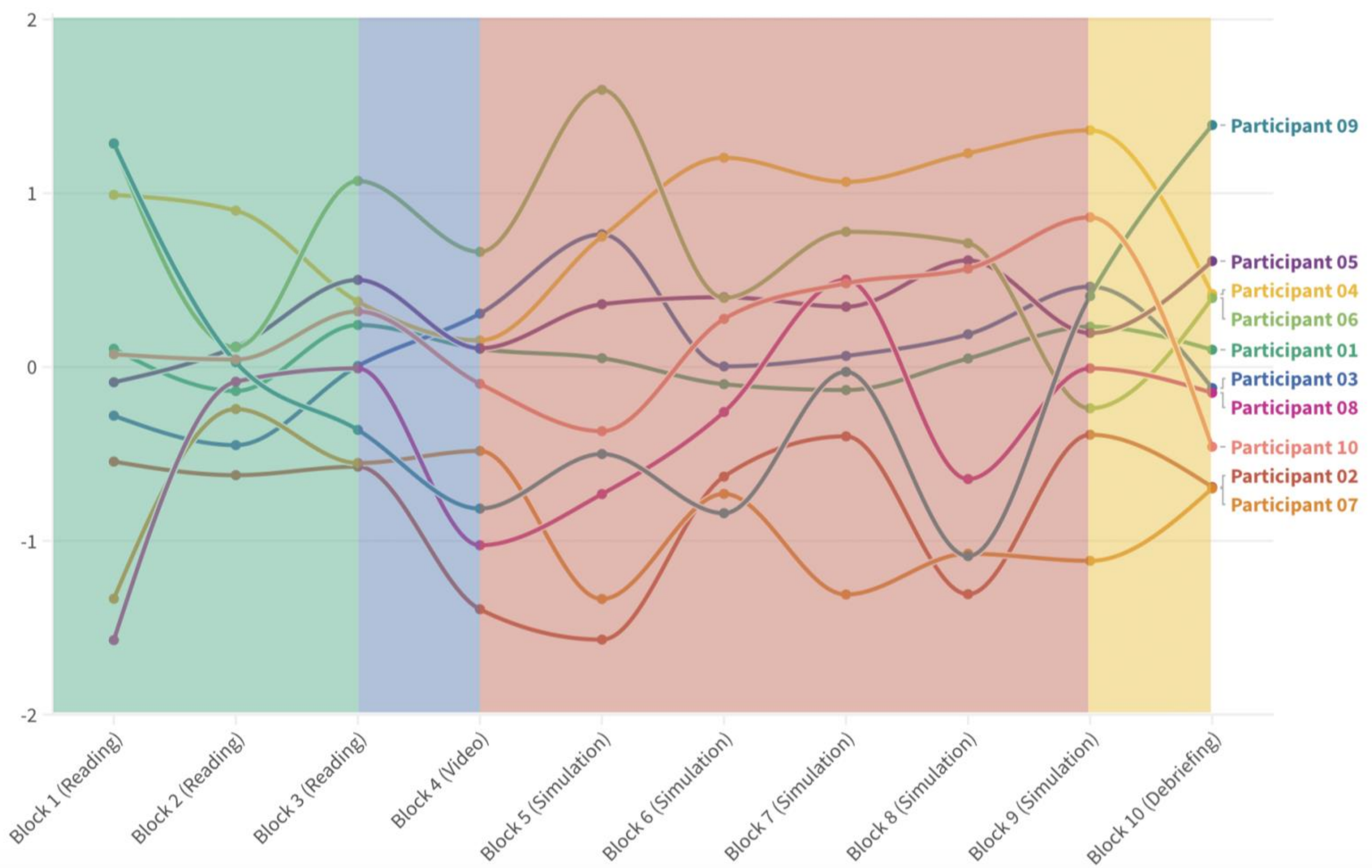
4.1.2 Key Results of Within-case Analysis

Similar to the approach used for Participant 01, a within-case analysis was conducted for the remaining nine participants. The detailed within-case analysis report for each participant can be found in Appendix D. This analysis included descriptive analysis of the synchronized video clips, analysis of interview responses, and repeated measures ANOVA to the fNIRS data. Table 6 summarizes the key results from both the descriptive and interview analyses for all participants.

Table 6

Within-Case Descriptive and Interview Analysis Results for Each Participant

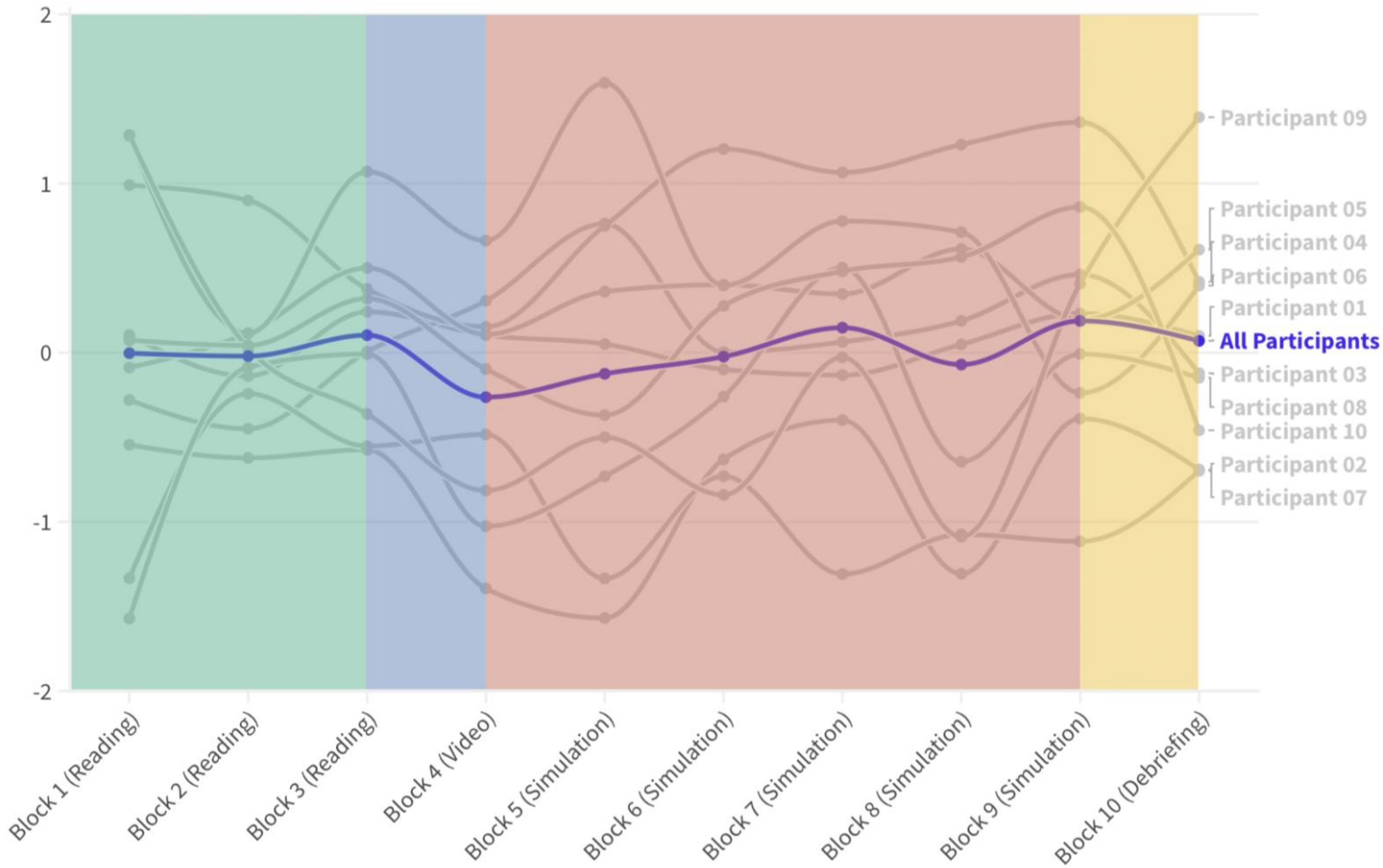
	Reading		Introductory Video		Virtual Simulation		Debriefing
Participant	Authenticity	Perceived Cognitive Engagement	Authenticity	Perceived Cognitive Engagement	Authenticity	Perceived Cognitive Engagement	Authenticity
01	Moderate to High	High	Low	Low	High	High	High
02	Moderate to High	Moderate to High	Low	Low	High	Moderate to High	High
03	Moderate	Moderate to High	Low	Low	High	High	High
04	Low	Moderate	Low	Moderate	High	High	High
05	Moderate to High	High	Low	Low	High	Moderate to High	High
06	Moderate	High	Low	Low	High	High	High
07	Moderate to High	Moderate to High	Low	Low	Moderate	High	High
08	Moderate	Moderate	Low	Moderate	High	High	High
09	Moderate	Moderate to High	Low	Low	High	Moderate to High	High
10	Moderate	Low	Low	Low	High	High	High



Note. Background color green: Reading. Background color blue: Video. Background color red: Simulation. Background color yellow: Debriefing.

Figure 5

Hemodynamic Response Fluctuations for Each Participant



Note. Background color green: Reading. Background color blue: Video. Background color red: Simulation. Background color yellow: Debriefing.

Figure 6

The Mean Hemodynamic Response Curve of All Participants

Figure 5 illustrates the trends and fluctuations in the hemodynamic responses across all participants throughout the learning module, while Figure 6 highlights the average hemodynamic response fluctuations, calculated by aggregating the data from all participants. To compare physiological measurements across participants, the fNIRS data used to create Figures 5 and 6 have been standardized. The specific standardization process is outlined in detail in the Cross-case fNIRS data analysis section of this chapter and further explained in Chapter 3.

Based on the results of the within-case analysis for all participants, as shown in Table 4, Figure 5, and Figure 6, significant relationships are consistently revealed between perceived authenticity, perceived cognitive engagement, and physiological cognitive engagement across various learning activities. These findings suggest a strong alignment between participants' subjective experiences of authenticity and engagement with their corresponding physiological responses.

These relationships underscore the impact of authentic learning environments on students' cognitive processes as reflected in both self-reported and physiological data.

a. Authenticity of Each Learning Activity.

- The reading phase was perceived by the majority of participants as a one-dimensional authentic learning activity. Specifically, seven out of ten participants acknowledged the real-world relevance of the reading material, aligning with the first dimension of authentic learning: Authentic Learning Content.
- None of the participants identified the introductory video phase as an authentic learning activity. In addition, this phase lacks elements from all three dimensions of authentic learning. Consequently, it is categorized as a non-authentic learning activity.

- The virtual simulation phase was consistently recognized by participants for encompassing all three dimensions of authentic learning. Specifically, nine participants acknowledged that this phase addressed the first two dimensions—Authentic Learning Content and Authentic Learning Activities. Furthermore, seven participants noted the inclusion of the third dimension, Authentic Outcome Assessment. These responses affirm that the virtual simulation phase functions as a comprehensive, three-dimensional authentic learning activity.
- The debriefing section is essential to the authentic learning experience as it is embedded with the metacognitive process and integrated assessment. These components align with two critical dimensions of authentic learning: Authentic Learning Activities and Authentic Outcome Assessment. Therefore, it is classified as a two-dimensional authentic learning activity.

b. Authenticity and Cognitive Engagement.

- Although cognitive engagement levels varied among participants, especially in phases like reading and virtual simulation, activities that were perceived as more authentic usually exhibited higher levels of cognitive engagement. This pattern was evident across multiple cases, where higher authenticity correlated with increased physiological engagement, irrespective of the activity type.
- For instance, Participant 01 found the second page of the reading particularly beneficial, correlating with peak hemodynamic response levels during this phase. Similarly, Participant 03 found the virtual simulation to be the most authentic activity, which corresponded with the highest levels of physiological responses.

- The precise and comprehensive analysis of the relationship between authentic learning segments and physiological cognitive engagement is detailed in the subsequent cross-case fNIRS data analysis section.

c. **Synthesize the Within-case Analysis Results.**

- The within-case analysis for all participants revealed a clear pattern: learning activities designed with high authenticity generally fostered greater cognitive engagement, supported by both qualitative responses and physiological data. For instance, the real-world examples in the reading material and challenging problems in the simulation were both associated with peak hemodynamic response levels for several participants.
- Conversely, the introductory video phase consistently exhibited lower levels of perceived cognitive engagement and reduced physiological responses. The diminished engagement can be attributed to the absence of authentic learning elements within this phase.

4.1.3. Cross-Case fNIRS Data Analysis

Based on the semi-structured interview responses, the researcher identified the specific segments perceived as authentic by participants during the reading and virtual simulation phases. These segments, along with the entire debriefing phase, were designated as authentic learning sections for the cross-case analysis of fNIRS data. Conversely, the introductory video phase was classified as a non-authentic learning section. The precise durations and time points of the authentic learning segments during the reading and virtual simulation phases are presented in Table 7.

Table 7

Perceived Authentic Learning Segments during Reading and Virtual Simulation

Participant	Reading	Virtual Simulation
01	122s - 180s	248s - 292s
02	Entire Phase	78s - 108s, 121s - 180, 241s - 300s
03	118s - 176s	7s - 67s, 228s - 289s
04	n/a	56s -122s, 129s - 226s, 235s - 283s
05	146s - 180s	182s - 231s
06	n/a	43s-114s, 210s-261s
07	52s – 180s	n/a
08	n/a	84s-111s, 126s-155s, 249s-300s
09	63s – 125s	106s - 177s, 236s - 300s
10	Entire Phase	96s - 139s, 155s - 222s, 271s - 300s

Note: The authentic learning segments during the reading and the virtual simulation phases are identified based on participants' interview responses.

The fNIRS measurements from the authentic learning sections were standardized, and a one-way ANOVA analysis was conducted to investigate significant differences in physiological cognitive engagement across the different learning activities.

a. Standardize fNIRS Data.

In the Cross-Case Analysis section of the study, the standardization process of fNIRS data is crucial for ensuring the comparability of physiological measurements across different participants. This process is critical because it adjusts for individual differences in baseline hemodynamic responses, which can vary significantly due to factors like skull thickness, skin blood flow, and other physiological characteristics that affect fNIRS signals (Huppert et al., 2009).

The standardization of fNIRS data involves converting raw hemodynamic measurements into Z-scores, a method that quantifies the number of standard deviations a data point is from the population mean during a baseline period. The formula used is: $ZO_2HB = \frac{O_2HB - MO_2Hb_i}{SDO_2Hb}$, where O_2HB represents the hemoglobin concentration during a specific block of a learning activity, MO_2Hb_i is the mean baseline hemoglobin concentration, and SDO_2Hb is the standard deviation of the baseline hemoglobin concentration.

By normalizing data relative to baseline, standardization increases the sensitivity of fNIRS to detect task-related changes. This sensitivity is crucial in educational research, where a major portion of the evoked hemodynamic responses is attributed to scalp blood flow rather than cognitive activity (Scholkmann et al., 2014). The standardization process allows for more accurately identifying patterns and differences in cognitive engagement across various learning activities and among participants.

b. Cross-Case One-way ANOVA Analysis.

One-way ANOVA with a significance level set at $\alpha = 0.05$ was used to analyze the standardized hemodynamic responses across different learning phases. The entire learning module was divided into four sections, each representing a different learning activity: reading, introductory video, virtual simulation, and debriefing. The SPSS software was employed to perform the analysis, focusing on the differences in hemodynamic response levels, which are indicative of cognitive engagement.

The analysis involved 502 data points, with the reading phase having 96 data points, the introductive video phase having 140 data points, the virtual simulation phase having 126 data points, and the debriefing phase having 140 data points. The descriptive statistics and the analysis results for standardized hemodynamic values across each learning phase are summarized in Table 8. The highest average standardized hemodynamic values were observed in the virtual simulation phase, followed by the debriefing phase and the reading phase. The introductive video has the lowest standardized hemodynamic values in the learning module.

Table 8

Descriptive Statistics and ANOVA Results for Standardized Hemodynamic Values

Learning Phase	Sample Size	*M*	*SD*	*F*	*p*	*Post Hoc*
Reading	96	0.2017	0.7677			Reading > Video Reading < Simulation
Video	140	-0.3610	0.7582	26.302	< .001	Video < Reading Video < Simulation Video < Debriefing
Simulation	126	0.4620	0.6263			Simulation > Reading Simulation > Video
Debriefing	140	0.2651	1.0146			Debriefing > Video

Levene's test for equality of variances was significant ($p = .002$), suggesting heterogeneity of variances across the different learning activities. Brown-Forsythe test was utilized for the analysis. The test is a robust alternative to the traditional ANOVA, providing reliable results even when the assumption of equal variances across groups is not met. The Brown-Forsythe test revealed significant differences in standardized hemodynamic values across the learning activities, $F(3, 448.456) = 26.302$, $p < .001$, indicating variability in hemodynamic responses related to different learning activities.

The effect sizes of this analysis provided insights into the magnitude of differences observed. The eta-squared value was estimated at 0.134, approaching a large effect size, indicating a reasonably strong influence of the learning activities on hemodynamic response levels.

Given the significant results in the Brown-Forsythe test, several post hoc comparisons using the Games-Howell test were conducted to identify the difference in the hemodynamic responses between each learning phase.

- The comparison between the introductive video phase (the non-authentic learning section) and other phases (sections perceived as authentic by the participants) revealed significant differences in the standardized hemodynamic values. This result suggests that the fNIRS data showed that the non-authentic learning section has a significantly lower physiological cognitive engagement level than authentic learning sections.
- The analysis revealed a significant mean difference between the reading phase and the virtual simulation phase. This finding highlights how a one-dimensional authentic learning activity, such as reading, and a three-dimensional authentic learning activity, such as virtual simulation, can impact participants' cognitive engagement.
- The comparisons between the reading phase (a one-dimensional authentic learning activity) and the debriefing phase (a two-dimensional authentic learning activity) did not yield significant results. Similarly, no significant differences were observed between the virtual simulation phase (a three-dimensional authentic learning activity) and the debriefing phase. These findings suggest that participants' cognitive engagement is not strongly influenced by smaller differences in the levels of authenticity embedded within the learning activities.

Figure 7 displays the mean standardized hemodynamic value for each learning phase.

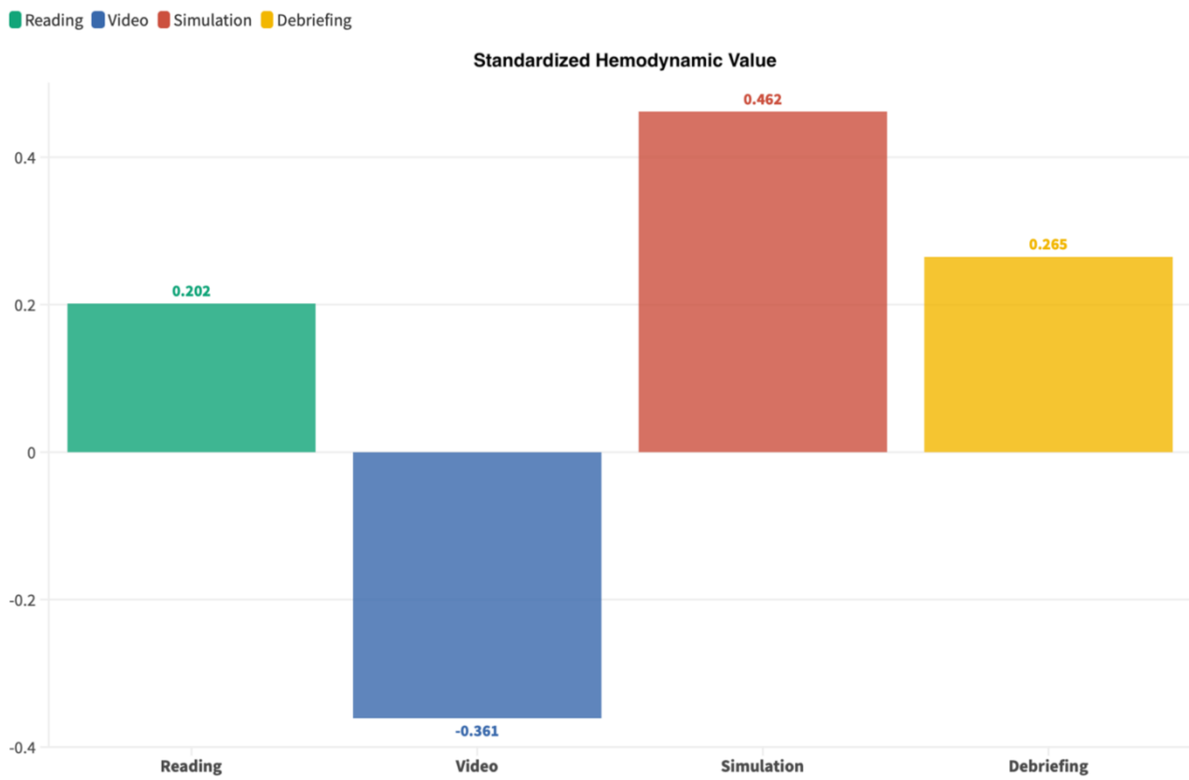


Figure 7

Mean Standardized Hemodynamic Value for Each Learning Phase

4.2 Results for Research Question One

This section presents the findings from the data analysis aimed at addressing Research Question One: What are the levels of authenticity students perceived according to different consecutive learning activities (reading, introductory video, virtual simulation, debriefing)? The data for this research question was collected from the semi-structured interviews.

4.2.1 Perceived Authenticity for Phase 1: Reading

The analysis of the reading phase reveals a prominent acknowledgment of the real-world applicability of the content by several participants, enhancing the perceived authenticity of this learning activity. Notably, Participants 01, 02, 03, 05, 07, 09, and 10 cited the knowledge gained from the reading material as applicable to real-life scenarios, significantly improving their learning experience. The second page of the reading material was frequently highlighted as particularly informative and beneficial, underscoring its impact on enhancing participants' understanding of the subject matter.

Responses from semi-structured interviews indicate that a majority—seven out of ten participants—perceived the reading material as having real-world relevance, which is the first element in the first dimension of authentic learning. It emphasizes the importance of grounding educational content in real-world contexts. This dimension was robustly represented in the reading phase, allowing participants to forge meaningful connections between the material and their everyday experiences.

However, despite its strengths in demonstrating real-world relevance, the reading activity failed to address the other two dimensions of authentic learning: Authentic Learning Activities and Authentic Outcome Assessment. None of the participants mentioned these aspects in relation to the reading phase during their interviews. This gap highlights a limitation in the reading material's ability to foster a comprehensive authentic learning environment as defined by the conceptual framework. While the content effectively introduced participants to applicable knowledge, it lacked interactive elements that mirror the complexity of real-world tasks, which are crucial for fostering active problem-solving and critical thinking. Moreover, the absence of integrated assessment within the reading phase may prevent learners from ongoing feedback to evaluate their understanding and apply it in a practical context. Thus, while the reading phase, as an one-dimensional authentic learning activity, scores high on content authenticity, it necessitates enhancements in activity design and outcome assessment to elevate its overall authenticity and educational impact.

Table 9 organizes the dimensions of authentic learning as perceived by each participant during the reading phase.

Table 9

Authentic Learning Dimensions During Reading Phase

Participant	Authentic Learning Content	Authentic Learning Activities	Authentic Outcome Assessment
01	Yes	No	No
02	Yes	No	No
03	Yes	No	No
04	No	No	No
05	Yes	No	No
06	No	No	No
07	Yes	No	No
08	No	No	No
09	Yes	No	No
10	Yes	No	No
Total (Yes)	7/10	0/10	0/10

4.2.2 Perceived Authenticity for Phase 2: Introductory Video

The introductory video phase consistently demonstrated low levels of perceived authenticity across participants. Notably, no participants referenced this phase when discussing aspects of perceived authenticity during semi-structured interviews. In addition, Participant 03 highlighted that the video was neither engaging nor informative. According to the conceptual framework, this phase does not incorporate elements from the three dimensions of authentic learning—Authentic Learning Content, Authentic Learning Activities, and Authentic Outcome Assessment. The video primarily served as an operational guide, with participants passively receiving information. It focuses exclusively on procedural instructions for navigating the virtual simulation without weaving in scientific concepts or substantial content. As a result, it did not foster meaningful connections to real-world applications, nor did it stimulate participants to engage in higher-order cognitive processes such as critical thinking, problem-solving, or decision-making. This phase is categorized as a non-authentic learning activity for the subsequent analysis.

4.2.3 Perceived Authenticity for Phase 3: Virtual Simulation

The virtual simulation phase was universally recognized by nearly all participants—excluding Participant 07—as the epitome of an authentic learning activity, characterized by its interactive and realistic problem-solving tasks. This phase was particularly appreciated for its hands-on learning experience, which seamlessly integrated theoretical knowledge into a simulated real-world context.

Participants found that the simulation's challenges often required multiple attempts to overcome, illustrating two essential elements of authentic learning: ill-defined problems and sustained investigation. Ill-defined problems were specifically noted by Participants 02, 03, 04, 05, 06, and 08. These types of problems are vital as they mirror real-world complexities and demand higher-order cognitive processes, including critical thinking, problem-solving, and decision-making skills.

Sustained investigation, another key aspect of authentic learning, was reported by Participants 01, 02, 03, 04, 06, 08, 09, and 10. This element encourages learners to study deeply into topics and concepts, fostering a thorough understanding and continuous engagement with the learning material. Moreover, several participants (e.g., Participants 02, 03, 04, 05, 06, 09, 10) demonstrated the use of diverse strategies to resolve simulation challenges, reflecting the authentic learning element of Multiple interpretations and outcomes. This approach emphasizes the importance of employing varied resources and perspectives to construct knowledge effectively.

During the virtual simulation, participants also received real-time feedback on the outcomes of their tasks, incorporating the Authentic Outcome Assessment dimension into the process. This feedback mechanism is crucial as it provides opportunities for learners to demonstrate their understanding and skills, thereby fostering continuous improvement and growth throughout the learning experience.

In summary, the virtual simulation phase was acknowledged by participants as embodying all dimensions of authentic learning, making it a profoundly effective and comprehensive authentic learning experience. This acknowledgment underscores the phase's role in enhancing cognitive engagement and reinforcing the practical application of theoretical concepts, establishing it as a comprehensive, three-dimensional authentic learning activity.

Table 10

Authentic Learning Dimensions During Virtual Simulation

Participant	Authentic Learning Content	Authentic Learning Activities	Authentic Outcome Assessment
01	Yes	Yes	No
02	Yes	Yes	Yes
03	Yes	Yes	Yes
04	Yes	Yes	Yes
05	Yes	No	Yes
06	Yes	Yes	Yes
07	No	Yes	No
08	Yes	Yes	No
09	Yes	Yes	Yes
10	Yes	Yes	Yes
Total (Yes)	9/10	9/10	7/10

Table 10 organizes the dimensions of authentic learning as perceived by each participant during the virtual simulation phase.

4.2.4 Perceived Authenticity for Phase 4: Debriefing

The debriefing section was integrated into the debriefing/interview phase, and the participants did not explicitly discuss it during the interviews. Still, the debriefing activity served important purposes for this study. The debriefing section is a fundamental component of the authentic learning environment. The segment effectively embodied two critical dimensions of authentic learning: Authentic Learning Activities and Authentic Outcome Assessment, specifically through the integration of Metacognition and Integrated Assessment.

This phase provided a structured opportunity for participants to engage in Metacognition, an element of Authentic Learning Activities, which involves reflection on one's own learning process. By articulating their understanding and insights gained from the previous activities, participants were able to self-assess and refine their learning strategies. Additionally, the Integrated Assessment element of the Authentic Outcome Assessment was prominently featured during this phase, offering participants a chance to demonstrate their learned skills and knowledge.

An exemplary instance of the effectiveness of this phase was demonstrated by Participant 05, who, during the debriefing, related the simulation tasks to real-life robotics applications. This participant's ability to connect theoretical knowledge with practical, real-world applications highlights the phase's role in enhancing perceived authenticity. Such connections validate the relevance of the learning activities and significantly enhance the learners' interest in the subject matter. As a result, this section is categorized as a two-dimensional authentic learning activity according to the authentic learning framework.

4.2.5 Summary of Perceived Authenticity

The analysis of participant perceptions across various learning phases reveals distinct levels of authenticity attributed to each activity. Both the reading and virtual simulation phases were generally perceived as authentic; however, the virtual simulation was recognized by a broader consensus among participants and across multiple dimensions of authentic learning, underscoring its effectiveness in providing a comprehensive authentic learning experience.

