Cyprus University of Technology

Faculty of Fine and Applied Arts

Doctoral Dissertation

Embodied Technologies: Integration and orchestration in authentic classroom contexts

Marianna Ioannou

Limassol, June 2023

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF FINE AND APPLIED ARTS

DEPARTMENT OF MULTIMEDIA AND GRAPHIC ARTS

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Approval Form

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ABSTRACT

A new generation of technologies that harness the affordances of motion is gaining the attention of the educational community due to evidence that they can enhance student engagement and embodied learning. However, integrating these embodied learning technologies in classroom contexts requires appropriate pedagogical strategies and guidelines, which are not yet well-defined. This dissertation addresses this gap by exploring the integration and orchestration of embodied learning technologies in authentic classroom contexts. It documents orchestration strategies and guidelines for successful integration, based on evidence drawn from four cycles of design-based research (DBR). The first DBR cycle investigated the main challenges of introducing technology-enhanced embodied learning in a classroom context and how the experience was perceived by the learners. The second DBR cycle sought to understand what pedagogical elements might be considered for establishing meaningful integration of embodied learning technology around complete lessons. It also extended our understanding of students' perceptions of the learning experience in high-embodied vs low-embodied technology-enhanced embodied learning conditions. In the third DBR cycle, we applied initial principles for orchestrating technology-enhanced embodied learning in the classroom. We designed a classroom experience for embodied learning in learning stations with students rotating on a fixed schedule, using high-embodied technologies along with more conventional paper-and-pencil tools. At the end of this cycle, newly generated design principles for real-world classroom settings were documented. In the fourth and last cycle of work, we aimed to replicate and confirm the orchestration strategy derived from the previous cycle and we revisited learning aspects in technology-enhanced embodied learning which were unclear in earlier cycles of the work. The dissertation concludes with practical guidelines and implications for educators and researchers who wish to incorporate embodied learning technologies in their curricula toward an engaging learning experience in real-world classrooms.

Keywords: embodied technologies, technology-enhanced embodied learning, technology integration, classroom orchestration

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LIST OF ABBREVIATIONS

CUT:	Cyprus University of Technology
DBR:	Design Based Research
AR	Augmented Reality
VR	Virtual Reality
XR	Extended Reality
LEAF	Learning in Embodied Activity Framework
TUIs	Tangible User Interfaces
IEF	Instructional Embodiment Framework
CSCL	Computer Supported Collaborative Learning
ICLS	International Conference of the Learning Sciences
INTELed	INnovative Training via Embodied Learning and multi-sensory techniques for inclusive Education
ULEs	Ubiquitous Learning Environments
ER	Educational Robotics
CSCL	Computer Supported Collaborative Learning
ADHD	Attention Deficit Hyperactivity Disorder
ASD	Autistic Spectrum Disorder
CAMYS	Computer Attitude Measure for Young Students questionnaire

1 INTRODUCTION

In recent years, there has been a renewed interest in embodiment with a growing corpus of studies exploring child computer interaction through gesture, touch, movement, and other modalities. The increased interest in embodiment reflects the need to highlight the aspects of motion and physicality as a crucial part of the learning process (Antle, Corness, & Droumeva, 2009; Melcer, & Isbister, 2016). This interest is also based on the growing awareness of the cultural, embodied and situated nature of human cognition in different scientific fields of cognitive science (Wilson, 2002; Wilson, & Foglia, 2011; Glenberg, Witt, & Metcalfe, 2013; Barsalou, 2008) and due to the widespread population of affordable motion-based technologies (e.g., Wii, Xbox Kinect, Leap Motion), natural user interfaces and extended reality technologies (AR, VR, XR) which have nowadays opened the doors for the design of technology-enhanced embodied interactions.

Many researchers stated that the effectiveness of employing technology to help teaching and learning processes varies depending on how technology is used during instruction (Chauhan, 2017; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). However, challenges of implementing technology-enhanced embodied learning in classroom settings and developing appropriate pedagogical strategies have not been explored (Southgate 2020). There is an important need for research that will provide guidelines for sensorimotor and embodied interactions which meaningfully exploit action-based experiences (Jha, Price, & Motion, 2020). According to Prieto, Villagrá-Sobrino, Jorrín-Abellán, Martínez-Monés, & Dimitriadis (2011), unless there is also a pedagogically effective orchestration of such technologies, the increasing use of various technologies in the classroom does not ensure an enhancement of the learning experiences of students. Identifying the best pedagogy can frequently be challenging whilst there is dearth of research demonstrating how to translate research in areas like embodied cognition and learning into classroom practice and how to best assess the effectiveness of this translation.

Drawing on these ideas, four Design-Based Research (DBR) cycles of work aimed to investigate the main challenges when implementing technology-enhanced embodied learning in authentic classrooms and present ways of integrating and orchestrating embodied interaction with digital content so that it can be educationally beneficial. This dissertation presents orchestration strategies and guidelines that researchers, learning designers, and educators should take into account when considering embodied technology for educational use.

1.1 Identifying the research gap

This millennium we have witnessed a surge in the creation of novel interfaces and new technologies that do not require external control devices (i.e., mouse) to manipulate objects on the screen but instead utilize the user's own gestures and body position (Black, Segal, Vitale, & Fadjo, 2012). These interfaces and technologies look very promising and, ultimately, an exciting development for education. They can bring new dynamics to classrooms and provide educators with more options for pedagogical activities that support active learning approaches (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014). Student learning, understanding, and motivation can be enabled by a rich perceptual environment using multiple sensory modalities (e.g., using visuals, voiceovers, and movement) (Han, & Black, 2011).

While there is a substantial body of literature describing the integration and orchestration of more traditional interface systems and technologies into learning environments, emerging technologies like embodied learning technologies typically lack this foundation (Girotto, Lozano, Muldner, Burleson, & Walker, 2016; Diáz, & Ioannou, 2019). They have been scattered efforts from researchers and educators to incorporate embodied learning technologies into classrooms (Xu, Kang, & Yan, 2021), yet a gap remains to be addressed relative to their potential for learning as well as practicalities of selecting and implementing them in classroom settings. For many schools and educators, the meaningful integration and orchestration of embodied technologies for learning remains a challenge.

Embodied learning technologies have shown efficacy in laboratories with ideal supportive conditions, but their effectiveness in classroom with "real-world" constraints is yet under studied (Alberto, van Helden, & Bakker, 2022). Yet, classrooms are socially active, often unpredictably unexpected environments that yield unique and valuable insights into the deployment of technology "in the field" (Southgate, Smith, Cividino, Saxby, Kilham, Eather, & Bergin, 2019). As embodied technology is finding its way into the classroom, understanding the facilitators and barriers for deployment has become an important part of the process. These constraints, referred to as the "logistics" of classrooms by Nussbaum and Diaz (2013), who emphasize that these issues do not relate to a broad theory of learning but rather to practical concerns that, if ignored, could sabotage even the most successful instructional design. To overcome the limitations of technology-enhanced embodied learning in authentic classroom settings and to design engaging and effective learning experiences for students, we need research looking at the classroom practicalities of improving teaching and learning, known as classroom orchestration.

The inclusion of embodied learning in a classroom setting increases the complexity that educators must deal with. When technology is available, techniques that are used in "traditional" settings can no longer be applied in a routine-like manner, and significant changes to what may be the typical classroom routine are also necessary. It is thus logical to assume that integrating embodied learning technologies in typical classroom will demand a new repertoire of teaching strategies (Munro, 2018; Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010) and different techniques, approaches, and activities. Models of successful embodied technology use must combine the introduction of embodied technology tools with new instructional approaches and new organizational structures. Unfortunately, the existing research falls short of providing such clear measures of effectiveness for technology-enhanced embodied learning in authentic classrooms. Furthermore, because embodied learning technologies are an "increasingly complex and varied medium, available in an expanding range of formats and places" (Olson, 2010, p. 185), it is likely that many educators feel ill-equipped to make informed decisions related to deploying technology-enhanced embodied learning for their classrooms. The scope of this research is to develop specific pedagogical strategies (Pirker, Holly, Almer, Gütl, & Belcher, 2019) for the effective orchestration of technology-enhanced embodied learning technologies in the classroom, to overcome the challenges associated with their implementation.