Table 11

Authenticity of Each Learning Activity

Learning Activity	Authentic Learning Dimension					
	Authentic Learning Content	Frequency	Authentic Learning Activities	Frequency	Authentic Outcome Assessment	Frequency
Reading	Yes	7/10	No	0/10	No	0/10
Introductory Video	No	0/10	No	0/10	No	0/10
Virtual Simulation	Yes	9/10	Yes	9/10	Yes	7/10
Debriefing	No	0/10	Yes	10/10	Yes	10/10

Conversely, the introductory video phase was not perceived as authentic despite serving an integral instructional role by orienting participants to the virtual simulation. This phase was evaluated through the lens of the authentic learning framework and found lacking across all three dimensions. This divergence in the perceived authenticity between the interactive simulation and the more passive video introduction highlights a critical insight: authentic learning is significantly enhanced by active participation and the application of knowledge in contexts that simulate real-life challenges. Table 11 summarizes the data analysis results for the first research question, indicating the alignment of each learning activity with the dimensions of authentic learning.

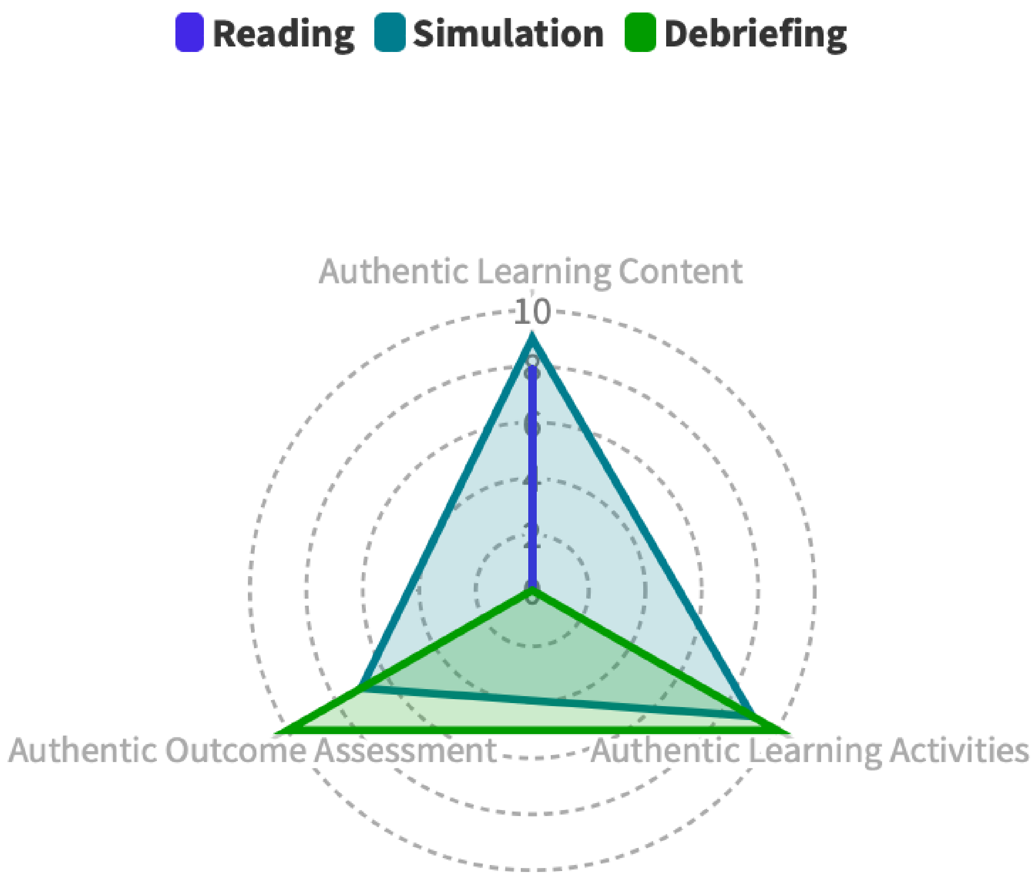


Figure 8

Authentic Learning Dimensions of the Learning Activities

Figure 8 displays the comparison of authentic learning dimensions across different learning phases. For the reading and virtual simulation phases, each time a dimension noted by a participant during the interview contributes one point towards that dimension's total score. The reading phase is depicted with a single purple line, reflecting its recognition as a one-dimensional authentic learning activity, specifically in Authentic Learning Content. The virtual simulation phase, embodying all three dimensions of authentic learning, is represented by a blue triangle. According to the authentic learning framework, the debriefing phase scored full points on the dimensions of Authentic Learning Activities and Authentic Outcome Assessment, categorizing it as a two-dimensional authentic learning activity. The introductory video phase, which did not meet any authentic learning dimensions, is excluded from the diagram.

4.3 Results for Research Question Two

This section addresses the findings from the data analysis aimed at addressing Research Question Two: What are the levels of students' cognitive engagement across four learning activities (reading, introductory video, virtual simulation, and debriefing)? Data regarding perceived cognitive engagement was collected from semi-structured interviews and supplemented with physiological data obtained through fNIRS measurements.

This research question is divided into three sub-questions. The first two sub-questions address participants' cognitive engagement from both perceived and physiological perspectives. The third sub-question focuses on identifying similarities between perceived and physiological cognitive engagement as derived from interview data and fNIRS measurements. Given that participants did not explicitly discuss their cognitive engagement during the debriefing/interview phase in their interview responses, the analysis of these similarities is concentrated on the first three phases of the learning module: Reading, Introductory Video, and Virtual Simulation. Investigating the alignment between these two forms of engagement data is critical for evaluating the reliability and validity of measurements. While perceived cognitive engagement provides insight into the learners' subjective experiences and self-assessments as they interact with different learning content and activities, physiological measures offer continuous, real-time monitoring of cognitive activity (Ayaz et al., 2012). This real-time capability of physiological measurements like fNIRS allows for an ongoing assessment of cognitive states throughout the learning process, providing a dynamic view of engagement that can capture fluctuations and shifts that self-report measures might miss (Schellens & Valcke, 2006).

During the reading and virtual simulation phases, the analysis of the physiological cognitive engagement focused on the specific segments that participants identified as authentic according to their interview responses. These key segments served as the basis for evaluating the cognitive engagement alignment. If a participant did not identify specific segments as authentic in the interview, the analysis considered the physiological cognitive engagement levels for the entire phase to assess alignment.

Based on the frequency of responses referring to each learning phase during the interview, the perceived cognitive engagement level is categorized into a 4-point scale: Low (1 point), Moderate (2 points), Moderate to High (3 points), and High (4 points).

To analyze the alignment between perceived and physiological cognitive engagement, the fNIRS data for each learning phase or key segments were also converted into a 4-point scale. This was done by calculating the average hemodynamic response level and its standard deviation for each block. Hemodynamic response levels were then categorized as follows:

- **Low (1 point)**: Hemodynamic response values below the mean minus 1 standard deviation.
- **Moderate (2 points)**: Hemodynamic response values between the mean and the mean minus 1 standard deviation.
- **Moderate to High (3 points)**: Hemodynamic response values between the mean and the mean plus 1 standard deviation.

- **High (4 points)**: Hemodynamic response levels above the mean plus 1 standard deviation.

The synchronization of subjective perceptions with real-time physiological data can reveal moments of alignment where students' self-reports match their biological cognitive activity, as well as instances of divergence, where the physiological data might indicate different levels or patterns of engagement than those perceived by the learners.

4.3.1 Criteria for Evaluating Similarity or Discrepancy in Cognitive Engagement

The criteria for evaluating the alignment between perceived cognitive engagement from interview data and physiological cognitive engagement from fNIRS data are as follows:

- **Direct Alignment:** A high level of similarity when engagement levels from interview responses align with hemodynamic responses measured by fNIRS data within the same learning phase.
- **Partial Alignment:** Moderate similarity is recognized when there are partial matches between perceived cognitive engagement levels and physiological data. For instance, a moderate level of perceived engagement corresponds with a moderate to high level of physiological engagement.
- **Discrepancy:** A discrepancy is identified when there is a clear mismatch, such as reports of high engagement not supported by the physiological data or vice versa.

4.3.2 Cognitive Engagement for Phase 1: Reading

a. Perceived Cognitive Engagement During Reading Phase.

The reading phase elicited a range of perceived cognitive engagement levels among participants, with some finding it highly engaging and others less so. Notably, Participants 01 and 05 described this activity as the most focused phase. This was echoed by Participants 06 and

07, who reported actively engaging with the content, applying critical thinking and reflection to the material presented. A significant number of participants, specifically Participants 01, 02, 03, 05, 07, 08, and 09, expressed that the reading material piqued their interest in the subject and motivated them to continue exploring the topic further.

Moreover, Participants 02, 06, and 09 found that the reading phase helped them bridge their previous knowledge with new information, enhancing their overall understanding of the content. This ability to connect past and present learning underscores the reading material's role in fostering a deeper cognitive involvement by integrating new concepts with existing knowledge frameworks.

However, not all responses were positive for the reading phase. Participant 04 critiqued the reading for lacking a clear objective, which decreased the engagement level. Similarly, Participant 07, despite acknowledging that the content was interesting and spurred a desire to learn more, admitted to not being highly focused during the reading phase.

b. Physiological Cognitive Engagement of Key Segments During Reading Phase.

The assessment of physiological cognitive engagement during the reading phase revealed varied levels of engagement across participants. Among the five participants who identified specific segments of the reading phase as particularly authentic (Participants 01, 03, 05, 07, and 09), four exhibited relatively high levels of physiological engagement. Specifically, Participants 01 and 05 demonstrated high levels of hemodynamic value, and Participants 07 and 09 showed moderate to high hemodynamic response levels. However, Participant 03, despite identifying a segment as authentic, displayed a moderate hemodynamic response level.

For the five participants who did not identify specific authentic segments during the reading phase, the overall results are slightly lower. None of them demonstrated high physiological cognitive engagement. Participants 02, 06, and 10 exhibited moderate to high hemodynamic response levels, while Participants 04 and 08 showed moderate levels of physiological engagement. Overall, while there was some variability in physiological cognitive engagement across different participants during the reading phase, none of the participants exhibited a low level of engagement throughout this phase.

c. The Cognitive Engagement Congruence During Reading Phase.

The corresponding levels and scores for each participant's perceived and physiological engagement are summarized in Table 12, allowing for a comparative analysis of cognitive engagement during the reading phase.

The perceived cognitive engagement and the physiological cognitive engagement were both presented in the 4-point scale form to evaluate the similarity or discrepancy between the two measurements. The analysis revealed a robust congruence between perceived and physiological cognitive engagement among participants. Out of the ten participants, seven (Participants 01, 02, 04, 05, 07, 08, and 09) demonstrated direct alignment between their self-reported cognitive engagement and their physiological data, suggesting a high degree of consistency between how they perceived their engagement, and their actual brain activity as measured by fNIRS. Two participants (Participants 03 and 06) exhibited partial alignment, indicating that while their self-reported engagement corresponded with the physiological data to some extent, there were some discrepancies.

Participant 10 was the only participant who displayed significant mismatches between their reported engagement levels and the physiological measurements. This discrepancy suggests that Participant 10's self-reported cognitive engagement may not fully capture the brain activity during the reading phase.

Table 12

Perceived and Physiological Cognitive Engagement Levels During Reading

Participant	Perceived Cognitive Engagement		Physiological Cognitive Engagement		
	Level	Score	Level	Score	Identified Authentic Segments
01	High	4	High	4	122s - 180s
02	Moderate to High	3	Moderate to High	3	Entire Phase
03	Moderate to High	3	Moderate	2	118s - 176s
04	Moderate	2	Moderate	2	Entire Phase
05	High	4	High	4	146s - 180s
06	High	4	Moderate to High	3	Entire Phase
07	Moderate to High	3	Moderate to High	3	52s – 180s
08	Moderate	2	Moderate	2	Entire Phase
09	Moderate to High	3	Moderate to High	3	63s – 125s
10	Low	1	Moderate to High	3	Entire Phase

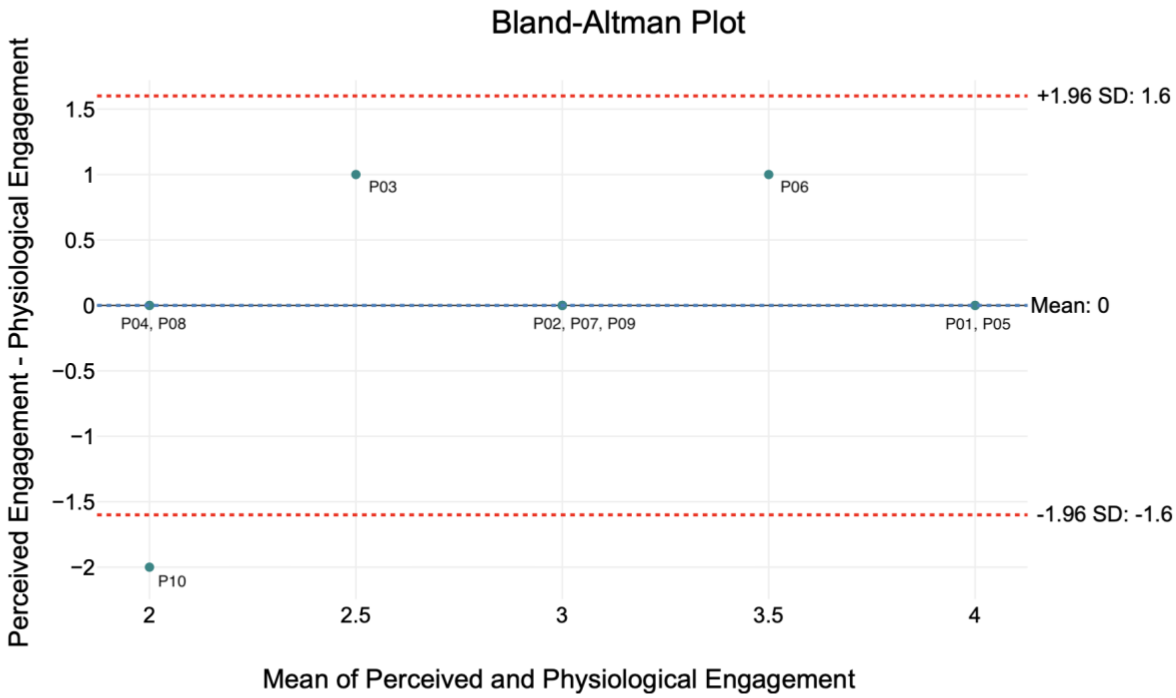
Note: Physiological Level: High: Hemodynamic Value > Mean + Standard deviation.

Moderate to High: Mean + Standard deviation > Hemodynamic Value > Mean.

Moderate: Mean - Standard deviation < Hemodynamic Value < Mean.

Low: Hemodynamic Value < Mean - Standard Deviation.

Figure 9 illustrates the alignment between participants' perceived and physiological cognitive engagements during the reading phase using a Bland-Altman plot. In this plot, the blue line at zero on the y-axis represents the mean difference equal to zero, indicating no systematic bias between the two measurements of cognitive engagement. The upper and lower limits of agreement, calculated as the mean difference ± 1.96 times the standard deviation, are marked by red lines on the plot, indicating the range of good alignment between the two measurements.



Note. y-axis: the difference between perceived and physiological cognitive engagement ($y = Perceived\ Engagement - Physiological\ Engagement$). x-axis: the mean value of perceived and physiological cognitive engagement for each participant ($x = (\frac{Perceived\ Engagement\ +\ Physiological\ Engagement}{2}$). The blue line represents the mean difference between perceived and physiological cognitive engagement for all participants. The red lines: upper and lower limit of agreement ($mean\ difference \pm 1.96 \times\ standard\ deviation$). The dots represent the difference between perceived and physiological cognitive engagement and the corresponding mean value for each participant. P#: Participant.

Figure 9

Cognitive Engagement Alignment during Reading

Each dot on the plot represents the difference between perceived and physiological cognitive engagement for each participant. The dots of seven participants with direct alignment fall directly on the mean difference line, at zero on the y-axis. There are some overlaps between the dots for Participants 01 and 05, Participants 02, 07, and 09, and Participants 04 and 08 because their average perceived and physiological cognitive engagement levels, as well as the differences between the two measurements, are the same. The dots of two participants (Participants 03, 06) with partial alignment positioned within the limits of agreement.

The distribution of these dots suggests that, for nine out of ten participants, self-reported cognitive engagement levels correspond well with physiological measurements. The only outlier is Participant 10, whose data point falls outside the limits of agreement, indicating a clear discrepancy between the two measures of cognitive engagement.

4.3.3 Cognitive Engagement for Phase 2: Introductory Video

a. **Perceived Cognitive Engagement During Introductory Video Phase.**

The introductory video phase was seldom mentioned by participants in their interviews, suggesting a lower level of perceived cognitive engagement compared to other learning activities. Participant 01 described this phase as the least interesting and noted a decreased focus level compared to the reading phase. Participant 04 and Participant 08 were the exceptions, as they expressed a more positive view; Participant 04 mentioned that the video effectively sparked interest in the simulation and encouraged further exploration of the topic. Similarly, Participant 08 felt highly attentive during the video, driven by anticipation of the upcoming simulation activity. Despite these few positive remarks, the general sentiment among participants was indifference towards this phase.

b. Physiological Cognitive Engagement During Introductory Video Phase.

The assessment of cognitive engagement through physiological data during the introductory video phase indicated predominantly low or moderate levels of engagement across the majority of participants, including Participants 02, 04, 06, 08, and 09 exhibited low levels of physiological responses, and Participants 03, 05, 07, and 10 exhibited moderate levels of physiological responses. Notably, Participant 01 exhibited moderate to high physiological engagement, as measured by fNIRS, marking the highest level of engagement observed during this phase. The cross-case analysis of standardized hemodynamic responses further corroborated these findings, consistently indicating an overall low level of cognitive engagement during the introductory video phase.

c. The Cognitive Engagement Congruence During Introductory Video Phase.

Table 13 organized the corresponding levels and scores for each participant's perceived and physiological engagement during the introductory video phase.

According to the results of the cognitive engagement levels and scores during this phase, three participants (Participants 02, 06, 09) demonstrated direct alignment between their perceived cognitive engagement and physiological measurements. Participants 03, 04, 05, 07, 08, and 10 exhibited partial alignment, where perceived and physiological cognitive engagement showed some correspondence. Notably, Participant 01 reported low cognitive engagement during this phase, while physiological measurements indicated a moderate to high level of hemodynamic response, suggesting a discrepancy between self-reported and physiological data.

Table 13

Perceived and Physiological Cognitive Engagement Levels During Video

Participant	Perceived Cognitive Engagement		Physiological Cognitive Engagement	
	Level	Score	Level	Score
01	Low	1	Moderate to High	3
02	Low	1	Low	1
03	Low	1	Moderate	2
04	Moderate	2	Low	1
05	Low	1	Moderate	2
06	Low	1	Low	1
07	Low	1	Moderate	2
08	Moderate	2	Low	1
09	Low	1	Low	1
10	Low	1	Moderate	2

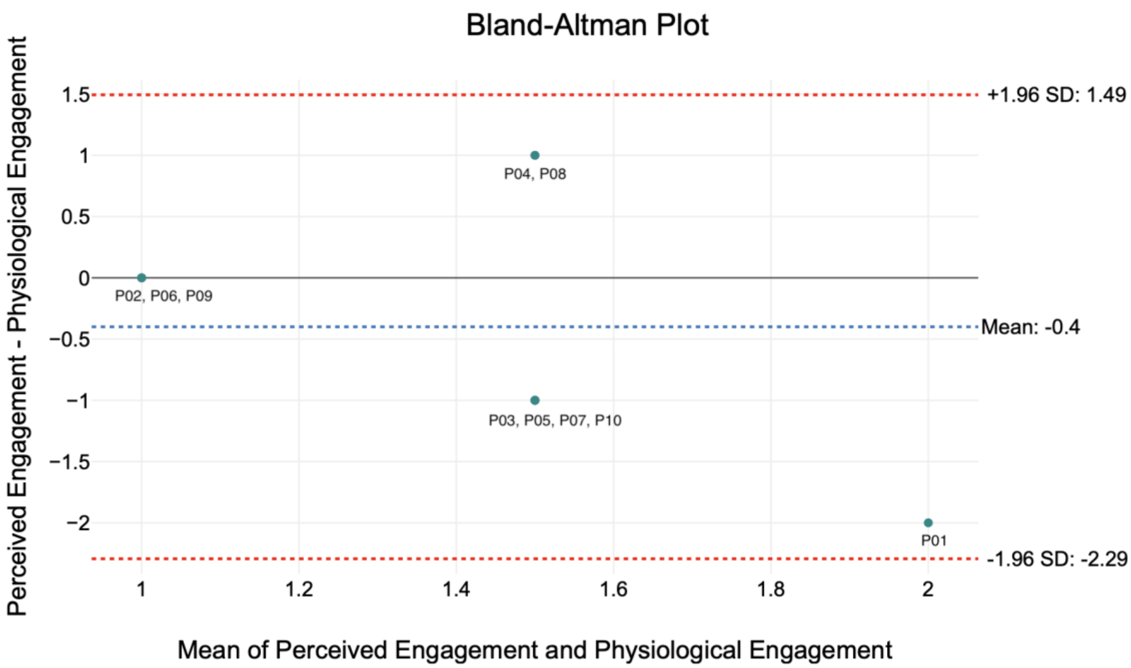
Note: Physiological Level: High: Hemodynamic Value > Mean + Standard deviation.

Moderate to High: Mean + Standard deviation > Hemodynamic Value > Mean.

Moderate: Mean - Standard deviation < Hemodynamic Value < Mean.

Low: Hemodynamic Value < Mean - Standard Deviation.

This relationship is also reflected in Figure 10 with a Bland-Altman plot. In the plot, the mean difference line is positioned at -0.4 on the y-axis, indicating that perceived cognitive engagement was, on average, slightly lower than physiological measurements. The result suggests that participants may have underestimated their cognitive engagement in the interview responses for the introductive video phase. However, all data points fall within the limits of agreement, suggesting that the self-reported engagement levels align well with the physiological measurements overall. For the three participants (Participants 02, 06, and 09) who had direct alignment between perceived and physiological measurements, their dots are located at the zero line on the y-axis. The dots overlap on the figure when the mean perceived and physiological cognitive engagement levels, along with the differences between these two measurements, are identical for specific participants.



Note. y-axis: the difference between perceived and physiological cognitive engagement ($y = Perceived\ Engagement - Physiological\ Engagement$). x-axis: the mean value of perceived and physiological cognitive engagement for each participant ($x = \frac{Perceived\ Engagement\ +\ Physiological\ Engagement}{2}$). The blue line represents the mean difference between perceived and physiological cognitive engagement for all participants. The red lines: upper and lower limit of agreement ($mean\ difference \pm 1.96 \times\ standard\ deviation$). The dots represent the difference between perceived and physiological cognitive engagement and the corresponding mean value for each participant. P#: Participant.

Figure 10

Cognitive Engagement Alignment during Introductory Video

4.3.4 Cognitive Engagement for Phase 3: Virtual Simulation

a. Perceived Cognitive Engagement During Virtual Simulation Phase.

During the virtual simulation phase, cognitive engagement levels, as reported by participants, varied but generally demonstrated significant involvement. Participant 01 reported a moderate level of cognitive engagement, marking the lowest level among all participants. Participants 02, 05, and 09 perceived their cognitive engagement as moderate to high. Participant 02 particularly noted that moments of failure followed by subsequent success were highly engaging, highlighting the impact of overcoming challenges on cognitive engagement.

The majority of participants, including Participants 03, 04, 06, 07, 08, and 10, rated their cognitive engagement as high, with Participants 03, 04, 07, 09, and 10 identifying the simulation as the most engaging activity of all. Moreover, Participants 02, 04, 05, 06, 07, and 08 acknowledged the cognitive effort required to solve the simulation tasks, indicating a substantial demand for their cognitive resources.

Additionally, all participants, except Participants 02 and 06, successfully connected previous knowledge to the simulation tasks, enhancing the depth of their engagement. Notably, Participants 04, 06, 07, 08, and 10 reported that the simulation increased their interest in the subject and inspired them to explore the topic further.

b. Physiological Cognitive Engagement During Virtual Simulation Phase.

The assessment of physiological cognitive engagement during the virtual simulation phase revealed relatively high levels of engagement across all participants, particularly during the segments identified as authentic by participants. Six participants—Participants 01, 03, 04, 05, 08, and 10—demonstrated high levels of physiological measurements. Three participants—Participants 02, 06, and 09—exhibited moderate to high levels. Notably, Participant 07 exhibited a moderate level of physiological engagement, marking the lowest level of engagement observed during this phase. Despite some variability in engagement among participants, none exhibited a low level of physiological engagement. The cross-case analysis of standardized hemodynamic responses further supported these results, consistently indicating a higher level of cognitive engagement during the virtual simulation phase.

c. The Cognitive Engagement Congruence During Virtual Simulation Phase.

For the virtual simulation phase, Table 14 presents the levels and scores for each participant's perceived cognitive engagement and physiological cognitive engagement from the authentic learning segments.

For the Virtual Simulation Phase of the learning module, the comparative analysis of cognitive engagement levels and scores reveals a notably higher consistency between participants' perceived engagement and physiological measures. Six participants (Participants 02, 03, 04, 08, 09, and 10) demonstrated direct alignment between their self-reported cognitive engagement and physiological measurements. Participants 05 and 06 exhibited partial alignment. Discrepancies between perceived and physiological engagement were observed in Participants 01 and 07. Overall, the results demonstrate an enhanced alignment of the two measurements in the authentic segments of the virtual simulation phase, suggesting that as participants engaged with interactive and challenging tasks in the simulation, their self-perceived engagement more accurately reflected their physiological responses.

Figure 11 visualizes the alignment between participants' perceived and physiological cognitive engagements during the simulation phase. In the Bland-Altman plot, the mean difference line on the y-axis is positioned at 0, indicating no systematic bias between the two measurements of cognitive engagement during this phase. The dots of the six participants who showed direct alignment fall on the mean difference line at zero on the y-axis.

Table 14

Perceived and Physiological Cognitive Engagement Levels During Simulation

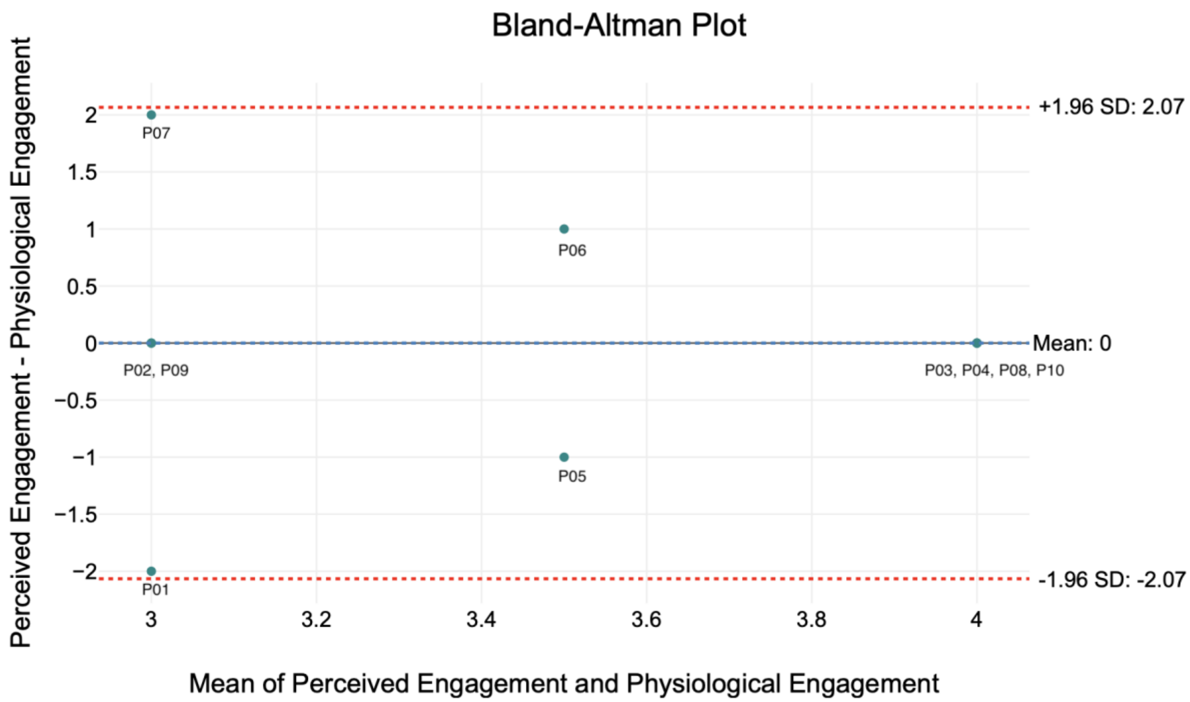
Participant	Perceived Cognitive Engagement		Physiological Cognitive Engagement		
	Level	Score	Level	Score	Identified Authentic Segments
01	Moderate	2	High	4	248s - 292s
02	Moderate to High	3	Moderate to High	3	78s - 108s, 121s - 180s, 241s - 300
03	High	4	High	4	7s - 67s, 228s - 289s
04	High	4	High	4	56s -122s, 129s - 226s, 235s - 283s
05	Moderate to High	3	High	4	182s - 231s
06	High	4	Moderate to High	3	43s-114s, 210s-261s
07	High	4	Moderate	2	Entire Phase
08	High	4	High	4	84s-111s, 126s-155s, 249s-300s
09	Moderate to High	3	Moderate to High	3	106s - 177s, 236s - 300s
10	High	4	High	4	96s - 139s, 155s - 222s, 271s - 300s

Note: Physiological Level: High: Hemodynamic Value > Mean + Standard deviation.