1.2 Research design and research objectives

The overarching goal of this work was to address technology-enhanced embodied learning in authentic classroom contexts and present orchestration strategies and guidelines that will enable wider application. This dissertation uses the Design-Based Research (DBR) methodology, which deals with the complexity of real-life settings by methodically designing and changing the learning environment over time, collecting evidence of the various changes that recursively feed into future designs (Brown, 1992; Collins, 1992; Design-based Research Collective, 2003; Barab, 2006; Reeves, 2006). The principal objectives of this research are as follows:

1) Understanding the main challenges of introducing technology-enhanced embodied learning in a classroom context and how the experience is perceived by the learners (RQ 1.1., RQ1.2)

2) Understanding students' learning and perceptions of the learning experience in a high-embodied vs low-embodied condition (RQ2.1, RQ2.2)

3) Documenting classroom orchestration strategies for successful embodied learning in the classroom (RQ3.1)

4) Replicating and confirming the orchestration strategy and revisiting learning aspects (RQ4.1, RQ4.2)

These objectives were addressed in the following DBR cycles:

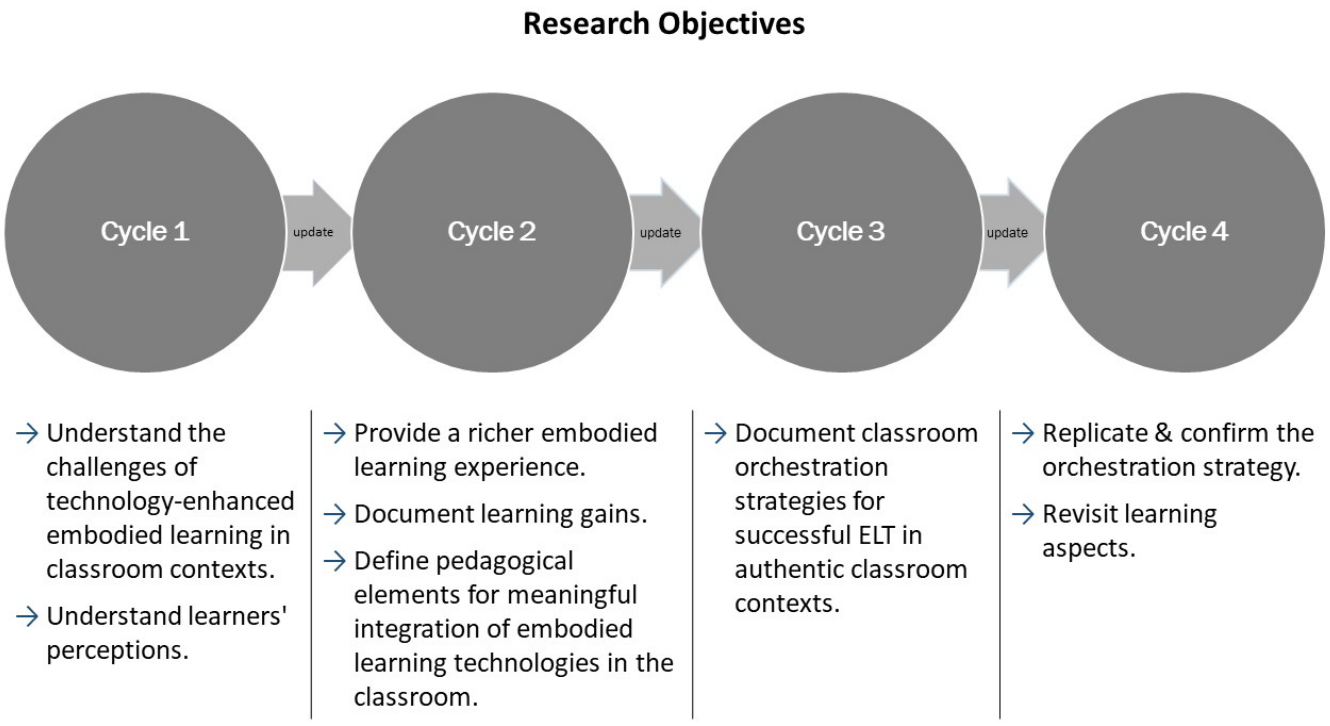
- DBR Cycle 1 was an exploratory case study of integrating embodied learning using interactive floor technology in a mainstream classroom in a math lesson about fractions. DBR cycle 1 aimed to advance our understanding of the main challenges of introducing technology-enhanced embodied learning in a classroom context and how the experience is perceived by the learners.

- DBR Cycle 2 aimed to provide a richer embodied learning experience (using Kinect based technology) and to document gains in the learning domain, in addition to revealing positive emotions evident in DBR Cycle 1. Also, drawing on DBR Cycle 1 outcomes, DBR Cycle 2 sought to understand what pedagogical elements might be considered for establishing meaningful integration of embodied learning technology in the classroom, around complete lessons.

- In DBR Cycle 3, we apply initial design principles for orchestrating technology-enhanced embodied learning in the classroom. We designed the classroom experience for embodied learning in learning stations with students rotating on a fixed schedule, using high-embodied technologies along with more conventional paper-and-pencil tools. At the end of this design-based cycle, newly generated design principles related to the real-world design setting and related literature were presented.

- In DBR Cycle 4, we tried to replicate and confirm the orchestration strategy that derived from DBR Cycle 3 and to revisit learning aspects in technology-enhanced embodied learning which were unclear in earlier cycles of the work. In DBR Cycle 4, all learning stations enacted some form of an embodied learning experience using technologies such as virtual reality, robot programming, tablets. Design principles that proved successful in the previous cycle were applied and enriched. Namely, this cycle presented a meaningful integration of such technology in a complete lesson, whilst documenting learning gains for the participating students.

Figure 1 presents a summary of the research objective and the research questions (RQs) for each DBR cycle.



Cycle 1:
→ Understand the challenges of technology-enhanced embodied learning in classroom contexts.
→ Understand learners' perceptions.

Cycle 2:
→ Provide a richer embodied learning experience.
→ Document learning gains.
→ Define pedagogical elements for meaningful integration of embodied learning technologies in the classroom.

Cycle 3:
→ Document classroom orchestration strategies for successful ELT in authentic classroom contexts.

Cycle 4:
→ Replicate & confirm the orchestration strategy.
→ Revisit learning aspects.

Figure 1: DBR cycles and research objectives

1.3 Structure of the thesis

This dissertation is structured into nine chapters, in addition to this introduction. The structure is the result of the Design-Based Research (DBR) methodology adopted in this work and elaborated in the third chapter. In summary

- Chapter 1 constitutes an introduction to the study, presenting the research gaps, and a summary of the major findings and the importance of this work.
- Chapter 2 presents the conceptual framework, which includes theoretical perspectives on embodied cognition, embodied learning taxonomies and models, and views on classroom orchestration along with orchestration frameworks.
- Chapter 3 presents an overview of empirical research in the field of embodied learning and orchestration of technology-enhanced embodied learning environments.
- Chapter 4 focuses on design-based research methodology (DBR) and our four stages of this DBR work in consecutive cycles. Per DBR methodology, each cycle of work operates with one another to inform theory, strengthen the design of learning experience and present practical examples and guidelines. This chapter develops by discussing the processes followed to ensure validity, reliability, and compliance with research ethics guidelines. This chapter also gives information regarding the participants in the four cycles of work, procedures, and data collection methods.
- The four chapters that follow - Chapter 5, Chapter 6, Chapter 7 and Chapter 8 - are detailed descriptions of the four cycles of the study, Cycle 1, Cycle 2, Cycle 3 and Cycle 4 respectively. The chapters follow the steps of this DBR, and all include a reflection on the findings of the study, becoming the trigger for the next cycles of work.
- In Chapter 9 we summarize key findings from the research cycles and discuss these findings holistically, drawing on knowledge from across cycles of work, demonstrating our progression of understanding regarding the overarching research objectives of the work. The chapter concludes with a discussion of contributions to current knowledge, limitations of the overall DBR work, and suggestions for future research.