Moderate to High: Mean + Standard deviation > Hemodynamic Value > Mean.

Moderate: Mean - Standard deviation < Hemodynamic Value < Mean.

Low: Hemodynamic Value < Mean - Standard Deviation.



Note. y-axis: the difference between perceived and physiological cognitive engagement ($y = Perceived\ Engagement - Physiological\ Engagement$). x-axis: the mean value of perceived and physiological cognitive engagement for each participant ($x = \frac{Perceived\ Engagement\ +Physiological\ Engagement}{2}$). The blue line represents the mean difference between perceived and physiological cognitive engagement for all participants. The red lines: upper and lower limit of agreement ($mean\ difference \pm 1.96 \times\ standard\ deviation$). The dots represent the difference between perceived and physiological cognitive engagement and the corresponding mean value for each participant. P#: Participant.

Figure 11

Cognitive Engagement Alignment during Virtual Simulation

All data points fall within the limits of agreement, suggesting that participants' self-reported engagement levels are well-aligned with their physiological measurements. The dots overlap on the figure for some participants since the mean values for perceived and physiological cognitive engagement levels, along with the differences between the two measurements, are identical.

4.3.5 Cognitive Engagement for Phase 4: Debriefing

Given the continuity of the entire learning module, the debriefing session seamlessly transitioned into the semi-structured interview without any break. As a result, participants did not explicitly discuss their engagement levels during the interview. However, the debriefing session allowed participants to articulate their understanding and reflect on their learning outcomes, which are crucial aspects of the authentic learning experience. Consequently, the assessment of cognitive engagement during this phase relies primarily on the physiological data captured through the fNIRS equipment.

Table 15

Physiological Cognitive Engagement during Debriefing

Participant	Physiological Cognitive Engagement
01	Moderate to High
02	Moderate to High
03	Moderate to High
04	Low
05	High
06	Moderate
07	Moderate to High
08	Moderate to High
09	High
10	Moderate

Note: Physiological Level: High: Hemodynamic Value > Mean + Standard deviation.

Moderate to High: Mean + Standard deviation > Hemodynamic Value > Mean.

Moderate: Mean - Standard deviation < Hemodynamic Value < Mean.

Low: Hemodynamic Value < Mean - Standard Deviation.

During the debriefing session, participants engaged in reflective activities, sharing their experiences and learning outcomes from the entire module. Most participants exhibited high or moderate to high levels of physiological engagement during this phase. However, Participant 06 and Participant 10 showed moderate levels of engagement, while Participant 04 displayed a low level of physiological engagement. The cross-case analysis of standardized hemodynamic values further corroborated these findings, indicating overall strong physiological cognitive engagement during this phase. Table 15 presents the results of categorized physiological cognitive engagement levels of this phase.

4.3.6 Summary of Cognitive Engagement

In summary, this section delineates the findings from data analysis pertaining to Research Question Two, which investigates the levels of perceived and physiological cognitive engagement experienced by students across four distinct learning phases and the alignment between the two measurements.

The authentic segments during the reading and virtual simulation phases consistently exhibited high levels of cognitive engagement, as evidenced by both perceived engagement and physiological responses. For instance, several participants found the reading phase highly engaging, particularly due to its relevance and its ability to connect new information with their prior knowledge. Physiologically, while engagement levels varied among participants, a noticeable peak in cognitive responses was observed when participants encountered the formulas and real-world examples in the reading material. Similarly, the virtual simulation phase prompted substantial cognitive effort and the application of theoretical knowledge, resulting in elevated levels of both perceived and physiological engagement, especially in the segments identified as authentic by the participants. In contrast, the introductory video phase was generally perceived as the least engaging, with minimal mentions of cognitive involvement during interviews. This perception was corroborated by physiological data, which indicated low engagement across most participants. Finally, during the debriefing phase, physiological data revealed strong hemodynamic responses as participants summarized their learning outcomes, suggesting that the reflective processes during this phase stimulated considerable cognitive activity.

The alignment analysis of cognitive engagement reveals generally strong alignment during the authentic segments of the reading and simulation phases, as well as the introductory video phase. This alignment illuminates the validity of both self-reported and physiological measurements despite their inherently distinct characteristics. Interview responses capture participants' perceptions of cognitive effort, often emphasizing specific moments that stood out during the learning process. In contrast, physiological measurements, as obtained through the fNIRS device, provide a continuous record of cognitive activity throughout the learning module. This methodological difference explains why perceived engagement sometimes diverges from physiological responses at certain points; physiological data encompass a broader range of cognitive activity that may not always correspond with the moments participants most vividly recall or consider significant. However, as we extract the segments that participants perceived as authentic to them, the alignment between the two measurements shows a high degree of consistency.

4.4 Results for Research Question Three

This section addresses Research Question 3: What relationship patterns emerge between students' perceived authenticity and cognitive engagement? This question is crucial for understanding how authenticity influences students' physiological cognitive processes. The inquiry is divided into two sub-questions:

i. What relationship patterns emerge between students' perceived authenticity and perceived cognitive engagement?
ii. What relationship patterns emerge between students' perceived authenticity and physiological cognitive engagement?

By comparing perceived and physiological data across the consecutive learning phases—Reading, Introductory Video, Virtual Simulation, and Debriefing—this section aims to identify the patterns that reveal how cognitive engagement is triggered by authentic learning experiences. Similar to the analysis of research question 2, Participants' cognitive engagement and their perceived authenticity levels were converted to 4-point scale variables: 4 represents high cognitive engagement or authenticity, 3 corresponds to moderate-to-high engagement or authenticity, 2 indicates moderate engagement or authenticity, and 1 reflects low engagement or authenticity.

These converted scores were then used to analyze the correlation between the two perceived authenticity and cognitive engagement. A difference of zero between the perceived authenticity score and cognitive engagement score indicates a high level of correlation, suggesting strong alignment between the two variables. A difference of one indicates moderate similarity, reflecting partial alignment. However, when the difference equals or exceeds two, it signifies minimal or no relationship between the variables, signaling a clear mismatch between perceived authenticity and cognitive engagement levels. Given the ordinal nature of the data and the relatively small sample size, Kendall's Tau was chosen to calculate this correlation.

Kendall's Tau is a non-parametric correlation coefficient designed for ordinal data and is particularly effective in handling datasets with small sample sizes and tied ranks (Kendall, 1938). This makes it an ideal choice for situations where variables are converted to ordinal scales, such as in this study, where cognitive engagement and perceived authenticity are represented on a 4-point scale.

Kendall's Tau measures the correspondence between the rankings of the two variables by comparing the number of concordant and discordant pairs in the data. A pair of observations is concordant if the ranks for both variables agree (i.e., higher ranks on one variable correspond to higher ranks on the other). Conversely, a pair is discordant if higher ranks on one variable correspond to lower ranks on the other. The coefficient ranges from -1 to +1, where +1 indicates perfect positive correlation, -1 indicates perfect negative correlation, and 0 indicates no correlation (Kendall & Gibbons, 1990). Kendall's Tau is particularly advantageous when the assumptions of linearity and normality are not met, as it is less sensitive to outliers and skewed distributions (Siegel & Castellan, 1988).

The interpretation of Kendall's Tau coefficient is similar to other correlation measures like Pearson's, but it accounts for ranks rather than values since it is based on ordinal data (Kendall, 1938). The strength of correlation can be interpreted as follows:

- 0.0 < 0.1: No correlation – indicates very weak or no association between variables.
- 0.1 < 0.3: Low correlation – suggests a slight relationship between the two variables, but the association is weak.
- 0.3 < 0.5: Moderate correlation – indicates a noticeable, moderate association between the variables.
- 0.5 < 0.7: High correlation – suggests a strong relationship between the variables.
- 0.7 < 1.0: Very high correlation – implies an extremely strong association, where the ranks of one variable closely follow the ranks of the other.

This categorization is widely accepted for interpreting Kendall's Tau, particularly in small or ordinal datasets. These benchmarks help determine the practical significance of the relationship, even if the correlation is not perfect (Dancey & Reidy, 2007; Siegel & Castellan, 1988).

4.4.1 Relationship Patterns Between Perceived Authenticity and Perceived Cognitive Engagement

The analysis of interview responses reveals a distinct pattern linking perceived authenticity with perceived cognitive engagement among the participants during the learning module. As discussed in Chapter 3 and the results for research question two, cognitive engagement during the debriefing phase is primarily evaluated using physiological data. Therefore, this section focuses on the first three phases of the learning module: reading, introductory video, and virtual simulation.

In the reading phase, most participants demonstrated positive correlations between perceived authenticity and perceived cognitive engagement, although the strength of these correlations varied. Notably, only two participants (Participants 05 and 06) showed clear discordance. Both reported moderate levels of perceived authenticity but indicated high levels of cognitive engagement.

The introductory video phase, designed as an operational guide for the virtual simulation, lacked elements from all three dimensions of authentic learning, making it less memorable to participants. Consequently, no participants referenced this phase when discussing perceived authenticity, and all were assigned low authenticity levels. As discussed in the results for research question two, three participants reported their cognitive engagement in the interview. Participant 01 reported a low level of cognitive engagement, while other participants—except for

Participants 04 and 08—did not mention feeling engaged during this phase, which aligns directly with the low authenticity level of the introductory video. This demonstrates a clear correlation, where the lack of authenticity corresponds to reduced engagement. Participants 04 and 08 reported moderate levels of cognitive engagement. This variance suggests that individual factors, such as learning preferences or anticipation of the upcoming simulation activity, may influence their perceived cognitive engagement despite the low authenticity of the video phase. For example, Participant 04 indicated that the video evoked interest in the simulation, while Participant 08 noted that the expectation of the forthcoming activity maintained the focus during the video.

During the virtual simulation phase, a strong positive correlation between perceived authenticity and perceived cognitive engagement was broadly evident across participants. This phase was recognized as highly authentic because it incorporated all three dimensions of authentic learning. However, Participants 01 and 07 exhibited discordance during this phase. Participant 01 reported a high level of perceived authenticity but only a moderate level of cognitive engagement. On the other hand, Participant 07 perceived moderate authenticity but reported a high level of cognitive engagement.

Table 16 summarizes the perceived authenticity and perceived cognitive engagement scores for the entire learning module, as well as the Kendall's Tau correlation analysis results, showing the correlation coefficient (r) and the p-value (p).

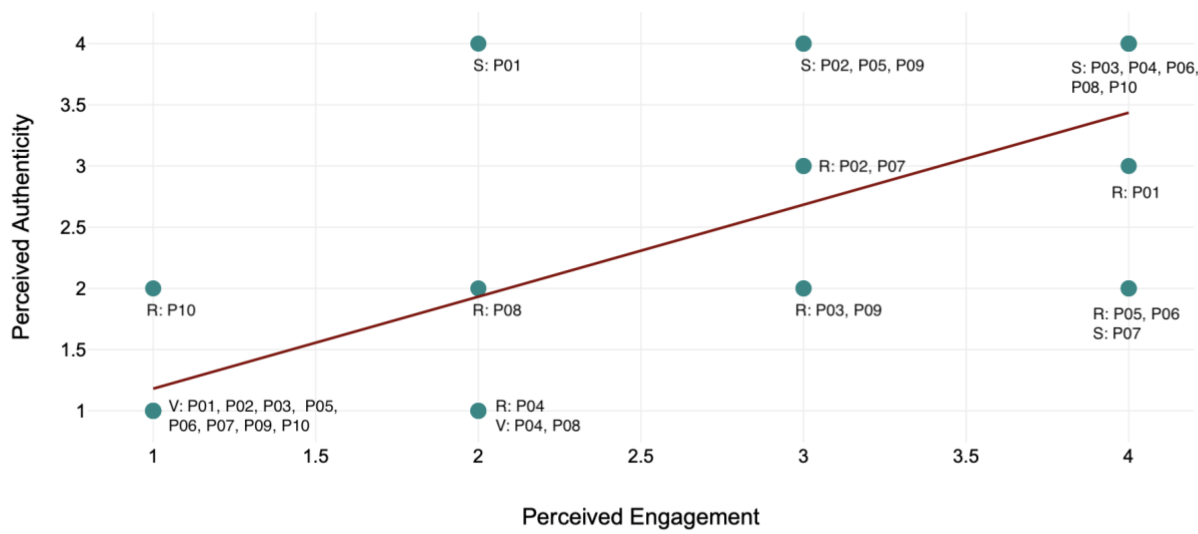
A Kendall's Tau correlation was conducted to assess the relationship between participants' perceived authenticity and perceived cognitive engagement during the learning module. The result of Kendall's Tau correlation showed that there was a very high positive correlation between perceived authenticity and perceived cognitive engagement. The correlation between perceived authenticity and perceived cognitive engagement was statistically significant, $r(28) = 0.77, p = 0.001$. This result implies that as perceived authenticity increases, cognitive engagement tends to increase as well.

Table 16

Perceived Authenticity and Perceived Cognitive Engagement Levels with Kendall's Tau Correlation

Learning Phase	Participant	Perceived Authenticity		Perceived Cognitive Engagement	
		Level	Score	Level	Score
Reading	01	Moderate to High	3	High	4
	02	Moderate to High	3	Moderate to High	3
	03	Moderate	2	Moderate to High	3
	04	Low	1	Moderate	2
	05	Moderate	2	High	4
	06	Moderate	2	High	4
	07	Moderate to High	3	Moderate to High	3
	08	Moderate	2	Moderate	2
	09	Moderate	2	Moderate to High	3
	10	Moderate	2	Low	1
Introductory Video	01	Low	1	Low	1
	02	Low	1	Low	1
	03	Low	1	Low	1
	04	Low	1	Moderate	2
	05	Low	1	Low	1
	06	Low	1	Low	1
	07	Low	1	Low	1
	08	Low	1	Moderate	2
	09	Low	1	Low	1
	10	Low	1	Low	1
Virtual Simulation	01	High	4	Moderate	2
	02	High	4	Moderate to High	3
	03	High	4	High	4
	04	High	4	High	4
	05	High	4	Moderate to High	3
	06	High	4	High	4
	07	Moderate	2	High	4
	08	High	4	High	4
	09	High	4	Moderate to High	3
	10	High	4	High	4
Kendall's Tau Value			$r(28) = 0.77$	$p = 0.001$	

Figure 12 presents each participant's perceived authenticity and perceived cognitive engagement, as well as the relationship between the two variables. Low levels of both perceived authenticity and cognitive engagement predominantly appear during the introductory video phase, whereas higher levels were mostly reported during the virtual simulation phase. The discordances are clearly identifiable by the dots that deviate farther from the regression line, particularly for Participants 05 and 06 in the reading phase, as well as for Participants 01 and 07 in the virtual simulation phase. These deviations highlight instances where participants' reported authenticity levels did not align with their cognitive engagement.



Note. Y-axis: Perceived Authenticity. X-axis: Perceived Cognitive Engagement. The red line represents the regression line. The dots represent the perceived authenticity and perceived cognitive engagement of each participant during each learning phase. R: Reading. V: Introductory Video. S: Virtual Simulation. P#: Participant.

Figure 12

Relationship of Perceived Authenticity and Perceived Cognitive Engagement

4.4.2 Relationship Patterns Between Perceived Authenticity and Physiological Cognitive Engagement

The comparative analysis of the learning module reveals consistent patterns when aligning perceived authenticity with physiological cognitive engagement levels. The results indicated a strong alignment between perceived authenticity and physiological cognitive engagement for most participants.

In the reading phase, the relationship between perceived authenticity and physiological cognitive engagement during the segments identified as authentic by participants became more pronounced compared to the relationship between perceived authenticity and perceived cognitive engagement. Notably, Participant 05 was the only participant to exhibit a clear mismatch between the two variables.

The Introductory Video Phase displayed expected results regarding the relationship between authenticity level and physiological cognitive engagement. Nine out of ten participants exhibited some degree of correlation between the two variables. Specifically, five participants (Participants 03, 04, 05, 08, and 09) demonstrated a high level of correlation, meaning their physiological engagement closely matched their perceived authenticity levels. Four participants (Participants 02, 06, 07, and 10) showed partial alignment, suggesting that their physiological cognitive engagement generally aligned with the perceived authenticity levels. Participant 01 presented an exception, as this individual reported low perceived authenticity but exhibited moderate to high physiological engagement, which was the highest level recorded among all participants. Notably, this phase did not generate any high physiological cognitive engagement level across the group, and the participants generally exhibited lower cognitive engagement. The results reinforce the notion that the video's low authenticity level could negatively impact cognitive engagement.

During the virtual simulation phase, all participants presented a robust positive correlation between perceived authenticity and physiological cognitive engagement. As a highly authentic learning activity, there was no mismatch between the two variables, which marked an improvement compared to the previous analysis, where two discrepancies were observed between perceived authenticity and perceived cognitive engagement. Especially for Participants 01 and 07, who had previously stood out due to a lack of correlation between perceived authenticity and perceived cognitive engagement. Participant 07 reported a moderate level of perceived authenticity paired with a high level of perceived cognitive engagement. Still, the moderate authenticity level was perfectly aligned with the moderate physiological cognitive engagement. In the case of Participant 01, while initially reported a moderate level of perceived cognitive engagement, the high perceived authenticity during this phase perfectly matched the high level of physiological cognitive engagement, highlighting a clear improvement.

In the debriefing phase, the majority of participants (Participants 01, 02, 03, 05, 07, 08, 09) demonstrated a positive correlation that associated high levels of authenticity with high or moderate to high levels of physiological engagement. However, three participants (Participants 04, 06, and 10) exhibited discrepancies between their perceived authenticity and physiological engagement. Notably, Participant 04 presented a unique case, showing low physiological cognitive engagement during the debriefing session, in contrast to the other participants, who generally displayed enhanced engagement during this reflective phase.

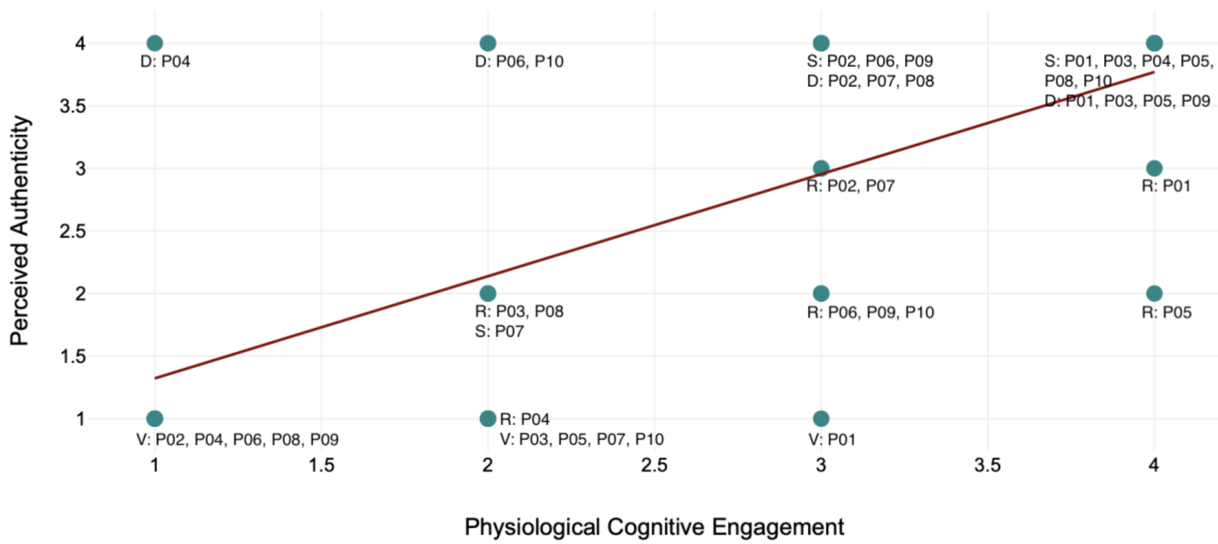
Table 17

Perceived Authenticity and Physiological Cognitive Engagement Levels with Kendall's Tau Correlation

Learning Phase	Participant	Perceived Authenticity		Physiological Cognitive Engagement		
		Level	Score	Level	Score	Identified Authentic Segments
Reading	01	Moderate to High	3	High	4	122s - 180s
	02	Moderate to High	3	Moderate to High	3	Entire Phase
	03	Moderate	2	Moderate	2	118s - 176s
	04	Low	1	Moderate	2	Entire Phase
	05	Moderate	2	High	4	146s - 180s
	06	Moderate	2	Moderate to High	3	Entire Phase
	07	Moderate to High	3	Moderate to High	3	52s – 180s
	08	Moderate	2	Moderate	2	Entire Phase
	09	Moderate	2	Moderate to High	3	63s – 125s
	10	Moderate	2	Moderate to High	3	Entire Phase Non-Authentic
Introductory Video	01	Low	1	Moderate to High	3	Entire Phase Non-Authentic
	02	Low	1	Low	1	Entire Phase Non-Authentic
	03	Low	1	Moderate	2	Entire Phase Non-Authentic
	04	Low	1	Low	1	Entire Phase Non-Authentic
	05	Low	1	Moderate	2	Entire Phase Non-Authentic
	06	Low	1	Low	1	Entire Phase Non-Authentic
	07	Low	1	Moderate	2	Entire Phase Non-Authentic
	08	Low	1	Low	1	Entire Phase Non-Authentic
	09	Low	1	Low	1	Entire Phase Non-Authentic
	10	Low	1	Moderate	2	Entire Phase Non-Authentic

Learning Phase	Participant	Perceived Authenticity		Physiological Cognitive Engagement		
		Level	Score	Level	Score	Identified Authentic Segments
Virtual Simulation	01	High	4	High	4	248s - 292s
	02	High	4	Moderate to High	3	78s - 108s, 121s - 180s, 241s - 300s
	03	High	4	High	4	7s - 67s, 228s - 289s
	04	High	4	High	4	56s -122s, 129s - 226s, 235s - 283s
	05	High	4	High	4	182s - 231s
	06	High	4	Moderate to High	3	43s-114s, 210s-261s
	07	Moderate	2	Moderate	2	Entire Phase
	08	High	4	High	4	84s-111s, 126s-155s, 249s-300s
	09	High	4	Moderate to High	3	106s - 177s, 236s - 300s
	10	High	4	High	4	96s - 139s, 155s - 222s, 271s - 300s
Debriefing	01	High	4	High	4	Entire Phase
	02	High	4	Moderate to High	3	Entire Phase
	03	High	4	High	4	Entire Phase
	04	High	4	Low	1	Entire Phase
	05	High	4	High	4	Entire Phase
	06	High	4	Moderate	2	Entire Phase
	07	High	4	Moderate to High	3	Entire Phase
	08	High	4	Moderate to High	3	Entire Phase
	09	High	4	High	4	Entire Phase
	10	High	4	Moderate	2	Entire Phase
Kendall's Tau Value				$r(38) = 0.76$	$p < 0.001$	

The detailed results of perceived authenticity and physiological cognitive engagement scores for the entire learning module, as well as the Kendall's Tau correlation results, are presented in Table 17. Kendall's Tau correlation showed that there was a very high, positive correlation between Perceived Authenticity and Physiological Cognitive Engagement. The correlation between Perceived Authenticity and Physiological Cognitive Engagement was statistically significant, $r(38) = 0.76, p =< 0.001$. This suggests that the two variables are highly correlated, meaning that as perceived authenticity increases, physiological cognitive engagement tends to rise accordingly.



Note. Y-axis: Perceived Authenticity. X-axis: Perceived Cognitive Engagement. The red line represents the regression line. The dots represent the perceived authenticity and perceived cognitive engagement of each participant during each learning phase. R: Reading. V: Introductory Video. S: Virtual Simulation. D: Debriefing. P#: Participant.

Figure 13

Relationship of Perceived Authenticity and Physiological Cognitive Engagement

Figure 13 presents the relationship between each participant's perceived authenticity and physiological cognitive engagement. Similar to the patterns observed in Figure 12, low levels of both perceived authenticity and physiological cognitive engagement are predominantly seen during the introductory video phase. Higher levels of perceived authenticity and physiological cognitive engagement are most commonly observed during the virtual simulation and debriefing phases. The dots that deviate significantly from the regression lines represent discordances, including Participants 05 in the reading phase, Participants 01 in the introductory video phase, and Participants 04, 06, and 10 in the debriefing phase. These discrepancies indicate cases where participants' reported perceptions of authenticity did not align with their physiological engagement levels.

4.4.3 Summary of Patterns Between Perceived Authenticity and Cognitive Engagement

The analysis revealed strong positive correlations between both perceived and physiological cognitive engagement with perceived authenticity. Notably, the relationship between physiological cognitive engagement and authenticity proved to be more robust overall. Although the correlation coefficient for perceived cognitive engagement ($r(28) = 0.77$) on perceived authenticity is slightly higher than that for physiological cognitive engagement ($r(38) = 0.76$), it is attributed to the exclusion of the debriefing phase from the analysis of perceived cognitive engagement and authenticity. When the debriefing phase is excluded from the analysis of physiological cognitive engagement and authenticity, the correlation coefficient increases significantly to $r(38) = 0.9$, underscoring a stronger alignment between physiological cognitive engagement and authenticity.

In the reading phase, both self-reported and physiological cognitive engagements demonstrated strong correlations with perceived authenticity, with physiological responses particularly evident in the segments participants identified as authentic. This positive correlation suggests that the authenticity of content plays a critical role in sustaining cognitive engagement, especially when learners perceive the material as relevant to real-world applications.

The introductory video phase, by contrast, received limited attention from participants and was consistently rated as having lower perceived authenticity. These perceptions align with the minimal authentic learning elements of this phase. The sparse references during the interviews and the general correspondence between low authenticity and reduced physiological responses emphasize the necessity of authentic content to stimulate cognitive engagement.

The virtual simulation phase revealed a consistently robust positive correlation between perceived authenticity and cognitive engagement. All participants exhibited either direct or partial correlations in the authentic learning segments of the phase. Physiological responses closely mirror the increased perceived authenticity reported during the simulation's complex problem-solving tasks. The patterns observed across both perceived and physiological data streams during the virtual simulation phase confirm that heightened perceptions of authenticity tend to enhance cognitive engagement.

The debriefing phase also revealed a positive correlation between perceived authenticity and cognitive engagement, particularly as participants reflected on their learning outcomes. This phase further validated the link between reflective processes and increased cognitive engagement, supported by physiological data.

In conclusion, the results section for research question three reveals that authentic learning sections—identified through semi-structured interview responses and encompassing specific segments of the reading and virtual simulation phases, as well as the entire debriefing phase—elicited significantly higher cognitive engagement levels compared to the non-authentic section (the introductory video phase). Additionally, the comprehensiveness of a learning activity in terms of authenticity also impacts participants' cognitive engagement. For example, the virtual simulation phase, recognized as a three-dimensional authentic learning activity, showed higher physiological cognitive engagement than the reading phase, which is categorized as a one-dimensional authentic learning activity.

CHAPTER 5

CONCLUSION AND DISCUSSION

This chapter provides a comprehensive conclusion and discussion of the research findings presented in Chapter 4. The primary focus of this study was to investigate the relationship between authenticity and cognitive engagement in a science learning module encompassing four learning activities. This investigation was conducted using a mixed-methods case study design, incorporating both qualitative data from semi-structured interviews and quantitative data from functional near-infrared spectroscopy (fNIRS) measurements.

The research aimed to answer three key questions regarding participants' perceptions of authenticity, their cognitive engagement during learning, and the relationship between authenticity and cognitive engagement. Understanding these questions is crucial as it helps elucidate how different dimensions of authenticity within a learning activity impact students' engagement levels. The subsequent sections of this chapter will summarize the key findings of the study, such as the authenticity of each learning phase, the alignment between perceived and physiological cognitive engagement, and the relationship between authentic learning and cognitive engagement. Furthermore, this chapter will discuss the implications of these findings for both theory and instructional practices and offer recommendations for future research.