1.4 Major findings and importance of this work

Technological advancements are rapidly creating new opportunities for education. With each new technology, there is a need to conduct research into its optimal application. Teaching and learning approaches should not remain static but should constantly evolve to embrace new pedagogies and technologies, such as technology-enhanced embodied learning. However, there has been limited empirical research on the intersection of pedagogy and practice of embodied learning in authentic settings. This work contributes to an underdeveloped area of research by addressing technology-enhanced embodied learning and classroom orchestration in real classrooms. At a time when embodied interaction becomes more commonplace through a range of devices, this dissertation offers practical examples of technology-enhanced embodied learning in authentic classrooms. We integrated and orchestrated several embodied learning technologies and tested learning experience designs that resulted in a set of guidelines. Our orchestration strategies and guidelines highlight effective ways of implementing technology-enhanced embodied learning in authentic classroom settings.

Across the four cycles of the DBR research, transforming of the classroom into an embodied learning environment presented challenges that included: (1) a single teacher in a dynamic environment, (2) addressing practicalities of serving a large group of students, (3) considering local contexts and adoption preferences, which are inherent in real classrooms but not captured by laboratory studies, and (4) providing professional development for teachers who are less familiar with, or convinced of, the embodied pedagogy. In terms of students' perceived experience, the study documented personal development factors, student relationship factors, and system maintenance and change factors affecting the learning experience. Overall, the findings from this study support the notion that technology-enhanced embodied learning can be significantly improved when evidence-based orchestration strategies are employed.

The dissertation presents concrete strategies for classroom orchestration of technology-enhanced embodied learning, which include aspects of learning design (i.e., co-designing the experience and professional development), classroom regulation and management (i.e., implementing a learning stations rotation model), teacher strategies (i.e., moving from group discussions to quick debriefing at plenary), teacher adaptability and flexibility in the dynamic environment, awareness and assessment (i.e., identifying misconceptions through formative assessment all the way). Orchestration strategies from DBR Cycle 3, were transformed into a set of practical guidelines on classroom orchestration for technology-enhanced embodied learning that were further refined and reinforced in DBR Cycle 4. These guidelines are framed by the three components of the orchestration model of Prieto et al., (2011): *Pragmatism/Practice*. The work was performed in real classroom settings making the guidelines a robust set of techniques for orchestrating embodied learning activities. *Alignment/Synergy*. Our approach used minimal and manageable resources for implementation; we used known technology that allowed learners to interact with the learning content via gestures/body movement. *Models/Theories*. We formulated a set of practical guidelines on classroom orchestration for technology-enhanced embodied learning that are detailed in DBR Cycle 3: co-design with stakeholders (i.e, researchers and practitioners designing the learning experience together), create learning stations (both high-tech and low-tech stations can be included), keep group-size small (i.e., support teamwork via collaboration scripts), holding debriefing sessions (i.e., encouraging reflection between stations), and scaffolding learning (i.e., providing guidance, feedback, and prompts).

Overall, this research is one of the few that employs DBR methodology to address the challenges of implementing technology-enhanced embodied learning in authentic classrooms. As embodied learning technologies continue to gain popularity, this research helps to identify and address issues related to their pedagogical use via empirical enactment and evaluation. Moreover, it provides evidence-based guidelines to assist in the integration and orchestration of technology-enhanced embodied learning in authentic classroom settings. These guidelines can be used by educators, learning designers, and researchers to further advance the field. Ultimately, this dissertation contributes valuable knowledge to the broader educational technology research community by shedding light on the effective use of embodied learning environments in school contexts.

2 FRAMEWORK

The conceptual framework of the study draws on theories of embodied cognition and embodied learning and on models of classroom orchestration with an emphasis on technology-enhanced embodied learning. The chapter starts with presenting theoretical work on embodied cognition, technology-enhanced embodied learning, and embodied learning taxonomies. Then, the chapter presents models of classroom orchestration as applied to the context of technology-enhanced (embodied) learning. The conceptual framework presented aims to guide the design of the interventions and learning environments in this study, building on knowledge from theory and practice.

2.1 Embodied cognition theory

Cartesian views on the body and mind dualism, which stance that mind and body are two distinct substances (Radford, 2014), have been left behind in the dust of modern cognitive theories which offer a different approach to the understanding of human cognition. New research builds on the idea that cognition takes place through an intimate coupling of brain, body, and environment (Chemero, 2009; Gibson, 1977, 1986; Goodwin 2007; Merleau-Ponty, 1962; Thelen, & Smith, 1994); that being a human has a significant impact on and limits human intellect, and that phenomenology must be used to study human experience. From this perspective, phenomenology suggests "a newwere" between the thinking self and what it feels like to experience ourselves in the first person, not as separate "minds" and "bodies," but rather as unified beings who act in the world because our bodies behave in certain ways (Merleau-Ponty, 1962). According to contemporary cognitive theories (Bautista, & Roth, 2012; Borba, & Villareal, 2006; Edwards et al., 2009; Lakoff, & Nunez, 2000; Sheets-Johnstone, 2009), our tactile-kinesthetic bodily experience of the world and our interaction with artifacts are much more than transient or merely secondary aspects of cognition.

Embodied cognition theory is a decades-long branch of research that encompasses a diverse set of theories from philosophy (Merleau-Ponty, 1962), psychology (Clearfield, 2004; Iverson, 2010), cognitive science (Barsalou, 2008; Wilson, 2002) and pedagogy (Ackermann, 2004) which are based on the idea that human cognition is influenced by the perceptual and motor systems and rooted in the bidirectional perceptual and physical interactions of the body with the world (Gibson, 2014; Wilson, 2002). Embodied cognition theory has roots in Piaget (e.g., Piaget, 1954), who described a child acquiring the practical knowledge which constitutes the substructure of later representational knowledge, particularly during the first sensorimotor developmental stage. This interpretation changed 30 years later, leading to the now common proposition, that sensorimotor activity is not merely a stage of development that fades away in more advanced stages, but rather is thoroughly present in thinking and conceptualizing (Nunez, & Freeman, 1999; Radford, Bardini, Sabena, Diallo, & Simbagoye, 2005; Oudgenoeg-Paz, Boom, Volman, & Leseman, 2016).