5.1 Summary of Findings

This section provides an overview of the key findings from this study, structured around three central themes: authenticity, cognitive engagement, and the relationship between authenticity and cognitive engagement. First, the analysis of authenticity across all phases of the learning module reveals important insights into how students interpret and connect with the learning activities and content. Second, the study assesses participants' cognitive engagement using two distinct measurement approaches: self-reported perceptions and physiological data obtained through fNIRS. The comparison between perceived and physiological cognitive engagement provides a unique perspective on the alignment—or misalignment—between participants' reported experiences and their physiological responses. This comparison not only triangulates the findings from these two data sets but also identifies potential discrepancies that could inform future practices and research. Lastly, and most importantly, the exploration of the relationship between authenticity and cognitive engagement reveals how the authenticity of learning activities influences learners' perception of their cognitive effort and corresponding physiological responses. These findings reflect the research objectives and are crucial for understanding the overarching inquiry: how different dimensions of authenticity in learning activities impact participants' cognitive engagement levels.

5.1.1 The Key Findings of Perceived Authenticity

The analysis of the perceived authenticity across the different phases of the learning module revealed that each phase varied in the extent to which it embodied the dimensions of authentic learning—Authentic Learning Content, Authentic Learning Activities, and Authentic Outcome Assessment.

a. Perceived Authenticity for Reading.

The reading phase emerged as a one-dimensional authentic learning activity, primarily focusing on Authentic Learning Content. Seven out of ten participants highlighted the real-world applicability of the reading material, with specific emphasis on formulas and examples that participants recognized as directly relevant to real-life scenarios. However, this activity lacked elements from the Authentic Learning Activities and Authentic Outcome Assessment dimensions. The absence of these components indicates that, while the content of the reading phase was perceived as authentic, the activity itself lacked the complexity and dynamism necessary for a comprehensive authentic learning experience. Additionally, the phase did not provide integrated feedback or assessment, which is essential for participants to evaluate their understanding and apply the knowledge in a practical context.

b. Perceived Authenticity for Introductory Video.

The introductory video phase was perceived as the least authentic. None of the participants referenced this phase when discussing authenticity, and Participant 03 explicitly found it unengaging and uninformative. The video lacked elements from all three dimensions of authentic learning, serving merely as an operational guide without embedding scientific concepts or fostering connections to real-world applications.

c. Perceived Authenticity for Virtual Simulation.

The virtual simulation phase emerged as the most authentic learning activity. Nearly all participants, except Participant 07, recognized it as embodying key elements of authentic learning. The simulation provided an interactive, hands-on experience that integrated theoretical knowledge into a simulated real-world context. The simulation featured ill-defined problems, which required participants to invest significant time and diverse strategies to overcome challenges. Moreover, the inclusion of real-time feedback provided an integrated assessment mechanism, fostering continuous improvement through direct application. Collectively, the virtual simulation encompassed all three dimensions of authentic learning.

d. Perceived Authenticity for Debriefing.

For the debriefing phase, although participants did not explicitly discuss the debriefing phase during the interview, its design inherently incorporated critical elements. The activity facilitated metacognition and integrated assessment from the Authentic Learning Activities dimension and Authentic Outcome Assessment dimension, encouraging reflection on learning experiences, self-assessment, and consideration of improvements. Through guided discussions, participants demonstrated acquired knowledge, received feedback, and connected experiences to broader concepts and real-world applications. As a result, the debriefing session was categorized as a two-dimensional authentic learning activity.

e. Synthesis of Findings.

In conclusion, the four phases of the science learning module were classified into four distinct types of learning activities based on the authentic learning framework. The introductory video phase functioned as a non-authentic learning activity, lacking elements from all three dimensions. The reading phase was classified as a one-dimensional authentic learning activity, incorporating only the Authentic Learning Content dimension through its real-world relevance. The debriefing phase embodied two dimensions—Authentic Learning Activities and Authentic Outcome Assessment—positioning it as a two-dimensional authentic learning activity by facilitating metacognition and integrated assessment. Finally, the virtual simulation phase encompassed all three dimensions, representing a three-dimensional authentic learning activity that allowed students to experience relevant content, interactive problem-solving processes, and receive immediate feedback.

5.1.2 The Key Findings of Cognitive Engagement—Perceived and Physiological Aspects

The analysis of participants' cognitive engagement across the four phases of the learning module, combined with the examination of the alignment between self-reported cognitive engagement and physiological measurements obtained through fNIRS, provided crucial information into the variations in cognitive engagement across different learning activities. By integrating perceived and physiological data, the study triangulated two distinct methods to corroborate each other. The findings provide a comprehensive understanding of cognitive engagement dynamics and validate the use of both self-reported and physiological data in assessing cognitive engagement.

a. Cognitive Engagement for Reading.

During the reading phase, participants exhibited varied levels of cognitive engagement. A majority of participants reported heightened interest and attention. Participants 01, 05, and 06 specifically identified this phase as the most focused. In contrast, Participant 04 found the reading lacked a clear objective, and Participant 07 admitted to not being highly focused, diminishing their perceived engagement. Physiological data collected via fNIRS revealed that participants who identified specific segments as authentic demonstrated relatively higher levels of hemodynamic response, further validating their self-reports. Notably, no participant exhibited a low level of physiological engagement during this phase.

Comparing perceived cognitive engagement with physiological data, a strong alignment was observed: seven out of ten participants exhibited direct alignment, and two showed partial alignment. Participant 10 displayed a significant discrepancy, suggesting that the self-reported engagement did not fully correspond with physiological indicators. A Bland-Altman plot further illustrated this alignment, with data points from nine participants falling within acceptable limits and indicating no systematic bias between the two measures.

b. Cognitive Engagement for Introductory Video.

The introductory video phase was reported as the least engaging by participants. It was seldom mentioned in interviews, and when it was, participants like Participant 01 described it as the least interesting phase with decreased focus. Only Participants 04 and 08 expressed a positive attitude, noting that the video sparked interest in the upcoming simulation and maintained their attention. Overall, the general sentiment was one of indifference toward this phase. Physiological data further supported this observation, recording low or moderate levels of engagement across most participants, except for Participant 01, who exhibited moderate to high level of physiological engagement.

Alignment between perceived and physiological cognitive engagement during this phase was less consistent compared to the reading and virtual simulation phases. Three participants showed direct alignment, while six participants exhibited partial alignment. Participant 01 demonstrated a discrepancy, with physiological data indicating higher engagement than self-reported. The Bland-Altman plot suggested participants might have underestimated their engagement during this phase, though overall alignment remained within acceptable limits.

c. Cognitive Engagement for Virtual Simulation.

The virtual simulation phase was characterized by high levels of cognitive engagement, both perceived and physiological. Participants noted that the complex problem-solving tasks involved in the simulation were particularly engaging, and many acknowledged the cognitive effort required to navigate and overcome the challenges. Only Participant 01 reported a moderate level of perceived cognitive engagement, the lowest among participants. Physiological measurements corroborated these self-reports, with six participants demonstrating high physiological engagement and three showing moderate to high levels. Participant 07 exhibited the lowest physiological engagement during this phase, with a moderate level.

Alignment between perceived and physiological engagement was notably high in this phase. Six participants showed direct alignment, while two participants had partial alignment. Discrepancies were observed with Participants 01 and 07, where self-reported engagement did not fully match physiological data. The Bland-Altman plot indicated no systematic bias, with all data points falling within acceptable limits, reinforcing the strong congruence between the two measures during this highly engaging activity.

d. Cognitive Engagement for Debriefing.

In the debriefing phase, participants did not explicitly discuss their cognitive engagement during interviews, as the session seamlessly transitioned into the semi-structured interview. However, this phase involved reflective activities where participants articulated their understanding and learning outcomes. Physiological data indicated that most participants exhibited high or moderate to high levels of cognitive engagement during this phase, likely due to metacognitive processes stimulating considerable cognitive activity. Participants 06 and 10 demonstrated moderate engagement, while Participant 04 displayed low physiological engagement, suggesting that the reflective process may not have been equally engaging for all participants.

e. Overall Alignment of Cognitive Engagement Measures.

Overall, the alignment between perceived and physiological cognitive engagement varied by phase but generally showed strong correspondence, especially during the more authentic learning activities. The reading and virtual simulation phases demonstrated robust alignment, suggesting that participants' self-reports closely matched their physiological responses when engaged in tasks requiring active cognitive effort. The introductory video phase exhibited less alignment, with some participants underestimating their engagement levels. These discrepancies may be attributed to the limitations of self-reported measures in capturing continuous cognitive fluctuations.

The use of fNIRS provided valuable real-time insights into cognitive engagement, capturing subtle shifts in cognitive states that self-reports might miss. The alignment analysis, utilizing methods such as Bland-Altman plots, validated the congruence between participants' perceptions and physiological data, reinforcing the reliability of combining both measures to assess cognitive engagement comprehensively.

5.1.3 The Relationship between Authenticity and Cognitive Engagement

The analysis examined the relationship between students' perceived authenticity and cognitive engagement across the four phases of the learning module. By integrating self-reported and physiological data, the study identified patterns that reveal how authentic learning experiences influence cognitive engagement.

a. Perceived Authenticity and Perceived Cognitive Engagement.

The findings indicate a clear positive correlation between perceived authenticity and perceived cognitive engagement during the learning module. During the reading phase, participants generally found the reading material authentic due to its real-world relevance, which corresponded with higher levels of reported cognitive engagement. Exceptions included Participants 05 and 06, who reported moderate perceived authenticity but high cognitive engagement, suggesting that other factors may have influenced their perceived engagement levels. In the introductory video phase, all participants perceived low authenticity. This corresponded with low perceived cognitive engagement, with most participants expressing indifference toward this phase. Participants 04 and 08 were exceptions, reporting moderate cognitive engagement despite the low authenticity, possibly due to anticipation of the upcoming simulation. The virtual simulation phase exhibited a strong positive correlation between perceived authenticity and perceived cognitive engagement. Most participants reported high levels of both authenticity and engagement. Discrepancies were observed with Participants 01 and 07: Participant 01 reported high authenticity but only moderate engagement, whereas Participant 07 reported moderate authenticity but high engagement.

A Kendall's Tau correlation confirmed a significant positive relationship between perceived authenticity and perceived cognitive engagement ($r(28) = 0.77, p = 0.001$). This indicates that higher levels of perceived authenticity are associated with increased cognitive engagement among participants.

b. Perceived Authenticity and Physiological Cognitive Engagement.

Aligning perceived authenticity with physiological cognitive engagement revealed consistent patterns across the learning phases. In the authentic segments of the reading phase, physiological data supported the positive correlation. Participant 05 was the exception, showing a mismatch between moderate perceived authenticity and high physiological engagement. During the introductory video phase, most participants exhibited low physiological engagement corresponding with low perceived authenticity. Participant 01 was an outlier, displaying moderate to high physiological engagement despite low perceived authenticity, suggesting individual differences or unrecognized elements that influenced the engagement level. In the virtual simulation phase, a robust positive correlation was evident across all participants. Physiological engagement levels closely matched perceived authenticity, reinforcing the link between authentic learning experiences and cognitive engagement. Notably, Participants 01 and 07, who previously showed discrepancies in self-reported engagement, demonstrated alignment between perceived authenticity and physiological engagement in this phase. The debriefing phase also revealed a positive correlation between authenticity and physiological measurements. Exceptions included Participants 04, 06, and 10, who showed discrepancies between authenticity and physiological engagement, possibly due to individual differences in reflective activity or fatigue.

A Kendall's Tau correlation between perceived authenticity and physiological cognitive engagement yielded a significant positive relationship ($r(38) = 0.76, p =< 0.001$). This suggests that increased perceived authenticity is associated with higher physiological cognitive engagement, further validating the strong connection between these variables.

In conclusion, the findings indicate strong positive correlations between perceived authenticity and both perceived and physiological cognitive engagement, with the relationship being particularly robust when considering physiological measures. The virtual simulation phase, embodying all three dimensions of authentic learning, elicited the highest levels of cognitive engagement. In contrast, the introductory video phase, lacking authentic elements, corresponded with the lowest engagement levels among all learning activities. These patterns underscore the impact of authentic learning experiences on cognitive engagement. Activities that integrate multiple dimensions of authenticity enhanced learners' perceptions of engagement and stimulated greater cognitive activity, as evidenced by physiological data. Table 18 provides a summary of the research questions and key information of the findings, aligned with the objectives of this study.

Table 18

Summary of Research Questions and Key Findings

Research Purpose: Investigate the relationships between perceived authenticity and learners' cognitive engagement level across four learning activities.		
Research Question		Findings
1. What are the levels of authenticity students perceived according to four consecutive learning activities?		● Non-authentic learning activity: Introductory Video ● One-dimensional authentic learning activity: Reading ● Two-dimensional authentic learning activity: Debriefing ● Three-dimensional authentic learning activity: Virtual Simulation
2. What are the levels of students' cognitive engagement across four learning activities?	i. The levels of perceived cognitive engagement.	● Reading: Most participants reported heightened interest and attention. ● Introductory Video: Reported as the least engaging activity. ● Virtual Simulation: Highest perceived cognitive engagement level.
	ii. The levels of physiological cognitive engagement.	● Reading: Relatively higher levels of physiological cognitive engagement. No low level overserved. ● Introductory Video: Lowest physiological cognitive engagement level. ● Virtual Simulation: Highest physiological cognitive engagement level. ● Debriefing: Relatively higher levels of physiological cognitive engagement similar to the reading phase. Only one participant displayed low physiological engagement.
	iii. The similarities between perceived and physiological cognitive engagement (using Bland-Altman plots).	● Reading: Robust alignment. No systematic bias between the two measures. ● Introductory Video: Alignment was less consistent but overall alignment remained within acceptable limits. Participants slightly underestimated their engagement during this phase. ● Virtual Simulation: Robust alignment, slightly lower than the reading phase. No systematic bias.
3. What relationship patterns emerge between students' perceived authenticity and cognitive engagement?	i. The relationship between perceived authenticity and perceived cognitive engagement.	Kendall's Tau correlation confirmed a significant positive relationship between perceived authenticity and perceived cognitive engagement (r (28) = 0.77, p = 0.001).
	ii. The relationship between perceived authenticity and physiological cognitive engagement	Kendall's Tau correlation confirmed a significant positive relationship between perceived authenticity and perceived cognitive engagement (r (38) = 0.76, p < 0.001).

For this study, the first two research questions and their corresponding findings focus on investigating the two primary constructs: Perceived Authenticity and Cognitive Engagement. The final research question examines the relationship between these two constructs, which forms the core purpose of the study. This table encapsulates how the research questions guide the exploration of authenticity and engagement, ultimately leading to an understanding of both individual constructs and their interconnectedness.

5.2 Discussion and Implication

5.2.1 Implication for Authenticity

The findings of this study offer critical insights into the role and interpretation of authenticity in learning environments. Authenticity, as defined by Reeves, Herrington, and Oliver (2002), significantly influences how students interact with learning content, shaping their cognitive and emotional responses. By exploring how different dimensions of authenticity—Authentic Learning Content, Authentic Learning Activities, and Authentic Outcome Assessment—affect learning experience, the study provides valuable implications for educators and curriculum designers.

Traditionally, the authenticity of learning activities has been assessed based on established frameworks (Herrington et al., 2014). However, this study challenges the conventional approach by emphasizing that authenticity is inherently subjective and should also be evaluated from the learners' perspectives. Recognizing the subjective nature of authenticity underscores the importance of involving students in evaluating learning activities. What one student perceives as authentic may not hold the same value for another, highlighting the need for adaptive and inclusive instructional design. By acknowledging learners as key stakeholders in determining authenticity, educators can craft more effective, personalized learning experiences that cater to diverse needs and perspectives (Savery & Duffy, 1995).

This subjective nature of authenticity was particularly evident in the first two dimensions: Authentic Learning Content and Authentic Learning Activities. For instance, during the reading phase, several participants identified the formulas in the material as highly authentic. Although these formulas might not represent real-world relevance in the traditional sense, students perceived them as authentic because they were useful and directly applicable to their academic lives. This finding aligns with the idea that, for learners, authenticity is not solely about solving real-world problems but also about engaging with tasks that are relevant and practical within their educational contexts (Lombardi & Oblinger, 2007). Since learning is a significant aspect of students' lives, authenticity often correlates with how applicable content is to their learning and how well it aids them in problem-solving within the educational framework (Herrington et al., 2014). This perspective is consistent with the frameworks of Reeves et al. (2002) and Herrington et al. (2014), which emphasize that learning tasks should enable students to develop meaningful connections between their education and their lives.

Furthermore, the study affirms the critical role of interactive, problem-based learning environments, such as virtual simulations, in fostering comprehensive authentic learning experiences. The virtual simulation phase, recognized by participants as a three-dimensional authentic learning activity, demonstrates the power of integrating real-world content, sustained investigation, and integrated assessment. This comprehensive learning activity encouraged active engagement in critical thinking and problem-solving tasks and provided real-time feedback, aiding continuous improvement of understanding. As learners navigated challenging tasks and received immediate feedback, they participated in metacognition and refined their approaches, reflecting all three dimensions of authentic learning. This finding aligns with existing literature supporting inquiry-based learning and active participation as central to authentic learning experiences (Lombardi & Oblinger, 2007; Herrington et al., 2014).

Additionally, the debriefing phase embodies the metacognition and reflection elements of authentic learning. Although not explicitly discussed by participants, this phase functioned as an important two-dimensional authentic learning activity by promoting metacognition and integrated assessment. By encouraging students to reflect on their learning experiences and self-assess their progress, the debriefing enabled them to consolidate knowledge and identify areas for improvement (Lombardi & Oblinger, 2007). The findings reinforce the importance of incorporating reflective practices into authentic learning environments, as reflection helps learners internalize the knowledge and connect the learning module to real-world applications (Reeves et al., 2002). By fostering metacognitive skills, authentic learning environments help learners develop self-regulation strategies that enhance both immediate performance and long-term knowledge retention (Savery & Duffy, 1995).

On the other hand, the study also underscores the limitations of passive learning methods. The introductory video phase highlights the challenges posed by learning activities that do not incorporate authentic learning elements. The absence of all three dimensions of authentic learning led to lower levels of engagement and was deemed inauthentic by participants. This reinforces the argument that passive, information-delivery methods are less effective and should be complemented or replaced with inquiry-based, learner-centered approaches that promote active learning (Reeves et al., 2002). When learners encounter tasks lacking real-world context or opportunities for reflection and feedback, they are less likely to find the experience meaningful or engaging (Schellens & Valcke, 2006).

In conclusion, this study contributes to the growing body of research advocating for authentic learning environments. By recognizing that authentic learning is a comprehensive, three-dimensional construct—not merely the inclusion of real-world examples—educators can design more effective instructional materials. These materials should incorporate real-world relevance, active problem-solving activities, and continuous feedback mechanisms to promote higher levels of cognitive process. Additionally, integrating reflection and self-assessment into the learning process can further enhance authenticity, preparing students to apply their knowledge in complex, real-world contexts (Herrington et al., 2014; Reeves et al., 2002).

5.2.2 Implication for Cognitive Engagement

The results of this study offer crucial information into how cognitive engagement fluctuates across different phases of the learning process, highlighting the reliability and validity of traditional assessments and physiological measurements of cognitive engagement.

One key implication is the value of employing multiple measurement methods— self-reports through semi-structured interviews and physiological data captured by fNIRS—to assess cognitive engagement comprehensively. Generally, perceived engagement demonstrated less variability than physiological engagement due to the nature of the two measurements. Physiological engagement fluctuated even within the single short learning phase, such as the introductory video and debriefing phases. The robust alignment between perceived and physiological engagement during more authentic learning activities, like the virtual simulation, and the slightly weaker alignment during non-authentic activities, such as the introductory video, validate the importance of using these methods in conjunction. Previous studies have demonstrated the limitations of self-reported data, which are susceptible to recall bias and do not capture continuous fluctuations of engagement (Schellens & Valcke, 2006).

The findings of this study reveal challenges in accurately assessing engagement, especially during less interactive or lower-impact learning activities. For instance, during the introductory video phase, participants generally underreported their engagement levels in interviews despite higher physiological engagement recorded by fNIRS. This discrepancy suggests that learners may not always be aware of their cognitive engagement, particularly in passive learning activities that are less memorable. This underscores the limitations of self-reported measures and the need for incorporating physiological data to capture engagement that might not be consciously perceived by learners (Nolen et al., 2011).

Since cognitive activity is not readily observable through traditional measures (Fredricks et al., 2004), physiological tools such as fNIRS offer a unique advantage by allowing researchers to directly monitor and assess cognitive processes (Pinti et al., 2020). Unlike traditional self-reported measures, which depend on participants' conscious awareness and ability to convey their cognitive experiences (van Gog & Scheiter, 2010), fNIRS captures both conscious and unconscious aspects of cognitive engagement. The capacity to continuously monitor cognitive activity addresses a longstanding limitation in educational research, where self-reported data often fall short in capturing the full spectrum of cognitive engagement due to the inherent challenges of assessing cognition (Pintrich et al., 2000; Azevedo, 2015).

fNIRS measures activation in the prefrontal cortex, a region associated with higher-order cognitive functions such as attention and working memory, and has proven to be a valuable tool for capturing neural correlates of engagement beyond participants' self-awareness (Miller & Cohen, 2001; Fishburn et al., 2014). By tracking cognitive engagement during various learning tasks, fNIRS allows researchers to identify moments of cognitive overload or disengagement, providing insights into how cognitive states fluctuate throughout the learning process (Liu et al., 2012). This unconscious aspect of cognitive engagement is particularly valuable, as learners may be unaware of their engagement levels, especially during challenging tasks that demand significant cognitive effort or monotonous activities that may diminish their conscious attention.

However, while physiological engagement levels are recorded continuously and objectively, the fNIRS measurement is sensitive to contextual factors and may not fully capture participants' learning experiences. For example, students participated in this study in a one-on-one learning format with only the participant and the researcher present. The setting and the novel equipment may have caused participants to focus intensely during learning, even during phases they did not find interesting or relevant. Therefore, although the data showed that interview responses underestimated cognitive engagement during the introductory video phase, these responses might reflect participants' true perceptions of the learning activity despite their physiological measures indicating slightly higher levels of cognitive engagement.

Consequently, it is essential to combine innovative methods like fNIRS with traditional measurement techniques such as surveys, interviews, and observational analyses to triangulate results, increase the reliability and validity of the results, and provide complementary insights into the dynamics and experiences of cognitive processes in educational settings.

5.2.3 Implication for Relationship between Authenticity and Cognitive Engagement

The findings of this study underscore the complex relationship between authenticity and cognitive engagement, suggesting that the comprehensiveness of authentic learning dimensions across various phases has a measurable influence on cognitive engagement.

The results highlight that learning activities encompassing multiple authentic dimensions—such as the virtual simulation, which incorporated real-world relevance, sustained investigation, and integrated assessment—elicited the highest levels of cognitive engagement.

Conversely, phases lacking authentic elements, like the introductory video, resulted in minimal cognitive engagement. These findings corroborate earlier research indicating that multidimensional authentic learning environments foster deeper cognitive engagement, thus enhancing learning outcomes (Herrington et al., 2014; Lombardi & Oblinger, 2007).

Building upon these observations, the cross-case fNIRS data analysis revealed significant differences in physiological cognitive engagement between the reading phase and the virtual simulation phase. This finding underscores how a one-dimensional authentic learning activity, such as reading, and a three-dimensional authentic learning activity, such as virtual simulation, influence participants' cognitive engagement significantly. Thus, as a multidimensional construct, the number of authentic dimensions embodied by a learning activity impacts the level of cognitive engagement.

Regarding the reading phase, the study demonstrates that although real-world relevance is a critical element of authenticity, merely integrating the elements from the first dimension is insufficient to sustain learners' engagement. The absence of elements from the other two dimensions resulted in a less comprehensive authentic learning experience, underscoring the need for more complex tasks that require higher-order thinking processes (Lombardi & Oblinger, 2007).

During the virtual simulation phase, participants exhibited the highest levels of engagement, both perceived and physiological. This demonstrates that when learners are exposed to comprehensive authentic learning activities combining real-world relevance, in-depth exploration, and reflective processes, they engage more deeply with the material. The findings suggest that virtual simulations and similar interactive tasks can effectively bridge the gap between theory and practice, providing an immersive environment that challenges students to apply their knowledge in meaningful ways. This aligns with prior research by Rotgans and Schmidt (2011), who found that authentic learning tasks, especially those requiring problem-solving and critical thinking, promote higher cognitive engagement.

However, comparisons between phases with smaller differences in authenticity levels did not yield significant differences in cognitive engagement. For instance, the comparisons between the reading phase (a one-dimensional authentic learning activity) and the debriefing phase (a two-dimensional authentic learning activity) did not show significant results. Similarly, no significant differences were observed between the virtual simulation phase (a three-dimensional authentic learning activity) and the debriefing phase. These findings suggest that participants' cognitive engagement is likely influenced by substantial differences in authenticity levels.

Another key finding is the varying degrees of alignment between perceived authenticity and cognitive engagement when measured through self-reports (interviews) versus physiological measures (fNIRS). Self-reported cognitive engagement often reflects learners' reflections or memorable moments of the learning process, which might be shaped by strong emotional responses or personal biases. This explains instances of either perfect alignment or total mismatch between perceived authenticity and perceived cognitive engagement, where participants reported either a high level of engagement or a complete lack of it during distinct phases of the learning module (Herrington et al., 2014).

Physiological measures, on the other hand, offered a more continuous, dynamic representation of cognitive engagement throughout the learning module. fNIRS data revealed more partial alignments between authenticity and cognitive engagement, as it tracks real-time neural activity, capturing the flow of cognitive effort across the entire duration of an activity (Peck et al., 2013). This finding is critical because it suggests that physiological tools like fNIRS can detect subtle shifts in engagement that may not be consciously perceived by learners, as evidenced by discrepancies between perceived and physiological engagement in certain phases (Peck et al., 2013).

While the results indicate a robust correlation between authenticity and cognitive engagement, it is essential to recognize that individual differences and contextual factors mediate this relationship. For example, the one-on-one format of the study, combined with the novel equipment like fNIRS, might have induced heightened focus or anxiety in participants, influencing their engagement regardless of perceived authenticity. Such situational factors may have prompted higher physiological engagement even during phases that participants reported as unengaging, such as the introductory video. This suggests that both self-reported and physiological measurements might sometimes introduce bias or error in assessing cognitive engagement. Therefore, beyond authenticity, educators should also consider learner-specific factors such as novelty, anxiety, and learning preferences when designing authentic learning environments.

In conclusion, this study's findings reinforce the significance of incorporating comprehensive, authentic learning activities to enhance cognitive engagement. The robust relationship between authenticity and cognitive engagement across individuals and learning phases, coupled with the slight variation in the results from interview reports versus physiological measures, underscores the necessity for a multi-dimensional approach to the design and assessment of authentic learning environments. Integrating self-report data with physiological measurements provides a more integrated understanding of cognitive engagement, capturing both perceived experiences and real-time cognitive processes. This layered approach enhances the accuracy of engagement assessments and informs more targeted and effective instructional strategies. By grounding engagement in both perceptual and physiological data, these findings offer substantial implications for future instructional design, particularly in the development of authentic tasks that actively engage learners at both cognitive and emotional levels (Herrington et al., 2014; Fredricks et al., 2004).

5.2.4 Implication for Research

The findings from this study provide valuable directions for future research, particularly concerning the complex relationship between authenticity and learning engagement. By employing both self-reported and physiological measures, this study has highlighted several areas for further exploration.

a. Multi-Dimensional Evaluation of Authenticity.

Continuing to explore the multi-dimensionality of authenticity in educational settings is critical for future research. While previous studies, such as Herrington et al. (2014) and Reeves, Herrington, and Oliver (2002), have established the importance of authentic learning content, activities, and assessment, this study suggests that authenticity is highly subjective and can vary significantly among learners. Future research should assess how individual differences shape learners’ responses to authentic tasks. Further exploration of how specific dimensions of authenticity—such as Authentic Learning Content and Authentic Learning Activity—impact engagement across different learners and contexts would be beneficial (Herrington et al., 2014; Lombardi & Oblinger, 2007).

b. Integration of Physiological and Perceived Measures.

The use of physiological measures, such as fNIRS, has proven instrumental in capturing dynamic, real-time changes in cognitive engagement that may not be detected through self-reported methods (Peck et al., 2013). This study showed that self-reported engagement often reflected the learner's overall impression, whereas physiological data captured continuous cognitive fluctuations throughout learning activities. Future research should continue integrating these complementary measures to gain a more comprehensive understanding of engagement, particularly in relation to authentic learning environments. The development of protocols for combining physiological data with traditional engagement assessments, such as interviews and surveys, could lead to a more comprehensive understanding of how learners interact with educational tasks (Fishburn et al., 2014; Miller & Cohen, 2001).

c. Contextual and Individual Differences.

The findings suggest that individual learner characteristics, such as prior knowledge, learning preferences, and even the novelty of the research setting (e.g., the use of fNIRS), can influence the relationship between authenticity and cognitive engagement. These results align with studies indicating that authenticity's impact may be moderated by personal and situational factors (Nolen et al., 2011). Future research should examine these mediating variables in more detail, investigating how factors such as anxiety, prior experience, or the novelty of learning environments influence cognitive engagement during authentic tasks. This would help refine the design of learning environments that cater to diverse learner needs (Fredricks et al., 2004; Schellens & Valcke, 2006).