One of the most influential theoretical approaches to embodied cognition has been Barsalou's (1999) framework of perceptual symbols. This approach holds that the peculiarities of human perceptual systems and human bodies influence and constrain cognitive and linguistic structures and processes, including fundamental ways of thinking, representations of knowledge, and strategies of organizing and communicating information. In other words, the human body's specific sensory and motor capabilities affect cognition (Engel, Maye, Kurthen, & König, 2013; Mahon, & Hickok, 2016; Dourish, 2001). This account suggests that humans use their sensory neural structures to create multisensory representations of their environment. Multimodal sensorimotor representations are created in the brain (Barsalou, 2008) in a highly interconnected "system" of cells, and cognition is the result of those brain functions. These cells respond to stimulation, i.e., signals that come from the outside world via ears, eyes, skin, nose, tongue, and motor actions, hence from organs of the body. The brain, an organ of the body, functions as the "mind," therefore it is no longer an abstract concept. The neural representations of events are based on brain states that were active in the past during the actual perception and interaction with objects and events in the real world, according to the perceptual symbol systems (Barsalou, 1999). This field of study showed that when humans visualize an object or an activity in their minds, those brain areas that are active during perception are reused (Barsalou, 1999, 2008; Anderson, 2010). According to current theories, perceptual symbols are multimodal brain activity traces that at least partially encode the motor information available during real sensory experience (Barsalou, 1999). Johnson-Glenberg, Birchfield, Savvides, & Megowan-Romanowicz, (2011) argue that "the more modalities (sensorimotor systems) are activated during the encoding of the information, the crisper and more stable the representations will be in schematic storage. These crisper representations, with more modal associative overlap, will be more easily recalled" (p. 130).

According to theories of embodied cognition, when we think about an object or a person, our brains simulate the experiences we've had with those things or people in the past

(Barsalou, 2008; Glenberg, & Gallese, 2012). In fact, research in the field of neuroscience has shown that processing of objects, spatial information, music, faces, flavors, and odors, as well as just thinking about these ideas, elicits sensorimotor responses, or body-related activity in the brain (Pulvermuller, 1999, 2005). This is dependent on earlier knowledge of how to manipulate objects, move around, eat, and smell things (Zwaan, 1999). Brain regions and structures involved in the process connect to generate neural networks that represent and store the information (Macedonia, 2019). Embodied cognition promotes the idea that the brain and body work together to perceive the environment, and this perception, in turn, affects how one thinks about and acts within the environment. Cognition takes place in an environment and, as such, interacts with that environment; that is, cognition is situated (Wilson, 2002).

In the theoretical framework of embodied or situated cognition, the mind is viewed as a property of living material bodies with a capability for responding to feelings. The perceptual and motor systems, including those of the body's shape and movement, the neural systems involved in action planning, and the systems responsible for sensation and perception, have an impact on ways of thinking, such as representations of knowledge and methods of organizing and expressing information (Glenberg, 2010). Yet, the embodied perspective further asserts that "abstract" thought, associated with higher levels of development, also shares a perceptual motor basis (Black et al., 2012). Memory and symbolic thinking are higher-order cognitive processes that are reliant on bodily experience and activity in a physical context (Abrahamson, & Lindgren, 2014; Barsalou, 2008). According to Gallagher, & Lindgren (2015), teachers can aid in their students' learning by finding physical cues that mirror the topics they want them to understand. Tools such as extended reality technologies (XR) can speed up this process by assisting students in connecting their lived experiences with the concepts they are learning (Gallagher, & Lindgren, 2015). According to the embodied or perceptually grounded cognition perspective, recalling knowledge or inferring conclusions about something requires the ability to simulate it in the mind (Barsalou, 2008, 2010; Black, 2010). Many psychological events that were previously believed to be exclusively symbolic exhibit perceptual consequences, according to findings from behavior and neuroimaging research (Black et al., 2012).

2.2 Embodied learning

Embodied learning is educational research incorporating findings from the research area of embodied cognition, which emphasizes the use of the body and perception in educational practice (Antle, 2013, 2009; Barsalou, 2010; Kosmas, Ioannou, & Retalis, 2018). According to Munro (2018), embodied learning is argued to be the deliberate use and recognition of multimodal body mind activities and strategies to facilitate shifts in perspectives, perceptions, paradigms, behavior, and actions. The relationship between embodied cognition and learning has a long history and has been the subject of decades of research (Chan, & Black, 2006; Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Lakoff, & Núñez, 2000). It has influenced classroom curricula in a variety of subjects, including science, linguistics, and mathematics. A person can perceive themselves as a holistic and integrated acting, feeling, and thinking being-in-the-world through embodied learning rather than as distinct bodily and mental attributes that have no bearing on one another.

The embodied learning approach embraces a perspective on learning as, at least partly, a situated (or embedded) process, where the interaction of the body in a real spatial context is a major gateway to cognition (Duijzer, Van den Heuvel-Panhuizen, Veldhuis, Doorman, & Leseman, 2019). As Stolz (2015) mentions, embodied learning from inside educational systems not only acts as a counterbalance to the strong pedagogical tendency to favor abstract and conceptual thinking, but more importantly, it provides students with meaningful experiences of the phenomenal body. Munro (2018) claims that the typical pedagogical practices used in embodied learning pedagogies include a transactional mode of knowledge sharing, dialogue, experiential processes, concurrent engagement with inductive and deductive learning strategies, as well as acknowledging and navigating the ongoing presence of emotions.

2.3 Technology-enhanced embodied learning

We are at the beginning of an aggressive expansion of interface capabilities with digital technologies that increasingly allows users to employ body movements (embodied interactions) to interact in more natural and physically expressive ways with computer systems (Jacob et al., 2008; Johnson, Pavleas, & Chang, 2013; Ottmar, Landy, & Goldstone, 2012; Ottmar, Landy, Weitnauer, & Goldstone, 2015), and researchers are beginning to consider these technologies as a powerful pedagogical tool to promote children’s learning (Hsu, 2011) through movement and particularly play (Bartoli, Corradi, Garzotto, & Valoriani, 2013; Lindgren, & Moshell, 2011). Such technologies include phones and tablet that permit mobility and augmented camera views, gesture-sensing devices (e.g., a Nintendo Wii, Leap Motion) and motion-tracking technologies (e.g., an XBox Kinect by Microsoft) that record students’ positions as they move (i.e., walk, run, and kick) and allow direct manipulation, as well as tangible interfaces and more immersive technologies that combine virtual and physical elements (e.g. AR, VR, XR).

According to Xu, Kang, & Yan (2021), two main categories - contactless and wearable - can be distinguished among the many prominent technologies that add embodiment aspects to the design of learning environments. Users using contactless technologies do not need to carry, attach, or wear any special equipment on their body, as the name implies. In order to engage with the environment, a user can move freely and focus on his or her own body movements in the absence of any peripherals like wires, clickers, or sensors. In contrast, when using a wearable device to enable embodied interactions with any interfaces or digital learning materials, a user holds or wears the wearable device, which detects the user's movements and delivers the information to the computing unit. On the other hand, embodied learning environments can make use of natural user interfaces, commonly referred to as gestural interfaces, and which come in two types: touch interfaces and free-form interfaces. Tangible User interfaces (TUIs) are based on a single touch point (e.g., SMART Board) or a multi-touch point (e.g., SMARTtable/iPhone/iPad/Surface), and they require the user to touch the device directly. Free-form gestural interfaces, like the Microsoft Kinect project, do not require the user to directly touch or manipulate the device (Black, Segal, Vitale, & Fadjo, 2012). Through a real or virtual body within the environment, these technologies enable direct interaction with that environment. The emerging ideas of embodied interaction link the physical, digital, and social interface with the human sensory system (Price, Sheridan, Falcão, & Roussos, 2008). As a result, embodied interaction is a blend of the virtual and real, intangible, and tangible, reality and fantasy. Learners interact with those digital graphics through physical manipulation, thus providing learners a more natural and interactive way to access learning content. These types of technology provide opportunities for incorporating a greater level of motoric engagement and embodiment into learning (Tran, Smith, & Buschkuehl, 2017).

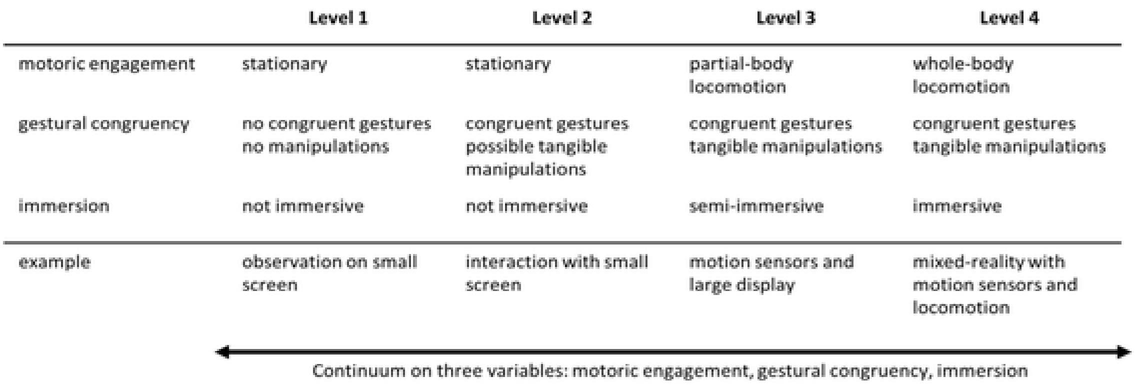
Technology enhanced embodied learning environments can provide user interfaces that are more natural, ergonomic (Shen, Everitt, & Ryall, 2003) and closer to the task to be achieved (Johnson, Levine, Smith, & Stone, 2010). They allow students to use their bodies while they are playing, which can reduce physical passivity and provide them with more interactive experiences. Moreover, gesture-based or full-body educational games as training simulators can improve users' fine motor control, visuospatial processing, hand-eye coordination, and two-dimensional depth perception (Hsiao, & Chen, 2016). Embodied engagement makes use of more of our senses, especially touch and movement, which are thought to aid in the retention of the knowledge that is being acquired. In a study concerning adding the haptic channel in a learning process with kinematics displays, Chan & Black (2006) demonstrated that the immediate sensorimotor feedback obtained through the hands can be transmitted to working memory for additional processing. This essentially allowed the learners to actively interact and participate in the meaning-making process, which improved learning for the students who were exposed to the direct manipulation and animation condition. Han & Black (2011) discovered that using three sensory modalities, including tactile feedback, helped participants effectively understand how basic machines function. The study uses the haptic channel as force feedback to teach participants how gears work. Additionally, the haptic simulation group outperformed the control group in both the close transfer test and the immediate posttest, demonstrating that the benefits of the embodied experiences with haptic simulation persisted while reading instructional material (Black et al., 2012). Because it involves the learner's entire being (i.e., brain, body, and environment), an embodied perspective is seen as a technique to enhance teaching and learning because it more accurately depicts how students use their physiological experience to understand abstract concepts (Hall, & Nemirovsky, 2012; Abrahamson, & Lindgren, 2014). In the fields of education, design, and technology, this is both timely and pertinent (Kopcha, Ocak, & Qian, 2021).

2.4 Embodied learning frameworks and taxonomies

Multiple taxonomies have been developed to help specify design decisions and attributes that define technology for embodied learning. In this section, we provide the most pertinent ones that have been documented in the literature so far.

2.4.1 Cube of embodiment

To identify the level of embodiment, Johnson-Glenberg, Birchfield, Tolentino, and Koziupa (2014) suggested a taxonomy which can be represented through the following three components: (1) motoric engagement (achieved through locomotion); (2) gestural congruency (determined by the alignment of the gesture with the mental model of the concept being taught); and (3) immersion level (which ranges from tablets and computers to large screens). They also partitioned the taxonomy into four levels or degrees. Level 1 represents the lowest degree of embodiment, which is defined by minimal motoric engagement, no gestural congruency, and a non-immersive experience. Materials are presented on a desktop computer or a tablet (Johnson-Glenberg et al., 2014). The next two levels that follow indicate moderate degrees of embodiment. In level 2, some degree of embodiment is defined, which is mostly upper body movement, but there is no gestural relevancy, and the learner does not perceive the environment as highly immersive as learners interact with smaller displays (monitor or tablet). Level 3 is defined by motoric engagement, some amount of gestural relevancy, and an immersive experience. The third level is reached when larger displays, full-body interactions (using motion-tracking devices), or both are integrated into an embodied learning setting (Johnson-Glenberg et al., 2014). Lastly, level 4 represents the maximum degree of embodiment with full-body interaction, gestural congruency, tactile manipulatives, and a very immersive experience. It is helpful to build upon this taxonomy in thinking about the use of technologies for an embodied learning experience. See Figure 2 for a visual representation of Johnson-Glenberg et al., (2014) taxonomy.



	Level 1	Level 2	Level 3	Level 4
motoric engagement	stationary	stationary	partial-body locomotion	whole-body locomotion
gestural congruency	no congruent gestures no manipulations	congruent gestures possible tangible manipulations	congruent gestures tangible manipulations	congruent gestures tangible manipulations
immersion	not immersive	not immersive	semi-immersive	immersive
example	observation on small screen	interaction with small screen	motion sensors and large display	mixed-reality with motion sensors and locomotion

Continuum on three variables: motoric engagement, gestural congruency, immersion

Figure 2: Jonhnson-Glenberg et al. (2014) taxonomy

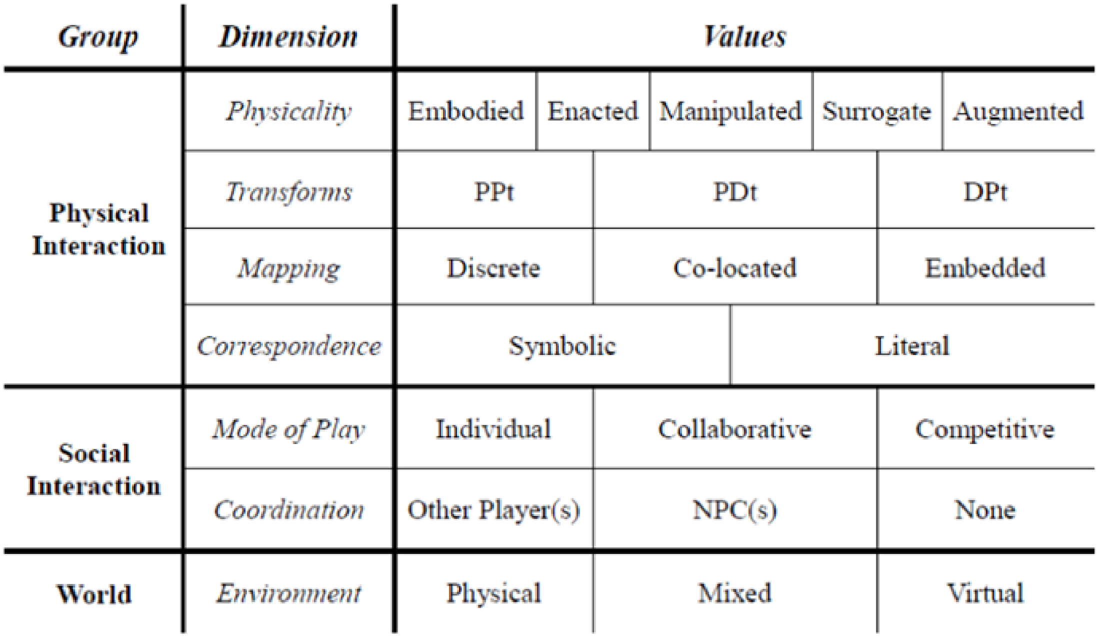
The assertion that there is a relationship between the four embodiment levels identified by Johnson-Glenberg et al., (2014) and learning performance has been contested by Tran, Smith, and Buschkuehl (2017). They argue that it is still unclear whether a higher level of embodiment in accordance with the four-level paradigm presented by Johnson-Glenberg et al. (2014) necessarily means a superior learning performance. They also question whether the various levels of embodiment, as defined by the taxonomy proposed by Johnson-Glenberg et al. (2014), have a corresponding impact on learning, such that level 1 embodiment would result in less learning than level 4 embodiment, with level 2 and level 3 embodiment being in the middle. Additionally, Skulmowski and Rey (2018) believe the four degrees of embodiment defined by the taxonomy proposed by Johnson-Glenberg et al., (2014) lack theoretical foundation. They also presented some flaws, namely questioning whether the combinations of the three factors - motoric engagement, gestural congruency, and perceived immersion - are the best descriptive dimensions for educational embodiment. Those three factors that Johnson-Glenberg et al., (2014) proposed have been the subject of several studies and have shown varying degrees of success in increasing learning performance (summary and related criticism in Tran et al., 2017). Studies supporting physical movement have been conducted (e.g. Mavilidi, Okely, Chandler, Cliff, & Paas, 2015; Mavilidi, Okely, Chandler, & Paas, 2016; Ruiter, Loyens, & Paas, 2015), but there have also been studies making the case for more restrained instructional designs that provide only very basic interactions, like starting and pausing a simulation (e.g. Song, Pusic, Nick, Sarpel, Plass, & Kalet, 2014). Gesture congruency, a concept related to the second component, has been presented as a factor in the effectiveness of embodied learning (Hald, de Nooijer, van Gog, & Bekkering, 2016; Hald, van den Hurk, & Bekkering, 2015). However, another study found no statistically significant differences regarding the accuracy of a transfer test between implementations that vary in regard to this factor (Pouw, Eielts, van Gog, Zwaan, & Paas, 2016). Therefore, despite the fact that gestural congruency may be a factor that should be taken into account when designing embodiment interventions, Skulmowski and Rey (2018) believe that this aspect may not be sufficiently illuminating to serve as a central classifier for embodied cognition research and should be revised. Also, according to Skulmowski and Rey (2018), immersion should not be one of the key components of an embodiment research taxonomy in the context of learning. Yet, there have been recent studies demonstrating that using devices that offer higher degrees of immersion result in significantly higher learning scores (e.g., Johnson-Glenberg et al., 2016; Johnson-Glenberg, Birchfield, Savvides, & Megowan- Romanowicz, 2011).