In conclusion, this study offers substantial insights into the complex relationship between authenticity and cognitive engagement, emphasizing the importance of employing a multi-layered approach to research these constructs. By refining the methodologies and frameworks used to assess both authenticity and engagement, future research can make meaningful contributions to the design of authentic learning environments that effectively promote deeper cognitive and affective engagement in learners (Herrington et al., 2014; Fredricks et al., 2004).

5.2.5 Implication for Practice

The findings from this study provide valuable insights for educators, instructional designers, and curriculum developers aiming to enhance learning engagement through the design of authentic learning environments. These implications for practice can guide the development of more effective, learner-centered learning experiences.

a. Designing Multi-Dimensional Authentic Learning.

The study highlights the importance of incorporating a range of authentic learning elements, such as real-world relevance, sustained inquiry, and integrated assessment, to engage learners at deeper cognitive levels. Research by Herrington and Oliver (2014) emphasizes that the inclusion of comprehensive, authentic tasks can facilitate problem-solving and critical thinking, leading to more robust learning outcomes. Practitioners should focus on creating complex, interactive tasks—such as virtual simulations—that mirror real-world scenarios and provide continuous feedback, as these have been shown to significantly increase cognitive engagement, according to the results of this study.

b. Aligning with Learner Perceptions.

The subjectivity of authenticity in learning highlights the need for adaptive instructional strategies that account for individual learner perceptions. Students may perceive authenticity differently based on their personal and educational experiences, as noted in studies by Gulikers et al. (2004). Incorporating student feedback into the design process can help tailor authentic tasks to a broader audience, making learning experiences more inclusive and effective.

c. Promoting Active, Inquiry-Based Learning.

The results reaffirm the limitations of passive instructional methods, such as lectures and videos, in fostering cognitive engagement. Instead, inquiry-based approaches that involve active problem-solving and collaboration, as outlined by Reeves, Herrington, and Oliver (2002), are more effective at engaging learners. To promote learners' cognitive engagement, Educators should consider creating learner-centered environments that challenge students to apply their knowledge through critical thinking and collaborative activities (Herrington et al., 2014).

d. Addressing Individual Differences and Contextual Factors.

Finally, the study suggests that individual learner characteristics, such as prior knowledge, learning preferences, and emotional states, will shape their attitudes and engagement toward the learning content. Designing instructional interventions that take these factors into account, providing personalized learning pathways and scaffolding could reduce cognitive overload or boredom, and support deeper engagement (Jansen et al., 2020). By integrating these practices, educators can create authentic, engaging learning environments, ultimately improving learning outcomes across diverse educational contexts.

5.3 Limitations and Future Directions

Building on the implications discussed earlier, this section addresses the study's limitations and outlines potential avenues for expanding the research in the future. While the findings underscore the importance of authentic learning in enhancing cognitive engagement, it is essential to acknowledge the constraints of the study's design and scope. These limitations, such as sample size and context specificity, may influence the generalizability of the results. Furthermore, the study's use of both self-reported and physiological data introduces unique considerations that warrant further exploration. In response to these limitations, the following subsections will discuss specific challenges faced during the study and propose future research directions to build on the current findings, ensuring more comprehensive insights into the relationship between authenticity and engagement across diverse learning environments.

5.3.1 Limitations

First, the relatively small sample size and the specific learning environment may limit the generalizability of the findings. Although the use of fNIRS provides rich data and detailed insights into cognitive engagement, the small number of participants and the learning environment settings restrict the extent to which the results can be applied across broader educational contexts. Future studies with larger and more diverse samples are needed to validate these findings and enhance their applicability (Fredricks et al., 2004; Herrington et al., 2014).

Second, the single-learner format used in this research does not account for the collaborative elements of authentic learning. Collaboration is a key element of authentic learning (Herrington et al., 2014) and is crucial for the Authentic Learning Activities dimension. Authentic tasks often require learners to work together to solve ill-defined problems and draw on multiple perspectives, which enhances cognitive and social engagement (Fredricks et al., 2004). However, because this study did not involve the collaborative component, it is difficult to assess how group dynamics and peer interaction might have influenced participants' cognitive engagement. The absence of this collaborative element limits the comprehensive evaluation of the authenticity of the learning experience and diminishes the generalizability of the findings to typical classroom settings, where teamwork plays an essential role in fostering engagement (Savery & Duffy, 1995).

Third, the study primarily focused on cognitive engagement and did not fully address the affective aspect of learning engagement. Affective engagement, which refers to interest, enthusiasm, and motivation during learning, is a critical component of overall engagement (Bergin & Bergin, 2009; Fredricks et al., 2004). It is also influenced by the perceived authenticity of learning activities, as authentic tasks enhance the sense of involvement, and learners are more likely to feel emotionally invested in tasks that they find meaningful and relevant (Herrington & Oliver, 2000). While fNIRS was employed to measure physiological cognitive engagement, it is possible that affective engagement could also be captured through physiological responses such as activation in specific brain regions, heart rate variability, or skin conductance, which reflect emotional arousal (Hong et al., 2020). The lack of direct assessment of affective engagement limits the comprehensiveness of the findings, particularly in understanding the full scope of students' engagement during learning activities.

Fourth, the study does not incorporate a counterbalanced design to control for extraneous factors such as participants' declining attention or fatigue as the experiment progresses (Van der Linden et al., 2003). Counterbalancing is commonly used in cognitive research to mitigate order effects that can arise when participants complete tasks in a fixed sequence (Pollatsek & Well, 1995). By varying the order of tasks across participants, counterbalancing helps to minimize biases associated with task order, such as fatigue or boredom, ensuring that the observed effects are not due to sequence but rather to the cognitive processes under investigation. However, the learning activities in this study are not parallel in terms of instructional content, making a counterbalanced design less suitable. Each phase—reading, introductory video, virtual simulation, and debriefing—serves a unique instructional purpose, collectively forming a complete learning module. As a result, implementing a counterbalanced design could disrupt the natural learning flow and compromise the integrity of participants' learning experiences.

Finally, while fNIRS provided valuable real-time data on cognitive engagement, methodological constraints related to this technology should be noted. fNIRS has limitations in terms of sensitivity to individual physical characteristics, such as skin tone and hair thickness, which can affect data quality (Kwasa et al., 2023). Participants with darker skin or thicker hair may have produced less reliable readings, which could lead to skewed interpretations of physiological engagement. This limitation reflects broader concerns about inclusivity in neuroimaging research and highlights the need for methodological improvements to ensure equitable data collection across diverse populations (Kwasa et al., 2023). Addressing these issues in future studies will help improve the accuracy and generalizability of physiological engagement measurements.

5.3.2 Future Directions

By acknowledging the limitations of the study, several future directions emerge that could further enhance the understanding of the relationship between authenticity and learning engagement, particularly in the integration of collaborative learning elements, the inclusion of social and affective engagement measures, and the refinement of neuroimaging methodologies to ensure more inclusive and accurate assessments. These directions will allow future research to build upon the current findings and provide more generalizable insights into the role of authenticity in fostering profound, meaningful learning experiences.

First of all, the social aspect of authenticity and learning engagement could be evaluated by incorporating collaborative learning environments. Group-based learning tasks would allow researchers to examine how peer interaction, communication, and shared problem-solving contribute to overall authenticity and how collaborative dynamics impact social, cognitive, and affective engagement. Such studies would offer a more thorough examination of authenticity and learning engagement, better reflecting typical classroom settings where teamwork and collaboration are integral to the learning process (Herrington et al., 2014; Fredricks et al., 2004).

Second, future research could incorporate methods that evaluate both the cognitive and affective dimensions of engagement during the learning process. Combining physiological measures, such as fNIRS, with traditional self-reported engagement tools can yield informative data on how learners' emotions interact with perceived authenticity during learning tasks (Hong et al., 2020). This integrated approach would expand the exploration to include the emotional dimension of engagement and provide insights into how authenticity affects both cognitive processing and emotional investment, enabling a more comprehensive understanding of engagement that reflects the full spectrum of learners' experiences in authentic learning environments.

Thirdly, future research could benefit from employing counterbalanced designs to more accurately assess cognitive engagement while controlling for order effects (Pollatsek & Well, 1995). A counterbalanced approach would be particularly valuable when evaluating learning tasks that are homogeneous or parallel in nature, as it allows researchers to better isolate the impact of authentic learning experiences on cognitive engagement. This method would be especially useful in studies of authentic learning environments, where learners' energy level or task complexity could skew results if participants are engaged in lengthy or demanding activities (Van der Linden et al., 2003). Thus, counterbalancing would help control for potential confounding factors, ensuring that participants' cognitive responses are driven by the learning conditions rather than the sequence of tasks.

Finally, future research should address the methodological challenges associated with using fNIRS, particularly in relation to data collection across diverse populations. To improve the validity and fairness of neuroimaging data, future studies need to explore advanced techniques and methodological adjustments that account for these physical characteristics, ensuring that the data accurately represent diverse student populations (Kwasa et al., 2023). Incorporating more inclusive neuroimaging methods will enhance the generalizability and accuracy of findings related to cognitive engagement.

In conclusion, future research should focus on key areas such as incorporating collaborative learning environments, exploring affective engagement, and enhancing neuroimaging methodologies to achieve a more comprehensive and generalizable understanding of how authenticity shapes learning engagement across various educational contexts. By addressing these aspects, researchers and practitioners can gain valuable insights into the interplay between social interaction, emotional investment, and cognitive processes within authentic learning environments. These efforts will contribute to the development of effective authentic learning experiences that foster immersive engagement and ultimately lead to improved learning outcomes.

REFERENCES

Aguilar, S. J., Holman, C., & Fishman, B. J. (2018). Game-inspired design: Empirical evidence in support of gameful learning environments. *Games and Culture*, *13*(1), 44-70.

Attwell, D., Buchan, A. M., Charpak, S., Lauritzen, M., MacVicar, B. A., & Newman, E. A. (2010). Glial and neuronal control of brain blood flow. *Nature*, *468*(7321), 232-243.

Axelson, R. D., & Flick, A. (2010). Defining student engagement. *Change: The magazine of higher learning*, *43*(1), 38-43.

Appleton, J. J., Christenson, S. L., & Furlong, M. J. (2008). Student engagement with school: Critical conceptual and methodological issues of the construct. *Psychology in the Schools*, *45*(5), 369-386.

Ayaz, H., Shewokis, P. A., Bunce, S., Izzetoglu, K., Willems, B., & Onaral, B. (2012). Optical brain monitoring for operator training and mental workload assessment. *Neuroimage*, *59*(1), 36-47.

Azevedo, R. (2015). Defining and measuring engagement and learning in science: Conceptual, theoretical, methodological, and analytical issues. *Educational psychologist*, *50*(1), 84-94.

Baker, J. M., Rojas-Valverde, D., Gutiérrez, R., Winkler, M., Fuhrimann, S., Eskenazi, B., ... & Mora, A. M. (2017). Portable functional neuroimaging as an environmental epidemiology tool: a how-to guide for the use of fNIRS in field studies. *Environmental health perspectives*, *125*(9), 094502.

Balardin, J. B., Zimeo Morais, G. A., Furucho, R. A., Trambaiolli, L., Vanzella, P., Biazoli Jr, C., & Sato, J. R. (2017). Imaging brain function with functional near-infrared spectroscopy in unconstrained environments. *Frontiers in human neuroscience*, *11*, 258.

Banda, H. J., & Nzabahimana, J. (2021). Effect of integrating physics education technology simulations on students’ conceptual understanding in physics: A review of literature. *Physical review physics education research*, *17*(2), 023108.

Bandura, A., Freeman, W. H., & Lightsey, R. (1999). Self-efficacy: The exercise of control.

Barnes, K., Marateo, R. C., & Ferris, S. P. (2007). Teaching and learning with the net generation. *Innovate: Journal of Online Education*, *3*(4).

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report*, *13*(4), 544-559.

Bergin, C., & Bergin, D. (2009). Attachment in the classroom. *Educational psychology review*, *21*, 141-170.

Boas, D. A., Elwell, C. E., Ferrari, M., & Taga, G. (2014). Twenty years of functional near-infrared spectroscopy: introduction for the special issue. *Neuroimage, 85*, 1-5.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *1989*, *18*(1), 32-42.

Bryk, A., & Schneider, B. (2002). *Trust in schools: A core resource for improvement*. Russell Sage Foundation.

Buelow, J. R., Barry, T., & Rich, L. E. (2018). Supporting learning engagement with online students. *Online Learning*, *22*(4), 313-340.

Carini, R. M., Kuh, G. D., & Klein, S. P. (2006). Student engagement and student learning: Testing the linkages. *Research in higher education*, *47*, 1-32.

Choi, J. I., & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational technology research and development*, 53-69.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of educational research*, *86*(1), 79-122.

Connell, J. P. (1990). Context, self, and action: A motivational analysis of self-system processes across the life span.

Cooper, R. J., Gagnon, L., Goldenholz, D. M., Boas, D. A., & Greve, D. N. (2012). The utility of near-infrared spectroscopy in the regression of low-frequency physiological noise from functional magnetic resonance imaging data. *NeuroImage*, *59*(4), 3128-3138.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative & mixed methods approaches* (5th ed.). Sage.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications.

Cutini, S., & Brigadoi, S. (2014). Unleashing the future potential of functional near-infrared spectroscopy in brain sciences. *Journal of Neuroscience Methods*, *232*, 152-156.

Cutini, S., Scatturin, P., & Zorzi, M. (2011). A new method based on ICBM152 head surface for probe placement in multichannel fNIRS. *Neuroimage*, *54*(2), 919-927.

Dancey, C. P., & Reidy, J. (2007). *Statistics without maths for psychology : using SPSS for Windows*. Pearson/Prentice Hall.

Dewey, J. (2022). *How we think*. DigiCat.

Dixson, M. D. (2010). Creating effective student engagement in online courses: What do students find engaging?. *Journal of the Scholarship of Teaching and Learning*, 1-13.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of science Education and Technology*, *18*, 7-22.

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random house.

Elliot, A. J., Murayama, K., & Pekrun, R. (2011). A 3× 2 achievement goal model. *Journal of educational psychology*, *103*(3), 632.

Elliot, A. J., Shell, M. M., Henry, K. B., & Maier, M. A. (2005). Achievement goals, performance contingencies, and performance attainment: An experimental test. *Journal of educational psychology*, *97*(4), 630.

Ewell, P. T. (2002). An emerging scholarship: A brief history of assessment. *Building a scholarship of assessment*, 3-25.

Ferrari, M., & Quaresima, V. (2012). A brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application. *Neuroimage*, *63*(2), 921-935.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. sage.

Finn, J. D. (1989). Withdrawing from school. *Review of educational research*, *59*(2), 117-142.

Finn, J. D., & Zimmer, K. S. (2012). Student engagement: What is it? Why does it matter?. *Handbook of research on student engagement*, 97-131.

Fishburn, F. A., Norr, M. E., Medvedev, A. V., & Vaidya, C. J. (2014). Sensitivity of fNIRS to cognitive state and load. *Frontiers in human neuroscience*, *8*, 76.

Fishburn, F. A., Ludlum, R. S., Vaidya, C. J., & Medvedev, A. V. (2019). Temporal derivative distribution repair (TDDR): a motion correction method for fNIRS. *Neuroimage*, *184*, 171-179.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of educational research*, *74*(1), 59-109.

Furrer, C., & Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of educational psychology*, *95*(1), 148.

Gee, J. P., & Hayes, E. R. (2011). *Language and learning in the digital age*. Routledge.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*(1), 5.

Gulikers, J. T., Bastiaens, T. J., & Kirschner, P. A. (2004). A five-dimensional framework for authentic assessment. *Educational technology research and development*, *52*(3), 67-86.

Henning, P. H. (2004). Everyday cognition and situated learning. *Handbook of research on educational communications and technology: A project of the association for educational communications and technology*, 829-861.

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational technology research and development*, 23-48.

Herrington, J., Reeves, T. C., & Oliver, R. (2014). *Authentic learning environments* (pp. 401-412). Springer New York.

Hew, K. F. (2016). Promoting engagement in online courses: What strategies can we learn from three highly rated MOOCS. *British Journal of Educational Technology*, *47*(2), 320-341.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: a response to Kirschner, Sweller, and. *Educational psychologist*, *42*(2), 99-107.

Hong, W., Zhen, R., Liu, R. D., Wang, M. T., Ding, Y., & Wang, J. (2020). The longitudinal linkages among Chinese children's behavioural, cognitive, and emotional engagement within a mathematics context. *Educational Psychology*, *40*(6), 666-680.

Hsieh, L. T., & Ranganath, C. (2014). Frontal midline theta oscillations during working memory maintenance and episodic encoding and retrieval. *Neuroimage*, *85*, 721-729.

Hu, P. J. H., & Hui, W. (2012). Examining the role of learning engagement in technology-mediated learning and its effects on learning effectiveness and satisfaction. *Decision support systems*, *53*(4), 782-792.

Hughes, R., & Pace, C. R. (2003). Using NSSE to study student retention and withdrawal. *Assessment Update*, *15*(4), 1-2.

Huppert, T. J., Diamond, S. G., Franceschini, M. A., & Boas, D. A. (2009). HomER: a review of time-series analysis methods for near-infrared spectroscopy of the brain. *Applied optics*, *48*(10), D280-D298.

Hutt, S., Hardey, J., Bixler, R., Stewart, A., Risko, E., & D'Mello, S. K. (2017). Gaze-Based Detection of Mind Wandering during Lecture Viewing. *International Educational Data Mining Society*.

Ichikawa, H., Kitazono, J., Nagata, K., Manda, A., Shimamura, K., Sakuta, R., ... & Kakigi, R. (2014). Novel method to classify hemodynamic response obtained using multi-channel fNIRS measurements into two groups: exploring the combinations of channels. *Frontiers in human neuroscience*, *8*, 480.

Jansen, R. S., van Leeuwen, A., Janssen, J., Conijn, R., & Kester, L. (2020). Supporting learners' self-regulated learning in Massive Open Online Courses. *Computers & Education*, *146*, 103771.

Jonassen, D. H. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm?. *Educational technology research and development*, *39*, 5-14.

Jonassen, D. H. (1997). Instructional design models for well-structured and III-structured problem-solving learning outcomes. *Educational technology research and development*, *45*(1), 65-94.

Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research*. Interaction Book Company.

Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational researcher*, *38*(5), 365-379.

Kendall, M. G. (1938). A new measure of rank correlation. *Biometrika*, *30*(1-2), 81-93.

Kendall, M. G., & Gibbons, J. D. (1990). *Rank correlation methods* (5th ed). E. Arnold ; Oxford University Press.

Keselman, H. J., Algina, J., & Kowalchuk, R. K. (2001). The analysis of repeated measures designs: a review. *British Journal of Mathematical and Statistical Psychology*, *54*(1), 1-20.

Kindermann, T. A. (2007). Effects of naturally existing peer groups on changes in academic engagement in a cohort of sixth graders. *Child development*, *78*(4), 1186-1203.

Klem, A. M., & Connell, J. P. (2004). Relationships matter: Linking teacher support to student engagement and achievement. Journal of school health, 74, 262-273.

Kreijns, K., Van Acker, F., Vermeulen, M., & Van Buuren, H. (2014). Community of inquiry: Social presence revisited. *E-learning and Digital Media*, *11*(1), 5-18.

Kuh, G. D. (2001). Assessing what really matters to student learning inside the national survey of student engagement. *Change: The magazine of higher learning*, *33*(3), 10-17.

Kuh, G. D. (2005). Exploring different dimensions of student engagement: 2005 annual survey results. *Bloomington, IN: Center for Postsecondary Research and Planning*.

Kuh, G. D. (2008). Excerpt from high-impact educational practices: What they are, who has access to them, and why they matter. *Association of American Colleges and Universities*, *14*(3), 28-29.

Kuh, G. D. (2009). What student affairs professionals need to know about student engagement. *Journal of college student development*, *50*(6), 683-706.

Kwasa, J., Peterson, H. M., Karrobi, K., Jones, L., Parker, T., Nickerson, N., & Wood, S. (2023). Demographic reporting and phenotypic exclusion in fNIRS. *Frontiers in Neuroscience, 17*, 1086208.

Lamb, R. L., & Etopio, E. (2019). Virtual reality simulations and writing: A neuroimaging study in science education. *Journal of Science Education and Technology, 28*, 542-552.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Liu, T., Saito, H., & Oi, M. (2012). Distinctive activation patterns under intrinsically versus extrinsically driven cognitive loads in prefrontal cortex: a near-infrared spectroscopy study using a driving video game. *Neuroscience letters, 506*(2), 220-224.

Logothetis, N. K. (2008). What we can do and what we cannot do with fMRI. *Nature*, *453*(7197), 869-878.

Lombardi, M. M., & Oblinger, D. G. (2007). Authentic learning for the 21st century: An overview. *Educause learning initiative*, *1*(2007), 1-12.

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.

Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2009). Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual review of neuroscience*, *24*(1), 167-202.

Milligan, C., Littlejohn, A., & Margaryan, A. (2013). Patterns of engagement in connectivist MOOCs. *Journal of Online Learning and Teaching*, *9*(2), 149-159.

Mirelman, A., Maidan, I., Bernad-Elazari, H., Nieuwhof, F., Reelick, M., Giladi, N., & Hausdorff, J. M. (2014). Increased frontal brain activation during walking while dual tasking: an fNIRS study in healthy young adults. *Journal of neuroengineering and rehabilitation*, *11*, 1-7.

Murphy, P., Lunn, S., & Jones, H. (2006). The impact of authentic learning on students' engagement with physics. *The Curriculum Journal*, *17*(3), 229-246.

Newmann, F. M. (1992). *Student engagement and achievement in American secondary schools*. Teachers College Press, 1234 Amsterdam Avenue, New York, NY 10027 (paperback: ISBN-0-8077-3182-X, $17.95; hardcover: ISBN-0-8077-3183-8, $38)..

Newmann, F. M. (1996). Authentic assessment in social studies: Standards and examples. In *Handbook of classroom assessment* (pp. 359-380). Academic Press.

Nolen, S. B., Ward, C. J., & Horn, I. S. (2011). Motivation, engagement, and identity: Opening a conversation. *Sociocultural theories of learning and motivation: Looking back, looking forward*, (pp. 109-135). Charlotte, NC, US: IAP

Paas, F., & Sweller, J. (2012). An evolutionary upgrade of cognitive load theory: Using the human motor system and collaboration to support the learning of complex cognitive tasks. *Educational Psychology Review*, *24*, 27-45.

Park, J. H., & Choi, H. J. (2009). Factors influencing adult learners' decision to drop out or persist in online learning. *Journal of Educational Technology & Society*, *12*(4), 207-217.

Parsons, J., McRae, P., & Taylor, L. (2006). Celebrating School Improvement.

Parsons, J., & Taylor, L. (2011). Improving student engagement. *Current issues in education*, *14*(1).

Peck, E. M., Afergan, D., & Jacob, R. J. (2013, March). Investigation of fNIRS brain sensing as input to information filtering systems. In *Proceedings of the 4th Augmented Human International Conference* (pp. 142-149).

Perkins, K. (2020). Transforming STEM learning at scale: PhET interactive simulations. *Childhood Education*, *96*(4), 42-49.

Piaget, J. (1970). Science of education and the psychology of the child. Trans. D. Coltman.

Pinti, P., Aichelburg, C., Gilbert, S., Hamilton, A., Hirsch, J., Burgess, P., & Tachtsidis, I. (2018). A review on the use of wearable functional near-infrared spectroscopy in naturalistic environments. *Japanese Psychological Research*, *60*(4), 347-373.

Pinti, P., Tachtsidis, I., Hamilton, A., Hirsch, J., Aichelburg, C., Gilbert, S., & Burgess, P. W. (2020). The present and future use of functional near-infrared spectroscopy (fNIRS) for cognitive neuroscience. *Annals of the New York Academy of Sciences*, *1464*(1), 5-29.

Pintrich, P. R., Wolters, C., & Baxter, G. (2000). Assessing metacognition and self- regulated learning. In G. Schraw & J. Impara (Eds.), *Issues in the measurement of metacognition* (pp. 43–97). Lincoln, NE: Buros Institute of Mental Measurement.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of educational Psychology*, *95*(4), 667.

Plichta, M. M., Heinzel, S., Ehlis, A. C., Pauli, P., & Fallgatter, A. J. (2007). Model-based analysis of rapid event-related functional near-infrared spectroscopy (NIRS) data: a parametric validation study. *Neuroimage*, *35*(2), 625-634.

Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *Journal of applied psychology*, *88*(5), 879.

Pollatsek, A., & Well, A. D. (1995). On the use of counterbalanced designs in cognitive research: a suggestion for a better and more powerful analysis. *Journal of Experimental psychology: Learning, memory, and Cognition*, *21*(3), 785.

Porges, S. W. (2007). The polyvagal perspective. *Biological psychology*, *74*(2), 116-143.

Reeves, T. C., Herrington, J., & Oliver, R. (2002). Authentic activities and online learning.

Reeve, J., & Tseng, C. M. (2011). Agency as a fourth aspect of students' engagement during learning activities. *Contemporary educational psychology*, *36*(4), 257-267.

Resnick, L. B., Pontecorvo, C., & Säljö, R. (1997). *Discourse, tools, and reasoning: Essays on situated cognition* (pp. 1-20). Springer Berlin Heidelberg.

Robinson, C. C., & Hullinger, H. (2008). New benchmarks in higher education: Student engagement in online learning. *Journal of Education for Business*, *84*(2), 101-109.

Rogoff, B. (1994). Developing understanding of the idea of communities of learners. *Mind, culture, and activity*, *1*(4), 209-229.

Rotgans, J. I., & Schmidt, H. G. (2011). Cognitive engagement in the problem-based learning classroom. *Advances in health sciences education*, *16*, 465-479.

Saivyer, R. K., & Greeno, J. G. (2009). Situativity and learning. *The Cambridge handbook of situated cognition*, *304*.

Savery, J. R. (2009). Problem-based approach to instruction. In *Instructional-Design Theories and Models, Volume III* (pp. 155-178). Routledge.

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational technology*, *35*(5), 31-38.

Schellens, T., & Valcke, M. (2006). Fostering knowledge construction in university students through asynchronous discussion groups. *Computers & Education*, *46*(4), 349-370.

Scholkmann, F., Kleiser, S., Metz, A. J., Zimmermann, R., Pavia, J. M., Wolf, U., & Wolf, M. (2014). A review on continuous wave functional near-infrared spectroscopy and imaging instrumentation and methodology. *Neuroimage*, *85*, 6-27.

Scholkmann, F., Spichtig, S., Muehlemann, T., & Wolf, M. (2010). How to detect and reduce movement artifacts in near-infrared imaging using moving standard deviation and spline interpolation. *Physiological measurement*, *31*(5), 649.

Siegel, S. and Castellan, N. J., Jr. (1988). Nonparametric Statistics for the Behavioral Sciences. New York: McGraw-Hill.

Simons, H. (2009). *Case study research in practice.* SAGE Publications, Ltd, https://doi.org/10.4135/9781446268322

Simon, S., Ola, H., Kristoffer, S., Lina, B. K., & Georg, K. H. (2022). Proactive cognitive control, mathematical cognition and functional activity in the frontal and parietal cortex in primary school children: An fNIRS study. *Trends in Neuroscience and Education*, 100180.

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational psychologist*, *50*(1), 1-13.

Smith, J. A., Flowers, P., & Larkin, M. (2009). *Interpretative Phenomenological Analysis*. SAGE.

Soltanlou, M., Sitnikova, M. A., Nuerk, H. C., & Dresler, T. (2018). Applications of functional near-infrared spectroscopy (fNIRS) in studying cognitive development: The case of mathematics and language. *Frontiers in psychology*, *9*, 277.

Stake, R. (1995). *Case study research*. thousand oaks, CA: Sage.

Sun, J., Anderson, R. C., Lin, T. J., Morris, J. A., Miller, B. W., Ma, S., ... & Scott, T. (2022). Children's engagement during collaborative learning and direct instruction through the lens of participant structure. *Contemporary Educational Psychology*, *69*, 102061.

Sweany, N. W., Finbow, E., Li, Y., & Burgner, R. L. (2020). The VIP Approach-Applying a Virtual, Interdisciplinary Partnership to Support Innovation and Authentic Learning in Distance Education. *TechTrends*, *64*, 646-654.

Sweller, J. (2011). Cognitive load theory. In *Psychology of learning and motivation* (Vol. 55, pp. 37-76). Academic Press.

Tachtsidis, I., & Scholkmann, F. (2016). False positives and false negatives in functional near-infrared spectroscopy: issues, challenges, and the way forward. *Neurophotonics*, *3*(3), 031405-031405.