2.4.2 Instructional Embodiment Framework

Black, Segal, Vitale and Fadjo (2012) suggested the Instructional Embodiment Framework (IEF), which is the use of embodiment as an engaging activity for the student that may be modelled by the teacher in a sequence or system of movement, imagination, and exploration within a formal instructional setting. IEF is composed of two main categories, physical and imagined embodiment. A physical instructional embodiment can be direct, surrogate, or augmented, whereas an imagined instructional embodiment can be explicit or implicit, allowing the individual to embody action and perception through imagination. Direct embodiment is when the learner physically enacts a scenario, using his or her body to enact statements or sequences. Surrogate embodiment is a type of physical embodiment that the learner controls and uses to manipulate an outside "surrogate" to represent the individual. To integrate the embodied learner within an augmented representational system, augmented embodiment refers to the employment of a representational system, such as an avatar, in conjunction with an augmented feedback system (such as Microsoft's Kinect and display system). Imagined embodiment is defined as the mental simulation of an explicit or implicit physical activity.

2.4.3 The 7-dimensions framework

Melcer and Isbister (2016) develop a framework with seven dimensions for how designs of existing embodied learning games and simulations can be described: physicality; transforms; mapping; correspondence; mode of play; coordination; and environment (see Figure 3).



Group	*Dimension*	*Values*				
Physical Interaction	*Physicality*	Embodied	Enacted	Manipulated	Surrogate	Augmented
	Transforms	PPt	PDt	DPt		
	Mapping	Discrete	Co-located	Embedded		
	Correspondence	Symbolic	Literal			
Social Interaction	*Mode of Play*	Individual	Collaborative	Competitive		
	Coordination	Other Player(s)	NPC(s)	None		
World	*Environment*	Physical	Mixed	Virtual		

Figure 3: Design framework for embodied learning systems by Melcer & Isbister (2016)

Similar dimensions are clustered under a group based on an overarching design theme, and the different values for each dimension are shown. Based on the dimensions' underlying design motifs within the construct of embodiment, they divided the dimensions into three groups (i.e., physical body and interactions, social interactions, and the world where interaction is situated).

“Physicality” describes how learning is physically embodied in a system, and it consists of five distinct values: the embodied, the enacted, the manipulated, the surrogate, and the augmented (see Figure 4). The “embodied value” focuses on gestural congruency and how the body can physically represent learning concepts (Johnson-Glenberg, et al., 2014). The term "enacted value" is used to describe "direct embodiment from the Instructional

Embodiment Framework" and "enactivism" which emphasizes "knowing as physically doing" (Holton, 2010). This type of embodiment focuses more on physically enacting sentences or sequences that represent knowledge. The “manipulated value” refers to the tangible embodied interactions (Marshall, Price, & Rogers, 2003) and the use of manipulatives in learning (Pouw, van Gog, & Paas, 2014). This type of embodiment results from the use of embodied metaphors, interactions with physical items, and the physical embodiment of learning concepts by those objects (Bakker, Antle, & Van Den Hoven, 2012; Pouw, van Gog, & Paas, 2014). The term "surrogate value" alludes to the Surrogate Embodiment concept from the Instructional Embodiment Framework, in which students control a physical agent or "surrogate" representative of themselves to put learning principles into practice (Black, et al., 2012). In systems with an interactive physical world that is directly connected to a real-time virtual simulation, this type of embodiment is used frequently (Gnoli, Perritano, Guerra, Lopez, Brown, & Moher, 2014; Kuzuoka, Yamashita, Kato, Suzuki, & Kubota, 2014). The term "augmented value" refers to the Instructional Embodiment Framework concept of "augmented embodiment" (Black et al., 2012), in which the learner is embedded within an augmented reality system through the use of a representational system (such as an avatar) and an augmented feedback system (such as Microsoft Kinect and a TV screen) (Black et al., 2012).

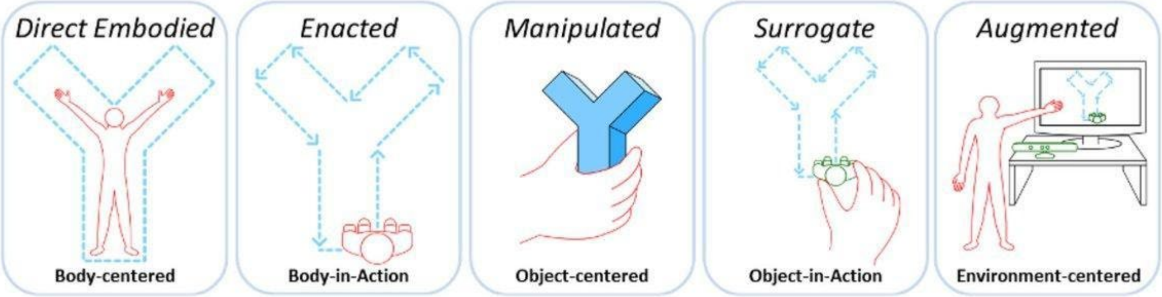


Figure 4: Physical dimensions of the framework by Melcer & Isbister (2016)

“Transforms” conceptualize a space and the relationships between physical or digital actions and the resulting physical or digital effects in the environment (Rogers, Scaife, Gabrielli, Smith, & Harris, 2002). “Mapping” borrows the notion of Embodiment from Fishkin's (2004) taxonomy's concept of embodiment and Price, Sheridan, Falcao, and Roussos' (2008) framework for a tangible learning environment, which describes the various spatial locations of output in relation to the object or action triggering the effect.