Tak, S., & Ye, J. C. (2014). Statistical analysis of fNIRS data: a comprehensive review. *Neuroimage*, *85*, 72-91.

Van der Linden, D., Frese, M., & Meijman, T. F. (2003). Mental fatigue and the control of cognitive processes: effects on perseveration and planning. *Acta psychologica*, *113*(1), 45-65.

Van Gog, T., & Scheiter, K. (2010). Eye tracking as a tool to study and enhance multimedia learning. *Learning and instruction*, *20*(2), 95-99.

Vitorio, R., Stuart, S., Rochester, L., Alcock, L., & Pantall, A. (2017). fNIRS response during walking—Artefact or cortical activity? A systematic review. *Neuroscience & Biobehavioral Reviews*, *83*, 160-172.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes* (pp. 84–91). Harvard University Press.

Wenger, E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press.

Wiggins, G. (1998). *Educative Assessment. Designing Assessments To Inform and Improve Student Performance*. Jossey-Bass Publishers, 350 Sansome Street, San Francisco, CA 94104.

Willging, P. A., & Johnson, S. D. (2009). Factors that influence students' decision to dropout of online courses. *Journal of Asynchronous Learning Networks*, *13*(3), 115-127.

Willms, J. D., Friesen, S., & Milton, P. (2009). *What did you do in school today? Transforming classrooms through social, academic, and intellectual engagement.(First National Report).*

Xiong, Y., Li, H., Kornhaber, M. L., Suen, H. K., Pursel, B., & Goins, D. D. (2015). Examining the relations among student motivation, engagement, and retention in a MOOC: A structural equation modeling approach. *Global Education Review*, *2*(3), 23-33.

Yassin, A. A. B. (2022). The Effect of Using Interactive Simulation (Phet) and Virtual Laboratories (Praxilabs) on Tenth-Grade Students' Achievement in Physics. *Britain International of Linguistics Arts and Education (BIoLAE) Journal*, *4*(2), 58-72.

Yin, R. K. (2003). Designing case studies. *Qualitative research methods*, *5*(14), 359-386.

Yin, R. K. (2009). *Case study research: Design and methods*(Vol. 5). sage.

Yücel, M. A., Lühmann, A. V., Scholkmann, F., Gervain, J., Dan, I., Ayaz, H., ... & Wolf, M. (2021). Best practices for fNIRS publications. *Neurophotonics*, *8*(1), 012101-012101.

Zimmerman, B. J. (1990). Self-regulated learning and academic achievement: An overview. *Educational psychologist*, *25*(1), 3-17.

Zimmerman, B. J. (2008). Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects. *American educational research journal*, *45*(1), 166-183.

APPENDICES

Appendix A

STUDENT PARTICIPANTS ASSENT FORM

The Relationship between Perceived Authenticity and Cognitive Engagement in a Multimedia Science Learning Environment: Using Functional Near-Infrared Spectroscopy (fNIRS) Measurements.

Dear Students,
We're doing a study to assess students' cognitive engagement in the authentic learning environment. The science program uses virtual simulations to help you learn. Our research team is very interested in how you feel about the learning experience. That's why you were chosen for this study.

Your participation will help us figure out how to support your teachers in integrating technology to support your learning. If you are willing to participate in this study, you will allow the researchers to collect the following data:

- Class observation: We will record the learning process.
- Student work: We will put the fNIRS device on your forehead. You will engage in a complete science class module, including a lecture, a science simulation/virtual experiment, and a debriefing session.
- A semi-structured interview: You will spend 10-15 minutes share your perceptions of authenticity and cognitive engagement during the learning activities.

Taking part is voluntary
Your participation is voluntary. You can decide whether to join this program or not. If you choose to join us, you will get to sign this form and let us use your information and work in this program. You don't have to answer any question that makes you feel uncomfortable during the study. You can also change your mind and stop being part of the study at any time, and it won't change your grades or how your teacher teaches you. If you decide to stop, we will discard all the information you gave us.

We will take steps to protect your privacy during the study. We will not collect your personal information and we will ensure that your name does not appear in our dataset or the reports we are sharing with other people.

If you have questions, you may contact Dr. Choi at ichoi@uga.edu or 706.583.0794, and contact Mr. Yang at hy85405@uga.edu or 757-509-8091. If you have any questions or concerns about your rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

Thank you for thinking about joining this important study.

I have read and understand the information given to me, and I agree to take part in the research.

Name of Child: ___________________________ **Parental Permission on File:** ☐ Yes ☐ No

(For Written Assent) **Signing here means that you have read this paper or had it read to you and that you are willing to be in this study. If you don't want to be in the study, don't sign.**

Signature of Child: ________________________________ **Date:** __________________

(For Verbal Assent) **Indicate Child's Voluntary Response to Participation:** ☐ Yes ☐ No

Signature of Researcher: ___________________________ **Date:** __________________

Appendix B

UNIVERSITY OF GEORGIA PARENTAL PERMISSION FORM

The Relationship between Perceived Authenticity and Cognitive Engagement in a Multimedia Science Learning Environment: Using Functional Near-Infrared Spectroscopy (fNIRS) Measurements.

Researcher's Statement

Dear Parents/Guardians,

Your child has been invited to join a research study about the learning experience of middle school students who use a multimedia-based, virtual science lab learning system. We ask for your permission for your child to participate in this study.

Before you decide to allow your child to participate in this study, it is important that you understand why the research is being done and what it will involve. This form is designed to give you information about the study so you can decide whether your child will be in the study or not. Please take the time to read the following information carefully.

Please ask the researcher if there is anything that needs to be clarified or if you need more information. When all your questions have been answered, you can decide if you want your child to be in the study or not. This process is called "informed consent."

Principal Investigator: Dr. Ikseon Choi
Learning, Design, and Technology Program,
University of Georgia
ichoi@uga.edu

Research Member: Haotian (Kevin) Yang
Learning, Design, and Technology Program
University of Georgia
hy85045@uga.edu

Purpose of the Study

This research aims to use functional near-infrared spectroscopy (fNIRS) to monitor students' cognitive engagement in the multimedia-based virtual lab learning system. The study will investigate how students' cognitive engagement levels vary across different learning activities within a simulation-based scientific inquiry learning process. The results of this study will provide valuable insights into the effectiveness of multimedia-based authentic learning environments and how they can be optimized to enhance students' engagement and cognitive processes.

In this project, Barrow County School System Innovative Center will organize a special workshop to provide students with hands-on experience with future learning technologies. Our research team will use fNIRS to assess students' engagement in the virtual science lab. fNIRS is a non-invasive neuroimaging technique that can monitor brain activity during learning. It is similar to an Apple Watch but will be worn on the forehead instead of the wrist.

Study Procedures

If your child is willing to participate in this study, you will allow the researchers to collect the following data:

- Class observation: We record the learning process from behind without showing students' faces.
- Student work: We will put the fNIRS device on students' foreheads. Students will engage in a complete science class module, including a lecture, a science simulation/virtual experiment, and a debriefing session.
- A semi-structured interview: Students will spend 10-15 minutes sharing their perceptions of authenticity and cognitive engagement during the learning activities.

The total expected duration of participation in this study is 30 – 45 minutes.

Benefits

There is no direct benefit from participating in this study. However, the research will provide insights into the relationship between engagement and authenticity of learning activities. In this special workshop, students will conduct authentic scientific inquiry learning in various virtual NGSS-aligned labs, which provide students with interactive science learning experiences. Individual students will be supported by the systems and teachers based on their performance and difficulties, which promotes their learning interests and outcomes.

Risk

It is reported that there are no significant foreseeable risks or discomforts to potential participants. Given that fNIRS is a non-invasive technique employing low-intensity near-infrared light, the probability of participants experiencing discomfort during the study is minimal.

Taking part is voluntary

Your child's involvement in the research activities is voluntary. You may choose not to allow your child to participate in the research activities or to stop at any time without penalty or loss of benefits to which your child is otherwise entitled. The decision to participate or not participate in the research will not affect your child's grades or class standing.

If your child decides to stop or you withdraw your child from the study, the information/data collected up to the point of your withdrawal will be destroyed and not be used in the study.

Privacy/Confidentiality

To answer a series of research questions, your child's data, including observation, fNIRS, and interview data, will be collected and analyzed. We will take steps to protect your child's privacy during the study. We will not collect your child's personal information and will ensure that your child's name does not appear in our dataset or the reports we share with other people. All data collected during this research will be deidentified, ensuring that personal identifiers are removed.

This deidentified data may be used for future research purposes without seeking additional informed consent from you. However, please be assured that this data will not be distributed to other researchers. We are committed to maintaining the confidentiality and integrity of your contribution to this study.

We acknowledge that there exists a potential risk of breach of confidentiality for participants involved in this study. To mitigate this risk, all personal identifiers in the data will be replaced with randomly assigned research numbers to protect your child's identity and maintain their confidentiality. Data will be stored on encrypted hard drives with restricted access, and only the approved researchers will access this data according to the IRB guidelines. All information, including direct identifiers that could be used to identify your child, will be deleted after the completion of the data analysis process. The video recordings from this research will be used to mark the duration of each learning activity in relation to the fNIRS data, aiding in the interpretation of the fNIRS results. Therefore, no facial information will be recorded. During the data collection process, the camera will be positioned behind the participants to capture the computer screen, enabling identification of each learning activity. Once data analysis is finalized, all recordings will be deleted. Additionally, any results or findings published will be presented in aggregate form, ensuring no individual participant can be identified.

The project's research records may be reviewed by departments at the University of Georgia responsible for regulatory and research oversight.

Researchers will not release identifiable results of the study to anyone other than individuals working on the project without your written permission unless required by law.

If you have questions

The researchers conducting this study are Dr. Ikseon Choi, Professor, and Mr. Haotian (Kevin) Yang, a doctoral candidate in Learning, Design, and Technology at the University of Georgia. Please ask any questions you may have. If you have questions later, contact Dr. Choi at ichoi@uga.edu or 706.583.0794 or Mr. Yang at hy85405@uga.edu.

If you have any questions or concerns regarding your rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

(You may keep the above study information for reference and only return this page to the researchers).

<u>Study Title:</u> **Exploring the Connection between Authenticity and Learning Engagement in a Multimedia-Based Science Simulation Learning Program using fNIRS Measurement**

To voluntarily allow your child to participate in this study, you must sign on the line below. Your signature below indicates that you have read or had read to you this complete Parental Permission Form and have had all of your questions answered.

(Print) Your Child's Name: _______________________________

(Print) Parent Name: _______________________________

Parent Signature: _______________________________ Date: _____________

Appendix C

Perceived Authenticity and Cognitive Engagement Interview

Debriefing the Learning Outcome:

1. Could you please describe what you have learned from today's materials?

2. Before today, how much did you know about this topic?

3. Which activities did you find most beneficial for your learning? Could you explain why?

4. How interested are you in today's learning topic?

Perceived Authenticity:

1. Which activity in this session do you feel is closely related to a real-world situation? (Real World Relevance)

2. Do you think you could use what you have learned today in real life?

3. Was there any moment during this session that you felt the problem you needed to solve didn't have a clear answer? Can you describe one such instance? (Ill-defined Problem)

4. Was there an activity that helped you really get into the topic (to dig deeper)? What did you do in that activity? (Sustained investigation)

6. Did you feel there could be multiple ways to solve the problems in today's activities? (Multiple interpretations and outcomes)

Perceived Cognitive Engagement:

1. Was there a time today when you felt really focused on learning? What were you doing at that moment?
2. How involved did you feel in today's activities? (Was there any moment you felt really active or more just listening and watching?) Can you tell me about one of those times?
3. Do you remember a time during the activities when you felt it was too hard to understand the content?
4. When we were learning today, how often did you think about things you already knew? Can you share one time when this happened?
5. Did any of today's activities make you want to learn more about balancing? What made you curious?

Closing:

Would you like to share anything else about your experience with the science learning activities that we haven't discussed?

Appendix D

Individual Case Analysis Report

Within-case analysis for Participant 02

a. **Descriptive Analysis of Synchronized Video Clip.**

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

According to the research design, the data collection for Participant 02 started with a 3-minute relaxation phase to establish a pre-experiment baseline. The participant sat quietly in a chair with no external stimuli. Brain activity levels were observed to be low to moderate.

- ***Reading Phase (0:03:19 - 0:06:18):***

Participant 02 began the reading phase with a moderate hemodynamic response level. The fNIRS brain map indicated that the left prefrontal lobe had a relatively higher activity level. At 0:04:33, the participant completed the first page and began reading the second page, during which brain activity increased. The participant maintained a moderate to high level of brain activity consistently for 1 minute 44 seconds. Brain activity decreased to a moderate level at 0:05:24 as the participant finished the reading for the first time but increased again to a high level when the participant began re-reading the material. Peak brain activity was noted around 0:04:08 and 0:06:11, corresponding to sections discussing real-world examples.

- ***Introductory Video Phase (0:06:40 - 0:07:39):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a moderate level of brain activity, with higher activity in the left prefrontal lobe.

- ***Virtual Simulation Phase (0:08:00 - 0:13:00):***

Participant 02 then did the virtual science simulation for 5 minutes. From the first to the fifth problem, the participant required two attempts each, with brain activity increased from moderate to high level. A consistently high level of hemodynamic response was observed from the ninth to the twenty-first problem as the difficulty increased and the participant became more familiar with the simulation. The detailed time and attempt data are summarized in Table 19.

Table 19

Participant 02 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	11	Incorrect	Correct
2	9	Incorrect	Incorrect
3	18	Incorrect	Correct
4	29	Incorrect	Incorrect
5	23	Incorrect	Incorrect
6	7	Correct	
7	4	Correct	
8	9	Incorrect	Incorrect
9	18	Correct	
10	6	Correct	
11	18	Correct	
12	11	Incorrect	Correct
13	10	Incorrect	Correct
14	18	Incorrect	Incorrect
15	11	Incorrect	Correct
16	6	Incorrect	Incorrect
17	7	Correct	
18	20	Incorrect	Incorrect
19	6	Correct	
20	16	Incorrect	Incorrect
21	29	Incorrect	Incorrect

b. Interview Analysis.

- ***Debriefing/Interview (0:13:33 - 0:23:01):***

The session proceeded with a debriefing/interview, starting with moderate brain activity. The participant reported that the reading material was informative and useful for learning the topic despite not generally enjoying reading in daily life. The participant shared an interest in simulation, and the colorful graphics were appealing. He mentioned using technology for learning more frequently since the pandemic, finding it easier to use a tablet or smartphone (see Excerpt 2, line 1 to 2). The participant believed the knowledge gained from the reading material could help him understand important physics principles applicable to real life. Some challenges were noted during the simulation, particularly when the participant had to guess the right answer. He suggested making the initial problems more challenging and acknowledged that the simulation allowed for multiple ways to solve problems. The participant felt focused throughout all activities, emphasizing the most engaging moments occurred when he failed an initial attempt but succeeded on a subsequent try (see Excerpt 2, line 3). The participant connected previous knowledge to the reading material and expressed a desire to continue learning the topic. The coding results for the interview are shown in Table 20.

Excerpt 2.	Perceived authenticity and cognitive engagement of Participant 02
1 2	I used more technology (tools) because of the Corona (Virus). It is easier for me to use a tablet or iPhone (to learn).
3	I feel like I can get it in one more try because it is really close.

Table 20

Participant 02 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation/Reading
		Apply	The knowledge can be used in real life.	Reading
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	Simulation
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners' attention during learning	n/a
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	Simulation (Active)
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	Simulation
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Reading
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Reading

- ***Post-Experiment Baseline (0:23:15 - 0:28:14):***

Finally, the participant entered a 5-minute rest phase to establish a post-experiment baseline, concluding the fNIRS data collection at 0:28:14.

c. fNIRS Data Analysis.

A repeated measures ANOVA was conducted for Participant 02. The analysis focuses on the levels of cognitive engagement during various science learning activities, and the learning activities were segmented into one-minute blocks to achieve equal sample sizes.

The mean and standard deviation for hemodynamic response levels across each learning activity are summarized in Table 21.

Table 21

fNIRS Descriptive Statistics for Participant 02

Activity	Mean	SD
Reading 1	0.053	0.106
Reading 2	0.044	0.067
Reading 3	0.050	0.097
Video 1	-0.049	0.072
Simulation 1	-0.075	0.087
Simulation 2	0.038	0.074
Simulation 3	0.066	0.101
Simulation 4	-0.044	0.082
Simulation 5	0.067	0.136
Debriefing	0.031	0.129

The multivariate test results showed a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.834, F (18, 7052) = 1969.798, $p < .001$, partial $\eta^2 = 0.834$. These results indicate a robust overall effect of the activity type on cognitive engagement levels as measured by fNIRS. The repeated measures ANOVA showed a significant main effect of learning activity on hemodynamic response levels, F (18, 127242) = 2429.265, p

< .001, partial $\eta^2 = 0.256$. This indicates that hemodynamic response levels significantly differed across the learning activities.

Figure 14 illustrates the mean hemodynamic response levels for each learning phase of Participant 02.

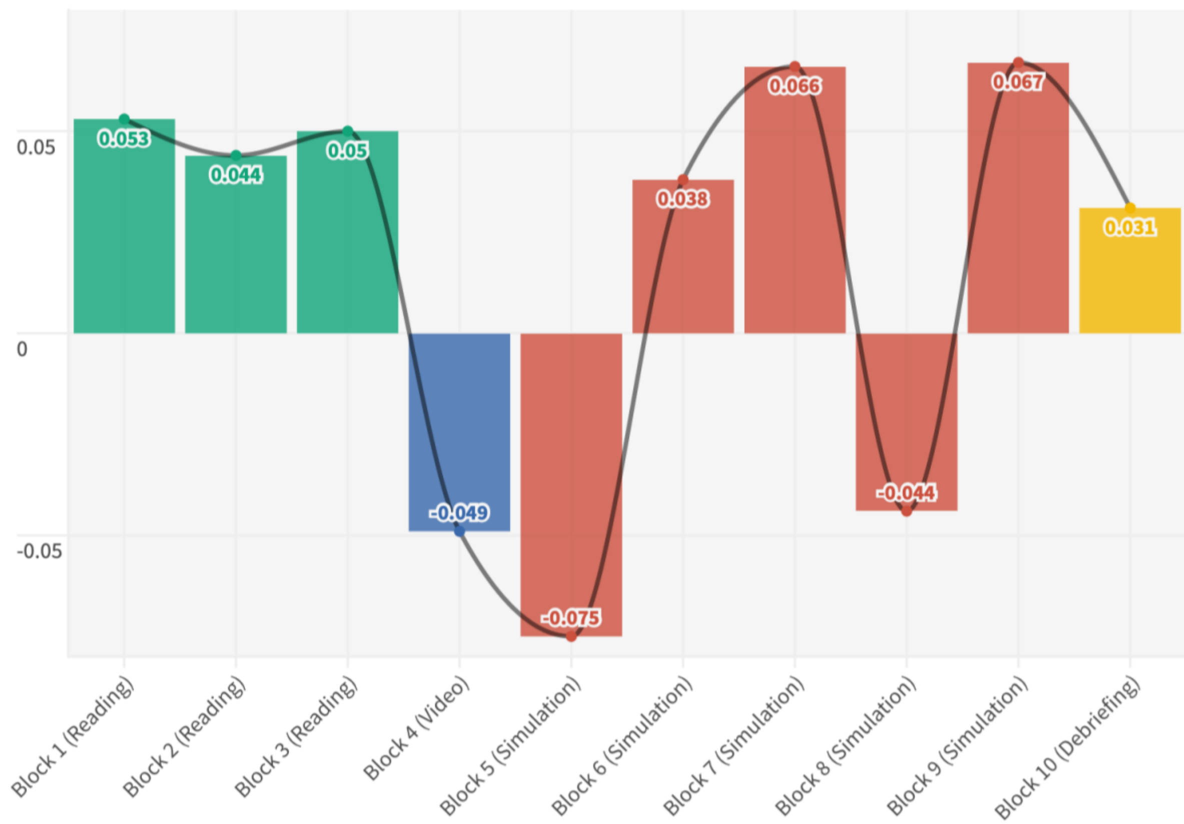


Figure 14

Mean Hemodynamic Response for Participant 02

d. Case Summary for Participant 02.

Participant 02's case analysis demonstrates a strong connection between authenticity and cognitive engagement. The findings indicate that learning activities perceived as authentic and relevant to real life are associated with higher levels of physiological engagement, as measured by fNIRS. This relationship is particularly evident when examining qualitative results and physiological responses within smaller segments of the learning process. For instance, the participant found real-world examples in the reading material particularly engaging, and the challenging problems in the simulation were both associated with peak hemodynamic response levels.

Within-case analysis for Participant 03

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

The data collection for Participant 03 began with a 3-minute relaxation phase to establish a pre-experiment baseline. During this phase, brain activity levels were observed to be low without any external stimuli.

- ***Reading Phase (0:03:19 - 0:06:18):***

Participant 03 started the reading phase with a low to moderate hemodynamic response level. The fNIRS brain map indicated an increase in brain activity 39 seconds into the reading. At 0:04:19, the participant completed the first page and began the second page. The participant maintained a moderate level of brain activity consistently throughout the reading. The initial reading was completed at 0:05:10, with a noted decrease in brain activity between 0:05:30 and 0:06:17 as the participant re-read the material. This phase concluded at 0:06:17, as marked in the fNIRS software. Brain activity for Participant 03 concentrated in the center of the prefrontal cortex, with no significant peaks observed during the reading.

- ***Introductory Video Phase (0:06:42 - 0:07:41):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a low to moderate level of brain activity, with higher activity in the center of the prefrontal cortex.

- ***Virtual Simulation Phase (0:07:47 - 0:12:46):***

Participant 03 engaged in the virtual science simulation for 5 minutes. The participant succeeded on the first attempt for problems one through five, with brain activity increasing slightly from low to moderate levels. From the sixth to the fourteenth problem, the participant maintained a moderate to high level of hemodynamic response as the difficulty increased. The participant answered most problems correctly on the first attempt, demonstrating an advanced understanding of the topic. The detailed time and attempt data are summarized in Table 22.

Table 22

Participant 03 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	6	Correct	
2	11	Correct	
3	17	Correct	
4	39	Correct	
5	7	Correct	
6	43	Incorrect	Incorrect
7	15	Incorrect	Correct
8	15	Incorrect	Correct
9	31	Correct	
10	7	Correct	
11	33	Incorrect	Incorrect
12	9	Correct	
13	13	Incorrect	Incorrect
14	17	Correct	

b. Interview Analysis

- ***Debriefing/Interview (0:13:03 - 0:23:01):***

The session proceeded with a debriefing/interview. A high brain activity level was observed when the participant began to debrief the learning experience. The coding results for the interview are shown in Table 23.

Table 23

Participant 03 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation
		Apply	The knowledge can be used in real life.	Simulation/Reading
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	Simulation
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Reading/Simulation
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	Simulation (Active)
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	n/a
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Reading

The participant reported that the simulation and reading provided most of the knowledge gained, whereas the video was less informative. The participant enjoyed the reading slightly more than the simulation, noting that the reading material offered substantial information but found the simulation more authentic (see Excerpt 3, line 1 to 2) and well-designed. She expressed a general interest in reading, especially if the content is informative or fictional. The participant found the knowledge from both the reading and simulation could be applied in real life (see Excerpt 3, line 3 to 4), though she felt she learned better from reading. No major challenges were noted by the participant. The participant suggested that the simulation would benefit from more explanation and acknowledged that problems in the simulation could be solved in multiple ways. The participant expressed a desire to continue learning the topic from reading (see Excerpt 3, line 5). She felt focused throughout all activities, particularly noting the simulation as the most involving activity (see Excerpt 3, line 6 to 7). The participant connected previous knowledge from math class to solve the simulation problems.

Excerpt 3.	Perceived authenticity and cognitive engagement of Participant 03
1 2	I did appreciate the authenticity of the game; it was a little bit easier at the beginning but still had the hard twist on it.
3 4	The passage did have a few things about why things were created. So, it kind of has a real life purpose to me.
5	The passage is a little bit short; I wish it was longer, I want to know more.
6 7	The game is probably the most involved because it really requires you to think about your answers and review them if you get it wrong.

- ***Post-Experiment Baseline (0:23:15 - 0:28:14):***

Finally, the participant entered a 5-minute rest phase to establish a post-experiment baseline, concluding the fNIRS data collection at 0:28:14.

c. fNIRS Analysis

This section presents the results of repeated measures ANOVA conducted to compare the hemodynamic response levels across different learning activities (Reading, Video Introduction, Simulation, and Debriefing) for Participant 03. The learning activities were segmented into one-minute blocks to achieve equal sample sizes. The mean and standard deviation for hemodynamic response levels across each learning activity are summarized in Table 24. Figure 15 illustrates the mean hemodynamic response levels for each learning phase of Participant 03.

Table 24

fNIRS Descriptive Statistics for Participant 03

Activity	Mean	SD
Reading 1	-0.028	0.095
Reading 2	-0.046	0.078
Reading 3	0.001	0.069
Video 1	-0.012	0.086
Simulation 1	0.077	0.109
Simulation 2	0.000	0.071
Simulation 3	0.007	0.090
Simulation 4	0.019	0.078
Simulation 5	0.047	0.100
Debriefing	0.031	0.079

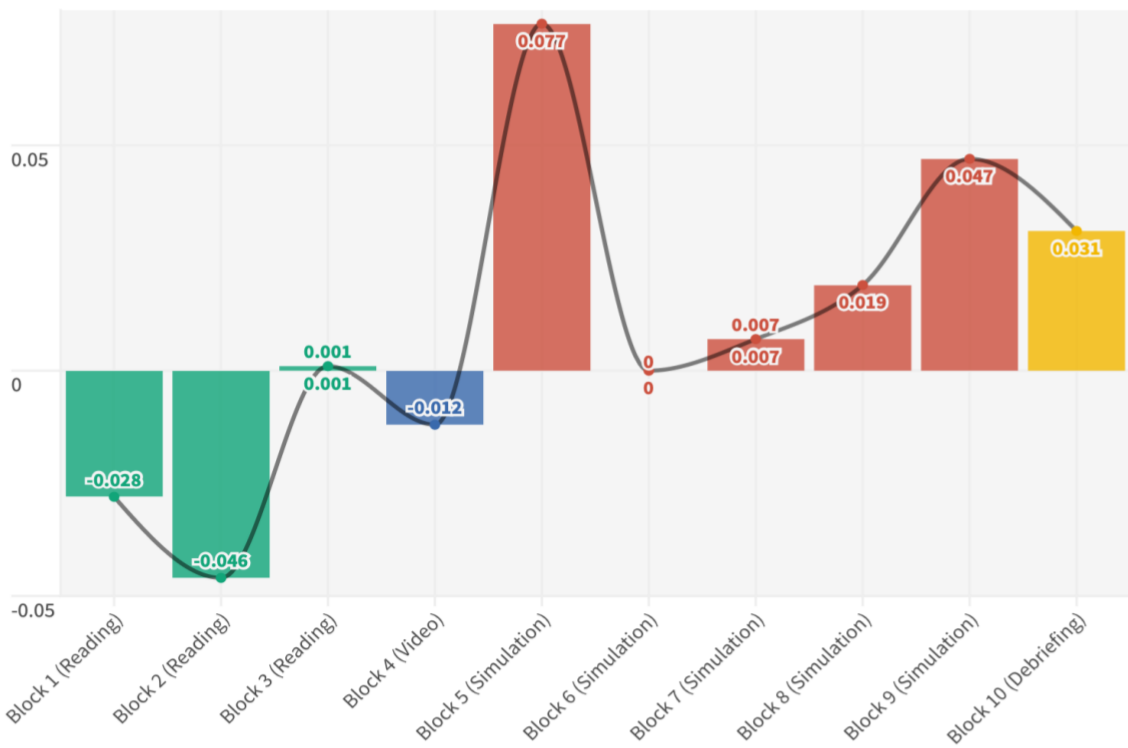


Figure 15

Mean Hemodynamic Response for Participant 03

The multivariate test results showed a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.810, $F(16, 5539) = 1471.390$, $p < .001$, partial $\eta^2 = 0.810$. These results indicate a robust overall effect of the activity type on cognitive engagement levels as measured by fNIRS. The repeated measures ANOVA revealed a significant main effect of learning activity on hemodynamic response levels, $F(16, 88864) = 1156.619$, $p < .001$, partial $\eta^2 = 0.172$. This indicates that hemodynamic response levels significantly differed across the learning activities.

d. Case Summary for Participant 03

Participant 03's case analysis illustrates a robust connection between authenticity and cognitive engagement. The findings indicate that learning activities perceived as authentic are associated with higher levels of physiological cognitive engagement, as measured by fNIRS. This relationship is particularly evident when the participant identified the simulation as the most authentic activity; it corresponded with the highest levels of physiological brain activity despite the participant showing a preference for reading over stimulation during learning.

Within-case analysis for Participant 04

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 04 established a pre-experiment baseline with a 3-minute relaxation phase. During this phase, brain activity levels were observed to be low, with no external stimuli present.

- ***Reading Phase (0:03:20 - 0:06:19):***

Participant 04 started the reading phase with a low hemodynamic response level. The fNIRS brain map indicated an increase in brain activity to a moderate level 29 seconds into the reading. This moderate level was maintained for 31 seconds before increasing to a moderate to high level. At 0:04:41, the participant completed the first page and began the second page. The initial reading was completed at 0:05:46. Brain activity fluctuated around low to moderate levels, while Participant 04 read the material for the second time. The reading phase concluded at 0:06:19, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:44 - 0:07:43):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a low to moderate level of brain activity.

- ***Virtual Simulation Phase (0:07:57 - 0:12:56):***

Participant 04 then started the 5-minute virtual science simulation. The detailed time and attempt data are summarized in Table 25.

Table 25

Participant 04 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	13	Correct	
2	12	Correct	
3	30	Correct	
4	16	Correct	
5	7	Correct	
6	43	Incorrect	Correct
7	6	Correct	
8	13	Incorrect	Incorrect
9	84	Incorrect	Incorrect
10	9	Incorrect	Correct
11	21	Correct	
12	16	Correct	
13	11	Correct	

The participant succeeded on the first attempt for problems one through five, with brain activity slightly increasing and maintaining a moderate to high level of hemodynamic response.

For the sixth problem, the participant spent more time and used two attempts to get the correct answer. The participant then selected problems from the last level of the simulation, which contained the most difficult problems. The participant's brain activity level increased significantly.

b. Interview Analysis

- ***Debriefing/Interview (0:13:13 - 0:21:10):***

The session proceeded with a debriefing/interview. A moderate to high brain activity level was observed when the participant began to share the learning experience. The participant expressed that most of the learning occurred during the virtual simulation because it helped visualize the concepts (see Excerpt 4, line 1 to 2). The participant mentioned that the reading was less effective for learning (see Excerpt 4, line 3) as he felt it lacked an objective. Participant 04 particularly enjoyed the simulation, finding it intriguing and information-rich (see Excerpt 4, line 4 to 5). The participant found the simulation relevant to real-world scenarios (see Excerpt 3, line 6 to 7) and believed the knowledge from the simulation could be applied in real life due to his interest in engineering. The different levels and challenges in the simulation motivated the participant to continue exploring the topic. The participant acknowledged that problems in the simulation could be solved in multiple ways and required different thought processes.

Excerpt 3.	Perceived authenticity and cognitive engagement of Participant 03
1 2	I knew nothing from reading. The game really helped me because it helped to visualize what I had to do.
3	I don't really understand what (concepts) the passage is trying to tell me.
4 5	During the game I was super involved and focused, but the passage I wasn't that interested. The game was like I was actually learning something.
6 7	The game, because it provided examples and situations that have happened to me before.

Table 26

Participant 04 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation
		Apply	The knowledge can be used in real life.	Simulation
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	Simulation
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Simulation
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	Simulation (Active)
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	Reading/Simulation
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Simulation/Video

Participant 04 felt highly focused when solving the most complex problems in the simulation. The participant noted that some concepts in the reading material were difficult to understand due to a lack of explanation. On the other hand, when he met challenges in the simulation, the visualization and interactive features could help him find the solutions. The participant frequently connected previous knowledge to solve simulation problems. In addition, the participant indicated that the video effectively piqued his interest in playing the simulation and exploring the topic further. The coding results for the interview are shown in Table 26.

- ***Post-Experiment Baseline (0:21:16 - 0:26:15):***

The participant ended the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, concluding at 0:26:15.

c. **fNIRS Analysis**

This section reports the results of fNIRS data analysis for Participant 04. The learning activities were segmented into one-minute blocks to achieve equal sample sizes.

A repeated measures ANOVA was conducted to compare the hemodynamic response levels across different learning activities. The significance level was set at $\alpha = 0.05$. The mean and standard deviation for hemodynamic response levels across each learning activity are summarized in Table 27.

Table 27

fNIRS Descriptive Statistics for Participant 04

Activity	Mean	SD
Reading 1	0.038	0.152
Reading 2	0.020	0.119
Reading 3	-0.082	0.171
Video 1	-0.125	0.117
Simulation 1	-0.009	0.086
Simulation 2	0.079	0.119
Simulation 3	0.052	0.100
Simulation 4	0.084	0.136
Simulation 5	0.110	0.180
Debriefing	-0.073	0.158

The multivariate test results showed a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.733, $F(15, 7560) = 1384.050$, $p < .001$, partial

$\eta^2 = 0.733$. These results indicate a robust overall effect of the activity type on cognitive engagement levels as measured by fNIRS. The repeated measures ANOVA revealed a significant main effect of learning activity on hemodynamic response levels, $F(15, 113610) = 1899.344$, $p < .001$, partial $\eta^2 = 0.200$. This indicates that hemodynamic response levels significantly differed across the learning activities.

Figure 16 illustrates the mean hemodynamic response levels for each learning phase of Participant 04.

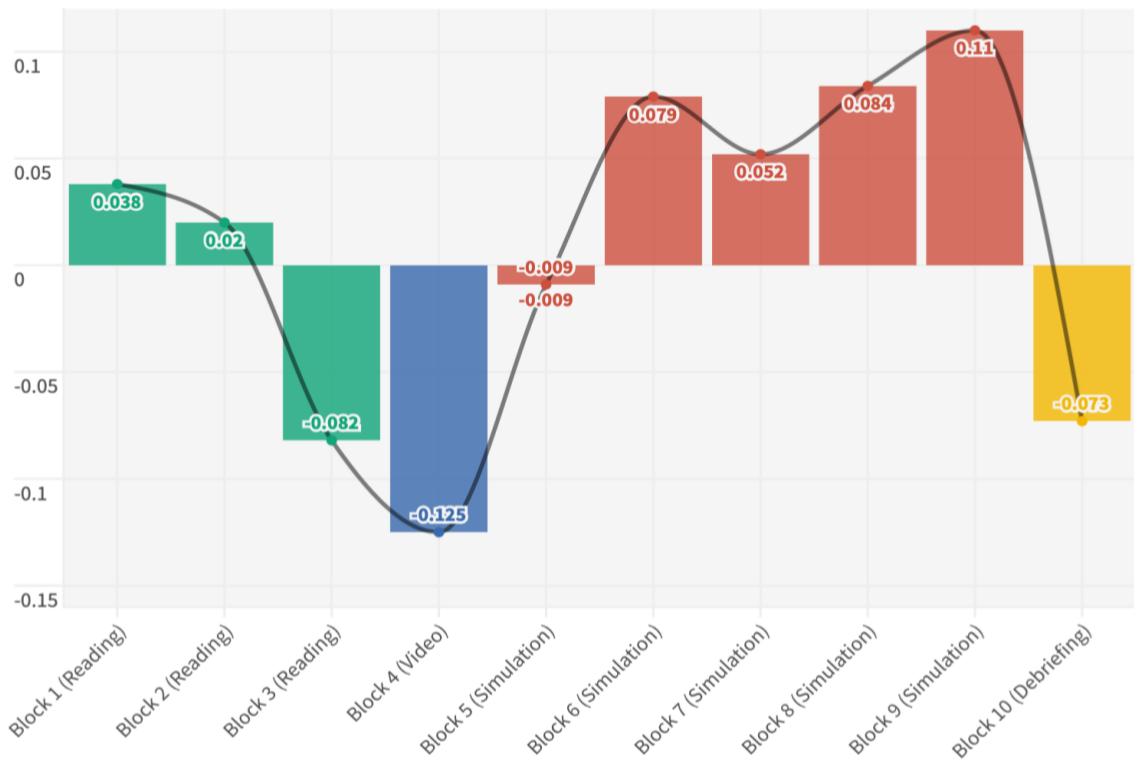


Figure 16

Mean Hemodynamic Response for Participant 04

d. Case Summary for Participant 04

Participant 04's case analysis illustrates a robust connection between perceived authenticity and cognitive engagement. The findings indicate that learning activities perceived as authentic and relevant to real life are associated with higher levels of cognitive engagement. This relationship becomes more pronounced when examining the qualitative results and physiological responses within smaller segments of the learning process. For instance, the participant found the simulation particularly beneficial for visualizing concepts and solving problems, which corresponded with peak hemodynamic response levels from the fNIRS data. On the other hand, despite the participant reporting that the video aroused the learning interest, there was still a significant gap in physiological response between the video and simulation phases. This disparity is attributed to the simulation being perceived as highly authentic, whereas the video was not.

Within-case analysis for Participant 05

a. **Descriptive Analysis of Synchronized Video Clip**

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 05 established a pre-experiment baseline with a 3-minute relaxation phase. Brain activity levels were observed to be low, with no external stimuli present.

- ***Reading Phase (0:03:18 - 0:06:17):***

Participant 05 started the reading phase with a low to moderate hemodynamic response level. The fNIRS brain map did not show significant changes during the reading. The participant completed the first page and began the second page at 0:05:43 but did not finish reading when the 3-minute period ended. The reading phase concluded at 0:06:17, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:42 - 0:07:41):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a low to moderate level of brain activity

- ***Virtual Simulation Phase (0:07:57 - 0:12:56):***

Participant 05 then started the 5-minute virtual science simulation. For the first three problems, the participant failed to get the correct answer for problems 1 and 3. Consequently, the participant decided to restart from the beginning of the simulation. The participant's brain activity level slightly increased thereafter and remained relatively stable throughout the phase. The detailed time and attempt data are summarized in Table 28.

Table 28

Participant 05 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	11	Incorrect	Incorrect
2	6	Correct	
3	20	Incorrect	Incorrect
4	10	Correct	
5	4	Correct	
6	14	Incorrect	Correct
7	17	Incorrect	Incorrect
8	10	Correct	
9	15	Incorrect	Incorrect
10	7	Correct	
11	6	Correct	
12	12	Incorrect	Incorrect
13	7	Correct	
14	23	Incorrect	Incorrect
15	17	Incorrect	Incorrect
16	5	Correct	
17	12	Incorrect	Incorrect
18	28	Correct	
19	7	Correct	

b. Interview Analysis

- ***Debriefing/Interview (0:13:20 - 0:22:59):***

The session proceeded with a debriefing/interview. A moderate brain activity level was observed at the beginning, which increased quickly when the participant started to share the experience of using an fNIRS device to monitor brain activity. The results of the interview are shown in Table 29.

Table 29

Participant 05 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Reading
		Apply	The knowledge can be used in real life.	Simulation
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	Simulation
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	n/a
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Reading
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	n/a
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	Simulation
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Reading

The participant noted that the learning experience was different from typical classes. The participant found the reading, especially on the second page, more relevant to real-world scenarios (see Excerpt 5, line 1 to 2) and believed the knowledge from the simulation could be applied in real life due to the interest in robots (see Excerpt 5, line 3 to 5). The participant acknowledged that the reading material was very informative and sparked further interest in the topic. The participant used multiple methods to solve the more difficult problems in the simulation and felt highly focused during the reading, mentioning a preference for reading and playing simulations in a quiet environment. The participant found some simulation problems challenging, especially those involving balancing objects of different weights. Previous knowledge was frequently applied to solve simulation problems.

Excerpt 5.	Perceived authenticity and cognitive engagement of Participant 05
1 2	The formular (in the reading), it's very easy for something to become unbalanced, and it happens a lot in the world.
3 4	Cause I deal with robots and stuff, so I do have to balance weight with the robot, so this could work.
5	The skill could be used on a lot of things.

- ***Post-Experiment Baseline (0:23:06 - 0:28:05):***

The participant ended the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, concluding at 0:28:05.

c. fNIRS Data Analysis

This section reports the results of the fNIRS data analysis for Participant 05. The learning activities were segmented into one-minute blocks to achieve equal sample sizes.

A repeated measures ANOVA was conducted to compare the hemodynamic response levels across different learning activities. The significance level was set at $\alpha = 0.05$. The mean and standard deviation for hemodynamic response levels across each learning activity are summarized in Table 30. The multivariate test results showed a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.840, $F(17, 6043) = 1869.252$, $p < .001$, partial $\eta^2 = 0.840$. The repeated measures ANOVA revealed a significant main effect of learning activity on hemodynamic response levels, $F(17, 103003) = 1524.802$, $p < .001$, partial

$\eta^2 = 0.201$. This indicates that hemodynamic response levels significantly differed across the learning activities. Figure 17 illustrates the mean hemodynamic response levels for each learning phase of Participant 05.

Table 30

fNIRS Descriptive Statistics for Participant 05

Activity	Mean	SD
Reading 1	-0.053	0.047
Reading 2	-0.024	0.029
Reading 3	0.032	0.064
Video 1	-0.025	0.043
Simulation 1	0.012	0.067
Simulation 2	0.018	0.048
Simulation 3	0.010	0.046
Simulation 4	0.049	0.075
Simulation 5	-0.012	0.039
Debriefing	0.048	0.099

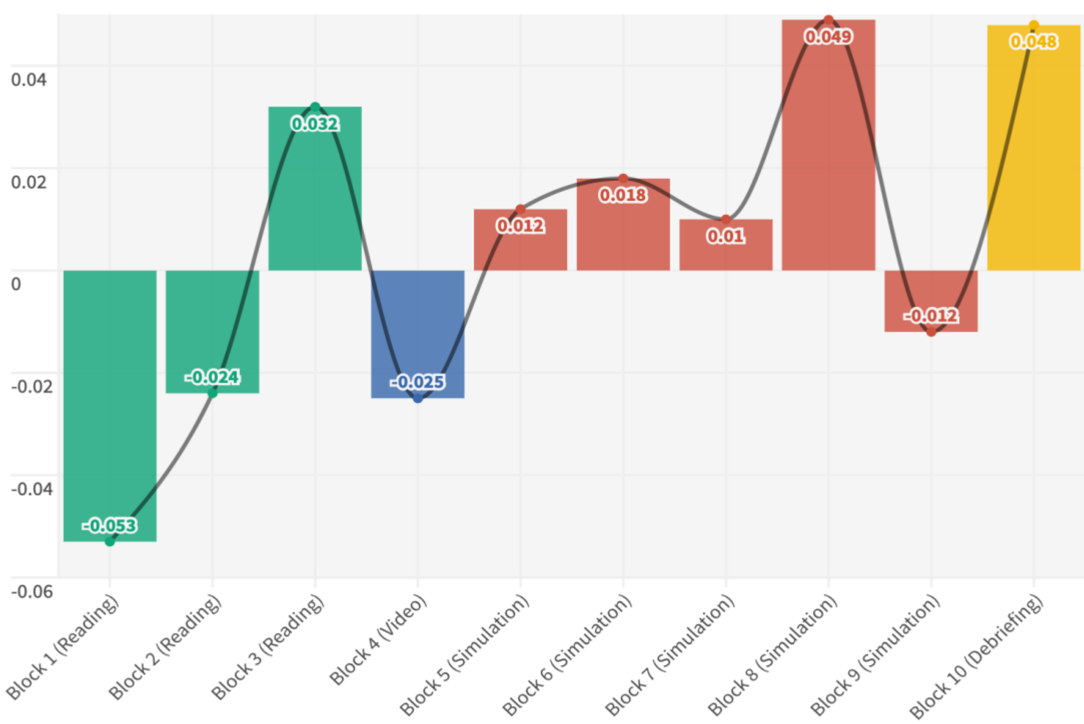


Figure 17

Mean Hemodynamic Response for Participant 05

d. Case Summary for Participant 05

This case summary integrates results from the picture-in-picture video clip and fNIRS data to provide a comprehensive understanding of Participant 05's learning experiences. The findings from Participant 05's case analysis indicate that learning activities perceived as authentic and relevant to real life, such as virtual simulation, are associated with higher levels of cognitive engagement. However, the self-reported cognitive engagement for the reading phase contradicted the physiological data. Although the participant reported a high perceived cognitive engagement level, the psychological data indicated a medium level of brain activity. Additionally, according to the picture-in-picture video analysis, the participant did not finish the reading material within the allotted time. Factors such as perceived authenticity, the difficulty level of the reading material, and the participant's interest in the topic and the activity type may have influenced Participant 05's cognitive engagement during the reading phase. During the interview, the participant admitted to being interested in the topic and generally enjoying reading. Therefore, the discrepancy could be attributed to the perceived authenticity and the difficulty level of the reading material.

Within-case analysis for Participant 06

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 06 began the session with a 3-minute relaxation phase to establish a pre-experiment baseline. During this phase, brain activity levels were observed to be low to moderate, with no external stimuli present.

- ***Reading Phase (0:03:17 - 0:06:16):***

Participant 06 started the reading phase with a low to moderate hemodynamic response level. Brain activity increased significantly within 15 seconds. The participant completed the first page and started the second page at 0:05:05. Brain activity decreased slightly by the end of the first page and increased again during the second page. The participant finished the second page at 0:06:05 and began to re-read the first page. The reading phase concluded at 0:06:16, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:35 - 0:07:34):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a moderate level of brain activity.

- ***Virtual Simulation Phase (0:07:50 - 0:12:49):***

Participant 06 then began the 5-minute virtual science simulation, starting with a moderate brain activity level.

Table 31

Participant 06 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	5	Correct	
2	7	Correct	
3	13	Incorrect	Incorrect
4	12	Correct	
5	5	Correct	
6	71	Incorrect	Incorrect
7	14	Incorrect	Correct
8	7	Correct	
9	21	Incorrect	Incorrect
10	10	Correct	
11	51	Incorrect	Incorrect
12	18	Incorrect	Incorrect
13	21	Incorrect	Incorrect

The participant correctly solved the first two problems in 12 seconds, with brain activity slightly increasing above a moderate level. The participant spent 71 seconds on the sixth problem, indicating it was challenging, and their brain activity increased to a high level. Participant 06 maintained a moderate to high brain activity level thereafter, which remained relatively stable throughout the phase. The detailed time and attempt data are summarized in Table 31.

b. Interview Analysis

- ***Debriefing/Interview (0:13:13 - 0:20:23):***

The session proceeded with a debriefing/interview, during which a moderate to high brain activity level was observed. The participant noted that the simulation was the preferred learning activity and found it more effective for learning (see Excerpt 6, line 1). The simulation was perceived as more relevant to real-world scenarios (see Excerpt 6, line 2 to 3), and the knowledge from both the reading and the simulation was considered applicable to real life (see Excerpt 6, line 4). The participant acknowledged some problems in the simulation were difficult (see Excerpt 6, line 5) and required sustained effort to solve (see Excerpt 6, line 6). Multiple methods were used to solve the simulation problems in the simulation. Participant 06 felt highly focused during the reading (see Excerpt 6, line 7) and was actively learning during both the reading and simulation phases. The simulation problems involving calculating the weights of objects on a seesaw were particularly challenging. Previous knowledge was used to understand the concepts in the reading. The participant emphasized his preference for the simulation and expressed a desire to continue exploring it at the end of the interview. The coding protocol for the interview is shown in Table 32.

Excerpt 6.	Perceived authenticity and cognitive engagement of Participant 06
1	The game, cause it was more interactive.
2 3	Maybe the game? I have used those stuffs before, like moving the weight (to get balance).
4	The game, also the readings, cause like those formulas, it’s (useful).
5	I was guessing the weight, not sure how to calculate (the weight).
6	I think I did (solve it) eventually, it took me a couple tries.
7	I was really focused on reading, trying to understand.

Table 32

Participant 06 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation
		Apply	The knowledge can be used in real life.	Reading/Simulation
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	Simulation
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners’ attention during learning	Reading
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	Reading/Simulation
	Effort	Difficulty	Learners’ internal efforts to comprehend complex ideas or solve the difficult problems.	Simulation
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Reading
	Persistence	Continue	The learning content facilitates learners’ interest to continue their learning.	Simulation

- ***Post-Experiment Baseline (0:20:29 - 0:25:28):***

The participant concluded the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, ending at 0:25:28.

c. fNIRS Analysis

The data were analyzed using repeated measures ANOVA to compare the hemodynamic response levels across different learning activities. The significance level was set at $\alpha = 0.05$. Descriptive statistics and multivariate tests were conducted to understand the differences in cognitive engagement as measured by fNIRS. The mean and standard deviation for hemodynamic response levels across each learning activity are summarized in Table 33.

Table 33

fNIRS Descriptive Statistics for Participant 06

Activity	Mean	SD
Reading 1	0.059	0.099
Reading 2	-0.061	0.073
Reading 3	0.037	0.084
Video 1	-0.005	0.077
Simulation 1	0.091	0.136
Simulation 2	-0.032	0.086
Simulation 3	0.007	0.097
Simulation 4	0.000	0.119
Simulation 5	-0.098	0.108
Debriefing	-0.032	0.094

The multivariate test results indicated a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.832, $F(15, 7055) = 2334.236$, $p < .001$, partial

$\eta^2 = 0.832$. The repeated measures ANOVA revealed a significant main effect of learning activity on hemodynamic response levels, $F(15, 7069) = 2367.373$, $p < .001$, partial $\eta^2 = 0.251$. This indicates that hemodynamic response levels significantly differed across the learning activities.

Figure 18 illustrates the mean hemodynamic response levels for each learning phase of Participant 06.

Figure 18

Mean Hemodynamic Response for Participant 06

d. Case Summary for Participant 06

Participant 06's case analysis illustrates a robust connection between perceived authenticity, cognitive engagement, and physiological responses. The findings indicate that learning activities perceived as authentic and relevant to real life are associated with higher levels of physiological engagement, as measured by fNIRS. For example, the simulation, perceived as an activity with authentic learning content and authentic learning activity, demonstrated a higher level of cognitive engagement compared to the reading, which only has authentic learning content but not authentic learning activity.

Within-case analysis for Participant 07

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 07 began the session with a 3-minute relaxation phase to establish a pre-experiment baseline. During this phase, brain activity levels were observed to be low, with no external stimuli present.

- ***Reading Phase (0:03:21 - 0:06:20):***

Participant 07 started the reading phase with a low to moderate hemodynamic response level. Brain activity increased significantly around 34 seconds into reading. The participant completed the first page and started the second page at 0:04:12. Brain activity decreased slightly by the end of the first page and increased again during the second page. The participant finished the second page at 0:05:13 and began to read the material for the second time. The participant maintained the brain activity at a moderate to high level until the end of the phase. The reading phase concluded at 0:06:20, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:44 - 0:07:43):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a low level of brain activity.

- ***Virtual Simulation Phase (0:08:02 - 0:13:01):***

Participant 07 then began the 5-minute virtual science simulation. Starting with a moderate brain activity level, the participant successfully solved 12 out of 17 problems on the first attempt. The participant's brain activity levels remained relatively stable throughout the simulation, fluctuating around a moderate level. The detailed time and attempt data are summarized in Table 34.

Table 34

Participant 07 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	6	Correct	
2	10	Correct	
3	15	Incorrect	Correct
4	32	Incorrect	Incorrect
5	5	Correct	
6	38	Correct	
7	4	Correct	
8	11	Correct	
9	23	Correct	
10	6	Correct	
11	24	Correct	
12	16	Correct	
13	14	Incorrect	Incorrect
14	18	Correct	
15	11	Incorrect	Incorrect
16	10	Correct	
17	11	Incorrect	Correct

b. Interview Analysis

- ***Debriefing/Interview (0:13:18 - 0:20:33):***

The session proceeded with a debriefing/interview, starting with a low to moderate brain activity level and increasing rapidly when the participant shared the learning experience. The results of the interview analysis are shown in Table 35.

Table 35

Participant 07 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Reading
		Apply	The knowledge can be used in real life.	Reading/Simulation
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	n/a
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	n/a
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	n/a
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Simulation
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	Reading/Simulation
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	Simulation
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Reading/Simulation

The participant noted that the simulation was more effective for learning due to its interactive nature (see Excerpt 7, line 1 to 2). The participant suggested that the reading was more closely related to the real world (see Excerpt 7, line 3) and considered the knowledge from the reading and simulation applicable in real life (see Excerpt 7, line 4). The participant believed that the problems in the simulation could be solved by different methods, but he only used his method. Participant 07 felt highly focused during the simulation, especially with more difficult problems, and less focused during reading (see Excerpt 7, line 5). The participant was actively learning during both the reading and simulation phases. Some difficult problems in the simulation required cognitive effort to solve (see Excerpt 7, line 6). Previous knowledge was frequently used to solve the problems in the simulation. The participant mentioned that both the reading and the simulation made him want to continue exploring the topic.

Excerpt 7.	Perceived authenticity and cognitive engagement of Participant 07
1 2	I think the game, cause it was more interactive compared to this, it was just reading.
3	Probably the reading, cause this (formular) is talking about the real-world force.
4	The game, cause I was actually doing it, to figure out the mass.
5	The game, I was pretty focused. The passage, not really (focused).
6	(The problem) took me a little time, but I got it.

- ***Post-Experiment Baseline (0:20:42 - 0:25:41):***

The participant concluded the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, ending at 0:25:41.

c. fNIRS Analysis

The data were analyzed using repeated measures ANOVA to compare the hemodynamic response levels across ten blocks during four learning activities. The activities included reading, video, virtual simulation, and debriefing. The significance level was set at $\alpha = 0.05$. The descriptive statistics for hemodynamic response levels across each learning activity are summarized in Table 36.

Table 36

fNIRS Descriptive Statistics for Participant 07

Activity	Mean	SD
Reading 1	-0.033	0.105
Reading 2	0.121	0.112
Reading 3	0.077	0.118
Video 1	-0.007	0.106
Simulation 1	-0.034	0.067
Simulation 2	0.052	0.085
Simulation 3	-0.030	0.093
Simulation 4	0.003	0.104
Simulation 5	-0.002	0.107
Debriefing	0.057	0.150

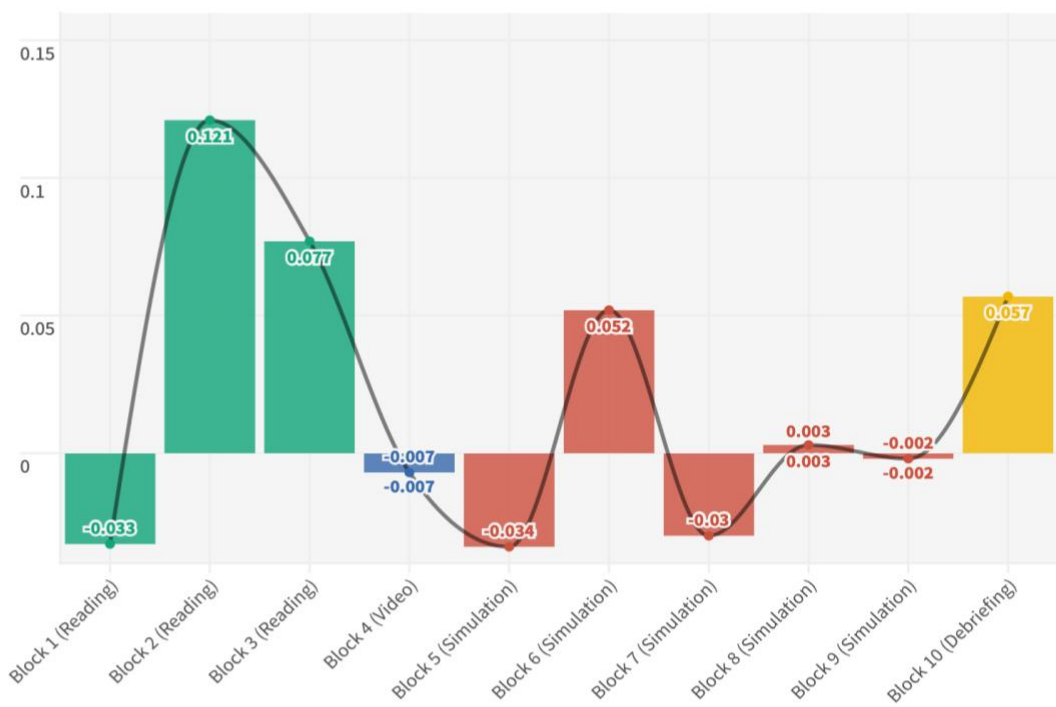


Figure 19

Mean Hemodynamic Response for Participant 07

The multivariate test results indicated a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.830, $F(15, 7055) = 2299.157$, $p < .001$, partial $\eta^2 = 0.830$. The tests of within-subjects effects showed significant differences in hemodynamic response levels across the different activities, $F(15, 106035) = 1861.779$, $p < .001$, partial $\eta^2 = 0.208$. Figure 19 illustrates the mean hemodynamic response levels for each learning phase of Participant 07.

d. Case Summary for Participant 07

Participant 07's case analysis reveals a discrepancy between self-reported engagement and physiological data. Cognitive engagement reversed between the reading and simulation phases. However, the data demonstrated a positive relationship between perceived authenticity and physiological cognitive engagement. The findings indicate that learning activities perceived as highly authentic are associated with higher levels of physiological engagement, as measured by fNIRS.