A mapping may be discrete, where input and output are separated (for example, an action may cause output to appear on a nearby screen), co-located, where input and output are contiguous (for example, an action may cause output to appear next to or on top of the physical space), or embedded, where input and output are contained within the same object. “Correspondence” builds upon the notion of Physical Correspondence from Price's et al.’s (2008) tangible learning environment framework, which refers to the degree to which the physical properties of objects are closely mapped to the learning concepts. They broaden this idea to encompass motions (e.g., congruency of gestures or physical manipulations to learning concepts). Correspondence can be literal—objects and actions are tightly matched to the learning concepts (e.g., arranging programming blocks to learn coding). The term "mode of play" describes how people engage in social interaction and play within a system. For learners, the system can support independent, group, or competitive play. “Coordination” highlights how, in order to properly achieve learning objectives, participants in a system may need to socially coordinate their activities (Oullier, de Guzman, Jantzen, Lagarde, & Kelso, 2008). In a socio-collaborative encounter with digital media, social coordination can take place with other players and/or NPCs (Tolentino, Savvides, & Birchfield, 2010). On the other hand, social coordination may not happen or may even be discouraged in a design with a narrow emphasis. “Environment” refers to the characteristics of the learning environment in which the educational content is situated. Environments can be either physical, mixed, or virtual (Rogers et al., 2002). The “environment” dimension is concerned with the physical location where learning takes place, unlike transformations, which construct a space through the description of activities and outcomes. In some systems, the player's bodily movements are monitored and mapped to influence digital effects superimposed on a scene that combines the actual world with augmented reality or extended reality (Lindgren, & Johnson-Glenberg, 2013). Others still place players in an entirely physical setting, tracking their movements only to keep score or digitally store data about the displayed educational content during the interaction (Gnoli et al., 2014). In sum, Melcer and Isbister’s (2016) categorization system is of a rather technical nature and provides a unifying foundation for the description, categorization, and evaluation of designs for embodied digital learning media (Melcer, & Isbister, 2016).

2.4.4 Bodily Engagement Grid

Skulmowski and Rey's (2018) taxonomy of embodied cognition in the field of learning and instruction is a more general model based on the dimensions of bodily engagement (i.e. how much bodily activity is involved) and task integration (i.e. whether bodily activities are related to a learning task in a meaningful way or not). To characterize an embodied learning setting in a meaningful way, they believe that it is important to ascertain if the intended form of embodiment is thoroughly incorporated into the learning process or if it is only an incidental component. The authors argue that if bodily activities are integrated into the learning task and participants perform bodily movements and locomotion (as opposed to sitting conditions), embodiment effects are larger (Skulmowski, & Rey, 2018). This taxonomy allowed them to compare and discuss embodied learning studies ranging from only limited degrees of movement to full-body movement systematically and informatively (see Figure 5).

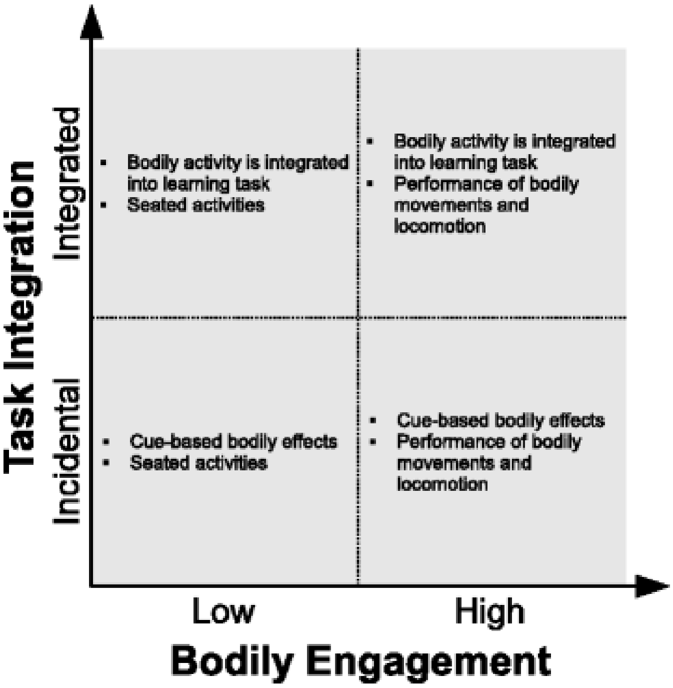


Figure 5: Skulmowski and Rey's (2018) taxonomy

2.4.5 Learning in Embodied Activity Framework (LEAF)

The Learning in Embodied Activity Framework (LEAF), which was proposed by Danish, Enyedy, Saleh and Humburg (2020), aims to support synthesis across sociocultural and individual theories of embodiment and thus offer a more complete explanation of how the body can contribute to both individual and group cognition and learning. This concept is very helpful in CSCL settings, but it may also be used in collaborative learning settings when embodiment isn't closely related to the computer. LEAF was created to plan for and assess situations in which students actively employ physical actions that are connected to conceptual understanding or that aid in the development of links to new conceptual domains. For designers and theorists interested in investigating how body movement may be utilized purposefully to promote learning, LEAF offers more comprehensive information. In addition, LEAF acknowledges that: 1) people alternately focus on their own personal objectives and actions and on the collective embodied activity system they form around a common goal; and 2) the system is partly built by people's ongoing individual actions. By explicitly identifying the effects of each of the important mediators of activity mentioned above and outlining how each is understood at both the individual and collective level while acknowledging that these are, by definition, mutually constitutive, LEAF seeks to articulate the role of embodiment in learning. The mediators are: 1) the subject or individual participant, 2) the object or purpose that organizes individual activity, 3) the instruments that the individuals employ, including computational tools, 4) the community in which they interact, and both 5) the rules and 6) division of labor that help define and structure those interactions (Engeström et al., 1999). The authors keep this idea of community inside the LEAF framework, but they pay particular attention to how the community creates and upholds agreed norms around embodiment and possible interpretations of embodiment.

2.5 Embodied learning classroom orchestration

According to Abrahamson (2023) implementing embodied design requires systemic change in how we conceptualize cognition, what activities we create, how we facilitate these activities, how we prepare teachers, what epistemic norms we sanction, and how we assess learning. In other words, the efficacy and success of technology-enhanced embodied learning in a classroom requires fostering a research-driven orchestration of the learning process. In this section, we present the classroom orchestration landscape, with a particular focus on different approaches that have been used to solve challenges associated with orchestration and scripting of technology-enhanced (embodied) learning in classroom contexts.

Classroom orchestration involves decisions made by the teacher to balance or cope with extrinsic constraints such as time management, curriculum relevance, space limitations, teacher effort, and more (Dillenbourg, 2013). It involves the teacher playing a driving role in the control and awareness of classroom interaction while s/he has the flexibility and freedom to change and adapt activities as necessary (Dillenbourg, 2013). In other words, the planning of learning interventions must be tailored for real-time implementations considering the learners’ needs and classroom dynamics (Roschelle, Dimitriadis, & Hoppe, 2013). Said in other words, "orchestration" refers to the process by which educators design, manage, adapt, and assess learning activities in the technology-enhanced classroom ecosystem, aligning the scaffolding at their disposal to achieve the maximum learning effect, informed by theory while complying pragmatically with the contextual constraints of the setting (Prieto, Holenko-Dlab, Abdulwahed, Gutiérrez & Balid, 2011). As Kollar and Fischer (2013) argue, just like musical pieces, technology-enhanced learning environments need to be created (i.e., orchestrated), adapted (i.e., arranged) and reified (i.e., conducted), and educational research must provide practical recommendations need to consider in these processes.