For example, the reading, perceived as having real-world relevance and application, demonstrated higher cognitive engagement levels compared to the simulation, which was perceived as less related to real-world situations. The video analysis results indicated that the participant solved most problems on the first attempt during the simulation. The lower difficulty level of the simulation tasks for Participant 07 may have reduced authenticity features such as real-world relevance, ill-defined problems, and sustained investigation, thereby affecting the participants' perceptions.

Within-case analysis for Participant 08

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 08 began the session with a 3-minute relaxation phase to establish a pre-experiment baseline. During this phase, brain activity levels were observed to be low, with no external stimuli present.

- ***Reading Phase (0:03:19 - 0:06:18):***

Participant 08 started the reading phase with a low to moderate hemodynamic response level. Brain activity increased significantly to a high level approximately 1 minute into the reading. The participant maintained this brain activity level relatively stable until the end of the phase. The first page was completed, and the second page started at 0:04:59, but the participant did not finish the second page by the end of the phase. The reading phase concluded at 0:06:18, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:43 - 0:07:42):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a moderate level of brain activity.

- ***Virtual Simulation Phase (0:08:02 - 0:13:01):***

Participant 08 then began the 5-minute virtual science simulation, starting with a low to moderate brain activity level. The participant successfully solved the first three problems on the first attempt. Brain activity levels gradually increased to high levels as the participant encountered some challenges, starting with the fourth problem. After the fourth problem, brain activity remained at a high level throughout the simulation. The detailed time and attempt data are summarized in Table 37.

Table 37

Participant 08 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	11	Correct	
2	9	Correct	
3	6	Correct	
4	49	Incorrect	Incorrect
5	8	Correct	
6	28	Correct	
7	7	Correct	
8	8	Correct	
9	29	Incorrect	Incorrect
10	4	Correct	
11	21	Incorrect	Incorrect
12	12	Correct	
13	13	Incorrect	Incorrect
14	36	Incorrect	Incorrect

b. Interview Analysis

- ***Debriefing/Interview (0:13:26 - 0:23:12):***

The session proceeded with a debriefing/interview, starting with a moderate brain activity level. The coding results for the interview are shown in Table 38.

Excerpt 8.	Perceived authenticity and cognitive engagement of Participant 06
	Probably more from the game, I am a hands-on person instead of reading or a lecture.
	Cause I can actually see how the different (weights) balancing on the seesaw instead of reading it.
	Maybe, I mean if you get a job need to balance things, yea, but if you don't get the job, maybe not.
	When I estimated the (weights), it will be easier if I have a little bit more, just a little bit more information.
	From the basic ways to think about it, and have to use other ways, like can we do this? And solve it in multiple ways.

Table 38

Participant 08 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation
		Apply	The knowledge can be used in real life.	Simulation/reading
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	Simulation
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	n/a
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Video
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	n/a
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	Simulation
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Simulation/reading

The participant noted that the simulation was more effective for learning due to its interactive nature (see Excerpt 8, line 1 to 2). The participant suggested that the simulation was more closely related to the real-world scenarios (see Excerpt 8, line 3 to 4), but expressed uncertainty about the practical application of the knowledge from reading and simulation in real life (see Excerpt 8, line 5). The participant admitted that some problems in the simulation were difficult and sometimes required estimation due to insufficient information (see Excerpt 8, line 7 to 8). Multiple methods were used to solve some problems in the simulation, and some problems required multiple attempts (see Excerpt 8, line 9 to 10). Participant 08 felt highly focused during the video, anticipating that the simulation would be the next activity. The participant did not find the simulation particularly difficult but still needed to put in effort. Previous knowledge was frequently used to solve the problems in the simulation. Both the reading and the simulation made the participant want to continue exploring the topic.

- ***Post-Experiment Baseline (0:23:26 - 0:28:25):***

The participant concluded the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, ending at 0:28:25.

c. fNIRS Analysis

The data were analyzed using repeated measures ANOVA to compare the hemodynamic response levels across ten blocks representing different learning activities, including reading, video, virtual simulation, and debriefing. The significance level was set at $\alpha = 0.05$. The descriptive statistics for hemodynamic response levels across each learning activity are summarized in Table 39.

Table 39

fNIRS Descriptive Statistics for Participant 08

Activity	Mean	SD
Reading 1	-0.080	0.059
Reading 2	0.034	0.076
Reading 3	0.040	0.041
Video 1	-0.038	0.074
Simulation 1	-0.015	0.073
Simulation 2	0.021	0.057
Simulation 3	0.080	0.060
Simulation 4	-0.009	0.043
Simulation 5	0.040	0.052
Debriefing	0.029	0.076

The multivariate test results indicated a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.864, F (18, 7557) = 2673.510, $p < .001$, partial $\eta^2 = 0.864$. The tests of within-subjects effects showed significant differences in hemodynamic response levels across the different activities, F (18, 136332) = 2445.270, $p < .001$, partial $\eta^2 = 0.244$. Figure 20 illustrates the mean hemodynamic response levels for each learning phase of Participant 08.

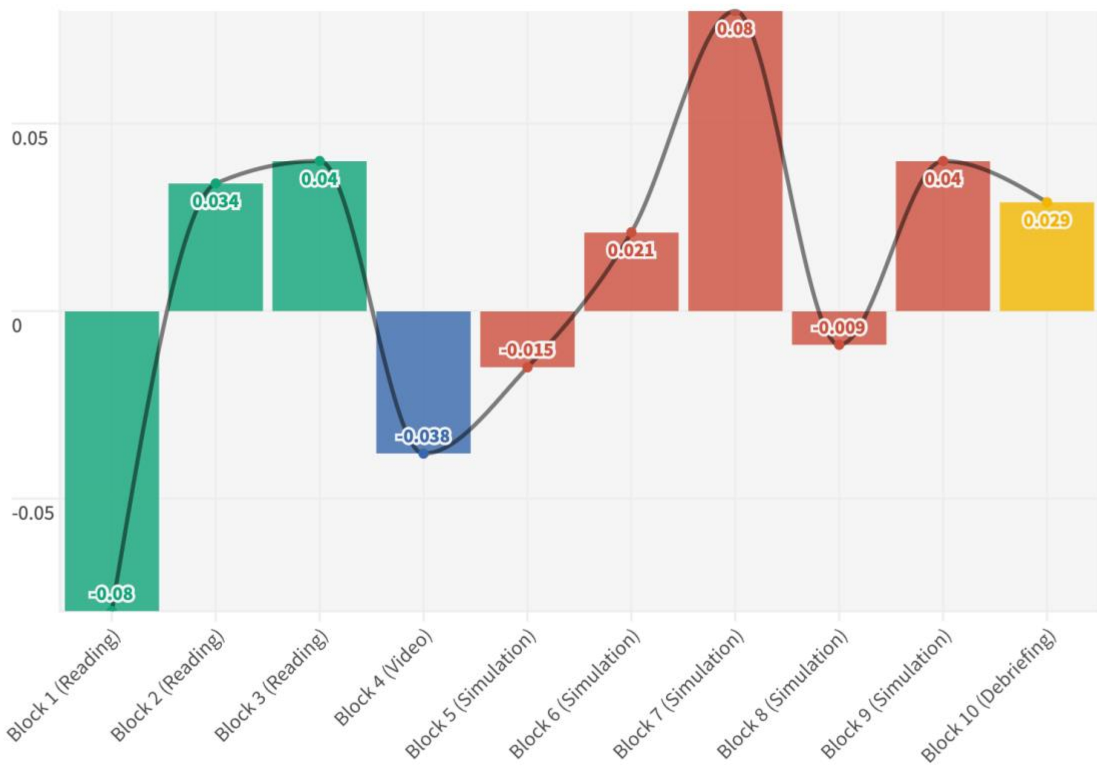


Figure 20

Mean Hemodynamic Response for Participant 08

d. Case Summary for Participant 08

Participant 08's case analysis reveals a discrepancy between self-reported engagement and physiological data. Cognitive engagement reversed for the video phase. However, the data demonstrated a positive relationship between perceived authenticity and physiological cognitive engagement. The findings indicate that learning activities perceived as highly authentic are associated with higher levels of physiological engagement, such as reading and simulation. On the other hand, the video phase was not perceived as authentic and had lower brain activity levels measured by fNIRS, despite the participant reported being highly focused during this phase.

Within-case analysis for Participant 09

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 09 began the session with a 3-minute relaxation phase to establish a pre-experiment baseline. During this phase, brain activity levels were observed to be low to moderate, with no external stimuli present.

- ***Reading Phase (0:03:18 - 0:06:17):***

Participant 09 started the reading phase with a low hemodynamic response level. Approximately 20 seconds into reading, brain activity increased significantly to a moderate to high level. The first page was completed at 0:04:20, with a slight decrease in brain activity to a moderate level towards the end of the first page. The participant finished the second page at 0:05:23, with brain activity slightly increasing from the end of the first page. The reading phase concluded at 0:06:17, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:47 - 0:07:46):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a low to moderate level of brain activity.

- ***Virtual Simulation Phase (0:08:03 - 0:13:02):***

Participant 09 then began the 5-minute virtual science simulation. Starting with a low to moderate brain activity level, the participant successfully solved the first eleven problems relatively quickly and got the correct answer for ten of them. Brain activity levels gradually increased to moderate to high levels as the participant progressed. After the fourth problem, brain activity remained at a moderate to high level throughout the simulation. The detailed time and attempt data are summarized in Table 40.

Table 40

Participant 09 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	6	Correct	
2	6	Correct	
3	14	Incorrect	Incorrect
4	17	Correct	
5	3	Correct	
6	16	Correct	
7	4	Correct	
8	7	Correct	
9	25	Correct	
10	4	Correct	
11	14	Correct	
12	24	Incorrect	Incorrect
13	12	Incorrect	Correct
14	21	Correct	
15	11	Incorrect	Incorrect
16	7	Correct	
17	8	Incorrect	Incorrect
18	23	Correct	
19	11	Incorrect	Incorrect
20	8	Correct	
21	21	Correct	

b. Interview Analysis

- ***Debriefing/Interview (0:13:20 - 0:19:42):***

The session proceeded with a debriefing/interview, starting with a low to moderate brain activity level that increased rapidly as the participant began to reflect on the learning experience. The coding results for the interview are shown in Table 41.

Table 41

Participant 09 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation
		Apply	The knowledge can be used in real life.	Simulation/reading
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	n/a
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Simulation
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	n/a
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	n/a
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation/reading
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Reading

The participant indicated that the knowledge was gained from both the reading and the simulation. The participant suggested that the simulation was more closely related to real-world scenarios and believed the knowledge from the simulation could be used in real life (see Excerpt

9, line 1). The participant did not find the problems in the simulation or the content from the reading particularly difficult but also not boring. Multiple methods were used to solve some problems in the simulation, and some problems required multiple attempts. Participant 09 felt the simulation held her attention longer, but the reading was more informative. Previous knowledge was frequently used in both the reading and the simulation (see Excerpt 9, line 2 to 3). The reading made the participant want to continue exploring the topic and felt the knowledge was useful in real life (see Excerpt 9, line 4 to 5).

Excerpt 9.	Perceived authenticity and cognitive engagement of Participant 09
1	Probably the game, because you can see how it plays out in real life.
2 3	Probably the both, I was thinking of the formulas when I was reading, and also used them in the simulation.
4 5	Probably the reading, because it has equations so I can think about it in a new perspective and use it in other situations.

- ***Post-Experiment Baseline (0:19:50 - 0:24:49):***

The participant concluded the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, ending at 0:24:49.

c. fNIRS Analysis

The data were analyzed using repeated measures ANOVA to compare the hemodynamic response levels across ten blocks representing different learning activities, including reading, video, virtual simulation, and debriefing. The significance level was set at $\alpha = 0.05$. The descriptive statistics for hemodynamic response levels across each learning activity are summarized in Table 42.

Table 42

fNIRS Descriptive Statistics for Participant 09

Activity	Mean	SD
Reading 1	0.020	0.088
Reading 2	0.066	0.096
Reading 3	0.029	0.129
Video 1	-0.032	0.138
Simulation 1	0.002	0.081
Simulation 2	0.034	0.059
Simulation 3	0.053	0.065
Simulation 4	-0.061	0.147
Simulation 5	0.116	0.111
Debriefing	0.226	0.207

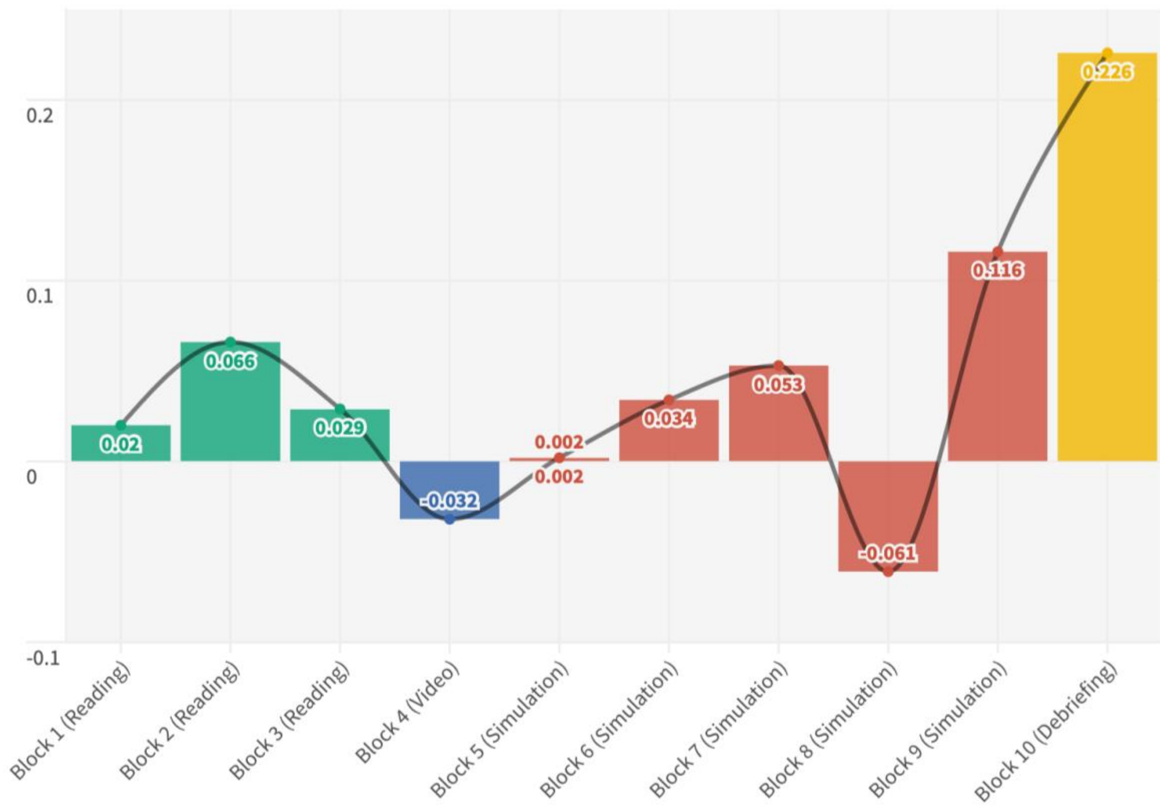


Figure 21

Mean Hemodynamic Response for Participant 09

The multivariate test results indicated a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.759, $F(14, 6046) = 1357.210$, $p < .001$, partial $\eta^2 = 0.759$. The tests of within-subjects effects showed significant differences in hemodynamic response levels across the different activities, $F(14, 84826) = 3291.460$, $p < .001$, partial $\eta^2 = 0.352$. Figure 21 illustrates the mean hemodynamic response levels for each learning phase of Participant 09.

d. Case Summary for Participant 09

Participant 09's case analysis reveals an overall positive relationship between perceived authenticity, perceived cognitive engagement, and physiological cognitive engagement. The fNIRS data indicated that during the reading and most of the simulation phase, brain activity levels were relatively stable and maintained at moderate to high levels. The simulation analysis report suggested that the participant solved most of the problems with ease, demonstrating an advanced understanding of the topic. This ease likely decreased the perceived authenticity level due to the lack of challenge.

However, as the difficulty increased for the last several problems, the brain activity level also increased significantly. The peak hemodynamic response level appeared during the beginning of the debriefing session, an authentic learning activity where the participant engaged in a metacognitive process to reflect on and assess the learning experience. This pattern underscores the importance of an appropriate difficulty level for authenticity and cognitive engagement.

Within-case analysis for Participant 10

a. Descriptive Analysis of Synchronized Video Clip

- ***Pre-Experiment Baseline (0:00:01 - 0:03:00):***

Participant 10 began the session with a 3-minute relaxation phase to establish a pre-experiment baseline. During this phase, brain activity levels were observed to be moderate, with no external stimuli present.

- ***Reading Phase (0:03:22 - 0:06:21):***

Participant 10 started the reading phase with a moderate hemodynamic response level. The first page was completed at 0:04:20, during which brain activity gradually increased from the beginning of the reading. The participant finished the second page at 0:04:59, with brain activity remaining stable. As the participant re-read the material, brain activity levels appeared slightly higher than during the initial reading. The reading phase concluded at 0:06:21, as marked in the fNIRS software.

- ***Introductory Video Phase (0:06:49 - 0:07:48):***

Following the reading phase, the participant watched a 1-minute introductory video for the virtual science simulation. The brain map indicated a low to moderate level of brain activity.

- ***Virtual Simulation Phase (0:08:07 - 0:13:06):***

Participant 10 then began the 5-minute virtual science simulation. Starting with a low to moderate brain activity level, the participant successfully solved the first five problems relatively quickly, answering correctly on the first attempt. Brain activity levels gradually increased to moderate to high levels as the participant progressed and remained relatively stable throughout the simulation. The detailed time and attempt data are summarized in Table 43.

Table 43

Participant 10 Virtual Simulation Outcome

Problem	Time (s)	Attempt 1	Attempt 2
1	8	Correct	
2	6	Correct	
3	7	Correct	
4	27	Correct	
5	4	Correct	
6	43	Incorrect	Correct
7	11	Incorrect	Correct
8	5	Correct	
9	27	Incorrect	Incorrect
10	7	Correct	
11	20	Correct	
12	10	Correct	
13	11	Incorrect	Correct
14	26	Incorrect	Correct
15	6	Correct	
16	9	Correct	
17	11	Incorrect	Incorrect
18	18	Correct	

b. Interview Analysis

- ***Debriefing/Interview (0:13:28 - 0:21:59):***

The session proceeded with a debriefing/interview. The coding results for the interview are shown in Table 44.

Excerpt 10.	Perceived authenticity and cognitive engagement of Participant 10
1	Probably more from the game because you got to try out.
2 3	Probably the game, once again, you had to try out, and figure out yourself. But in the passage, it’s kind of like just giving it to you.
4	Definitely the games. Because of the examples, and objects, stuff like that.
5 6	Yea, definitely, if you try to weigh something or balance something, I think it would help.
7	I think the reading gives the basics (principles), and the game helps you practice it.
9	Yea, I have tried (multiple ways) to figure it out.
10	Pretty often, I tried to refer to the formular reading and apply that to the simulation.

Table 44

Participant 10 Interview Data Coding Results

Construct	Dimension	Code	Definition	Activity
Authenticity	Real World Relevance	Relate	The learning activity is closely related to a real-world situation.	Simulation
		Apply	The knowledge can be used in real life.	Simulation/Reading
	Ill-defined Problem	Challenge	The problem is challenging and does not have a clear answer.	n/a
	Sustained investigation	Keep	The learning task requires sustained investigation to complete.	Simulation
	Multiple interpretations and outcomes	Methods	Using multiple ways to solve the learning tasks.	Simulation
Cognitive Engagement	Attention	Focus	Learners' attention during learning	Simulation
		Active/Passive	Whether the learners are actively learning or passively receiving the information.	Simulation
	Effort	Difficulty	Learners' internal efforts to comprehend complex ideas or solve the difficult problems.	n/a
	Previous knowledge	Connect	Using previous knowledge to understand new knowledge or solve new problems.	Simulation
	Persistence	Continue	The learning content facilitates learners' interest to continue their learning.	Simulation

The participant began to reflect on the learning experience with moderate brain activity. The brain activity gradually increased to a moderate to high level after one minute into the simulation. The participant indicated that most of the knowledge was gained from the simulation (see Excerpt 10, line 1), and highlighted the interactive nature of it (see Excerpt 10, line 1 to 3). The participant suggested that the simulation was more closely related to real-world scenarios (see Excerpt 10, line 4) and believed the knowledge from both the reading and the simulation could be used in real life (see Excerpt 10, line 5 to 8). The participant did not find the problems in the simulation or the content from the reading particularly difficult. Multiple methods were used to solve some problems in the simulation, and some problems required multiple attempts (see Excerpt 10, line 9). Participant 10 felt highly focused and actively learning during the simulation. The participant mentioned that the reading and some of the problems in the simulation felt a little too easy and expressed a preference for more challenging content. Previous knowledge was frequently used in the simulation (see Excerpt 10, lines 10 to 11). The simulation made the participant want to continue exploring since it became more and more challenging towards the end.

- ***Post-Experiment Baseline (0:22:17 - 0:27:16):***

The participant concluded the fNIRS data collection with a 5-minute rest phase to establish a post-experiment baseline, ending at 0:24:49.

c. fNIRS Analysis

The data were analyzed using repeated measures ANOVA to compare the hemodynamic response levels across ten blocks representing different learning activities, including reading, video, virtual simulation, and debriefing. The significance level was set at $\alpha = 0.05$. The descriptive statistics for hemodynamic response levels across each learning activity are summarized in Table 45.

Table 45

fNIRS Descriptive Statistics for Participant 10

Activity	Mean	SD
Reading 1	0.022	0.042
Reading 2	0.020	0.047
Reading 3	0.043	0.046
Video 1	0.008	0.049
Simulation 1	-0.014	0.045
Simulation 2	0.039	0.046
Simulation 3	0.056	0.066
Simulation 4	0.063	0.060
Simulation 5	0.088	0.079
Debriefing	-0.022	0.110

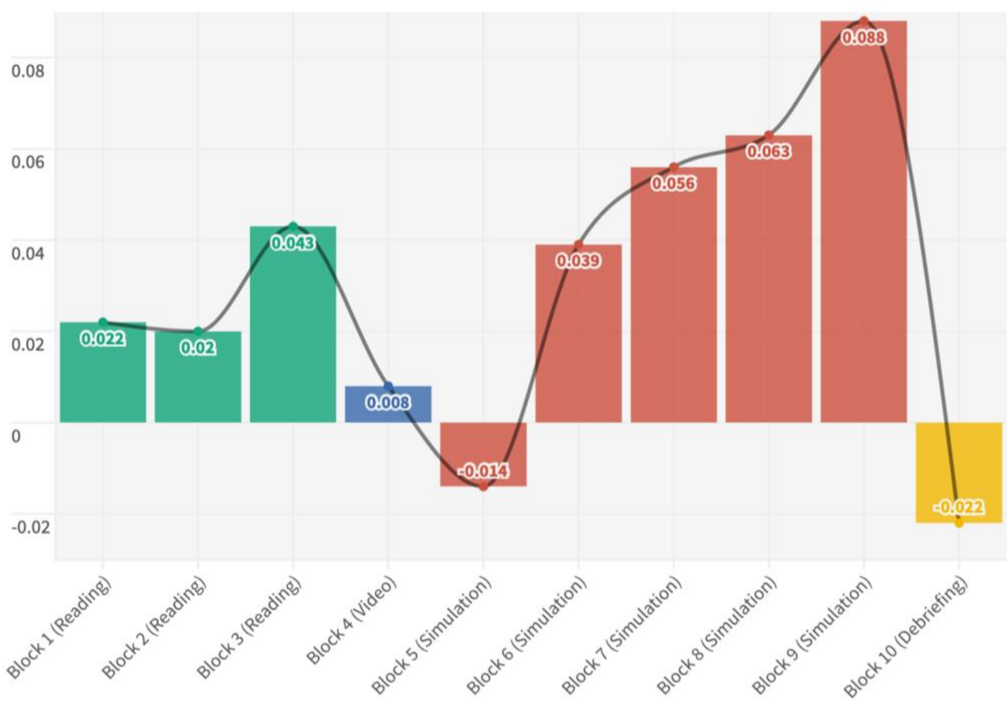


Figure 22

Mean Hemodynamic Response for Participant 10

The multivariate test results indicated a significant effect of learning activity on hemodynamic response levels, Pillai's Trace = 0.892, $F(16, 7559) = 3915.203$, $p < .001$, partial $\eta^2 = 0.892$. The tests of within-subjects effects showed significant differences in hemodynamic response levels across the different activities, $F(16, 121184) = 5487.830$, $p < .001$, partial $\eta^2 = 0.420$. Figure 22 illustrates the mean hemodynamic response levels for each learning phase of Participant 10

d. Case Summary for Participant 10

Participant 10's case analysis reveals an overall positive relationship between perceived authenticity, perceived cognitive engagement, and physiological cognitive engagement. The fNIRS data indicated that during the reading and most of the simulation phases, brain activity levels were relatively stable and maintained at moderate to high levels. The simulation analysis suggested that the participant solved most of the problems with ease, demonstrating an advanced understanding of the topic. This ease likely decreased the perceived authenticity level due to the lack of challenge. As the difficulty increased for the last several problems in the simulation, the perceived authenticity rose, and the brain activity level correspondingly increased.

Appendix E

fNIRS Data Preprocessing Operation

Figure 23 is a screenshot of the NIRSIT Quest software that presents the steps used to preprocess the fNIRS data, which include removing invalid values, checking the signal-to-noise ratio (SNR) for each channel, correcting motion artifacts, and applying digital filtering.

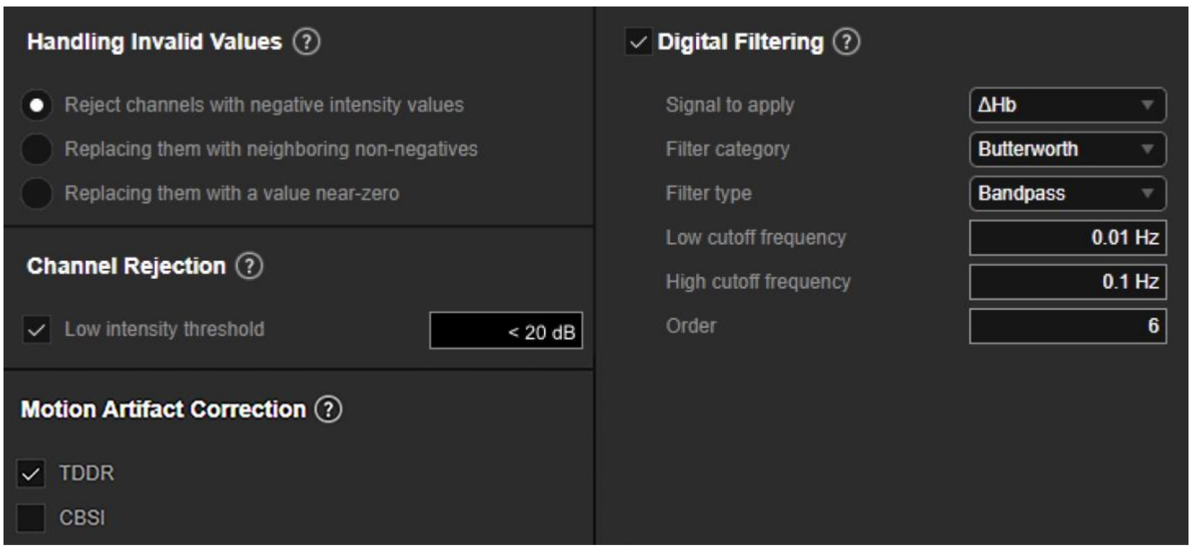


Figure 23

Advanced Options for fNIRS Data Preprocessing

- **Handling Invalid Values:** Channels with invalid values (such as negative intensity values, which can occur when the device is not properly attached to the participant's forehead) are excluded from further analysis.
- **Channel Rejection:** Remove channels where the SNR is below 20 dB (Yücel et al., 2021).

- **Motion Artifact Correction:** Use the Temporal Derivative Distribution Repair (TDDR) method to identify and correct discontinuities in the fNIRS data caused by motion (Fishburn et al., 2019).
- **Digital Filtering:** The Butterworth bandpass filter, with low and high cutoff frequencies, is applied to process the hemoglobin concentration signal (Cooper et al., 2012). The low cutoff frequency is set at 0.01 Hz, while the high cutoff frequency is set at 0.1 Hz (Vitorio et al., 2017).