Fischer and Dillenbourg (2006) provided a definition for orchestration in the field of computer-supported collaborative learning (CSCL), according to which orchestration is the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels (Fischer, & Dillenbourg, 2006). Later, Dillenbourg, Järvelä, and Fischer (2009) expanded this definition by stating that learning environments are integrated with activities taking place at various social levels (such as individual, group, and class), across various contexts (such as classroom, home, laboratory, field trips, etc.), and through media (with or without computers, video, etc.). Drawing from these and other sources, Prieto, Dlab, Abdulwahed, Gutiérrez, and Balid (2011) elaborated that orchestration is often guided by a design (in the form of a script or not) that may be flexibly modified during the enactment (automated or not) of the activity, in response to emergent occurrences. To make the idea of designing for orchestration clearer, Tchounikine (2013) suggested classifying technologies used in the classroom as either orchestration technologies (i.e., to help teachers run the classroom with some assistance, to make an attempt to control the educational environment) or orchestrable technologies (i.e., technology that reifies instructional aims in some way e.g. arranging learners' group activities through a workflow).

The increasing introduction of heterogeneous computing devices in the classroom imposes additional tasks on teachers of orchestrating complex interactions with students (Schaper, Malinverni, & Pares, 2014). When planning for orchestration of the technology-enhanced learning, Sharples et al., (2014) outline three methods for handling these interactions: (1) complex systems components could be simplified, resulting in technology that is easier to use, simpler lesson plans and simplified tasks; (2) the orchestration technology layer could be removed, and orchestration would only be used to describe the real-time management designs used during orchestration; or (3) a more disruptive strategy could be used, which would result in the teacher and students sharing the orchestration workload. Some attempts have been made to provide formal orchestration models that are aimed at providing a theoretical basis for understanding orchestration. Specifically, Prieto, Holenko-Dlab, Abdulwahed, Gutiérrez and Balid (2011) gathered relevant orchestration literature in TEL research and proposed the "5 + 3 Aspects Orchestration Framework", which characterizes orchestration into eight aspects, five of which provide a descriptive view of orchestration and three of which are key factors describing how orchestration must be implemented.

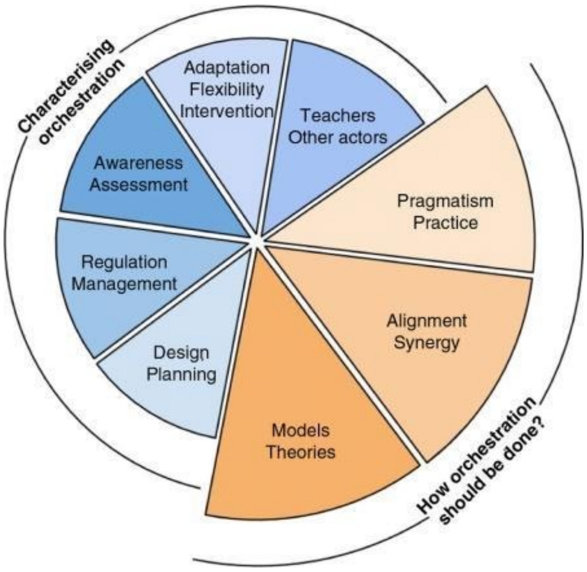


Figure 6: The "5+3" Aspects Orchestration Framework (Prieto et al., 2011)

The “5 + 3 Aspects Orchestration Framework” is aimed at technology enhanced learning environments and involves the following planning: *Design/planning*: An important component of orchestration is planning the learning activities that will be coordinated. This is referred to as learning design. *Regulation/management*: Well- orchestrated learning takes place when the processes of learning and teaching as well as their constraints are managed to maximize outcomes. *Adaptation/flexibility/intervention*: The process of modifying and adapting the design/plan to both the specific context of the classroom and the emergent occurrences during the execution of learning activities through social mechanisms or through technological systems. *Awareness/assessment*: A well-orchestrated learning scenario includes awareness of what is happening in the classroom and within the learners’ minds. A proper adaptation of the learning design can be made because of assessment (either formative or summative), which can give insight into the learners' progress towards the targeted learning outcomes as they gradually attain them. *Roles of the teacher and other actors*: Teacher presence is essential to achieve orchestration. Teachers act as guides, not as knowledge sources. Also, there is a correlation between concepts of orchestrating learning and principles of constructivist pedagogy as a means of facilitating authentic learning. Based on the “5 + 3 Aspects’ Orchestration Framework” good orchestration can be done when the following are considered: Pragmatism/practice: the actors must deal with both intrinsic and extrinsic contextual limitations, such as adhering to the required curriculum, having only a small amount of time for a lesson, needing to maintain discipline in the classroom, having access to financial resources, etc. Emphasis is given to pragmatic research efforts and changing everyday teaching practice in real-world settings (as opposed to controlled experiments). Alignment/synergy: how the orchestrators can coordinate the various factors present in the scenario—including new technology and legacy tools, educational activities at various social levels, students' prior knowledge, and learning preferences—in order to ensure effective learning. The alignment of as many of these elements as possible (learning activities at various social levels, tools and scaffoldings used, including teacher and peer actions), through the changing conditions of a learning situation, to attain the learning goals that are desired at different levels, to better orchestrate a learning scenario. Models/theories: Mental models that various actors have about how the scenario should be orchestrated, including students' internal models of how they should operate inside the scenario, researchers' own models and theories, and teachers' pedagogical views, attitudes, and notions about "what works" in the classroom.

Dillenbourg and Jermann (2010) provided a different conceptual framework for orchestration, describing how educators orchestrate an activity by dealing with technical, pedagogical, and social constraints. Leadership, flexibility, control, integration, linearity, continuity, drama, relevance, physicality, awareness, design for all, curriculum relevance, assessment relevance, minimalism, and sustainability are among the 15 components that make up their conceptual framework for teacher-centric design. These design factors are categorized under nine constraints that shape orchestration and provide a teacher-centric, integrated view of educational technologies in the classroom. The nine constraints highlighted in the work of Dillenbourg and Jermann (2010) are: Teacher-centrism, Cross-plane integration, Sequentiality, Time Management, Physicality, The "Ecosystem" model, Selection, Legacy, Sustainability. Their framework is explained in full detail in Dillenbourg and Jermann (2010).

Roschelle, Dimitriadis, and Hoppe (2013) noted that there are two core components to orchestration: (1) pre-session management, which entails scripting i.e., planning and organizing learning activities for typical learning scenarios; and (2) session management, which entails putting the learning activities into practice. In preliminary exploratory study, the minimum set of fundamental pre-session management orchestration elements necessary for the simplification of orchestration was determined to be activity management, resource management, and sequencing, described as follows: *Activity management*. This aspect is meant to enable the structuring and organizing of learning activities to be performed during session management. *Resource management*. The ability to organize teaching and learning resources for orchestration during session management is provided for educators. Every resource is identified and connected to the activities chosen for Activity Management. *Sequencing activities*. This aspect enables educators to explicitly specify the order of orchestrating learning activities. The workbench platform's design aims to make it possible for tools and services to be seamlessly integrated into learning activities even if its primary goal is to facilitate the orchestration of learning activities.

Cuendet, Bonnard, Do-Lenh, Dillenbourg (2013) proposed five principles for creating a classroom learning environment: *integration, awareness, empowerment, flexibility, and* *minimalism*. To reduce the need for orchestration, the learning environment should be incorporated into the workflow. Technology should only support one of the various educational tasks that take place on an individual, group, class, or higher level, and the amount of orchestration needed will depend on how well data is shared between tasks. For empowerment orchestration, the learning environment should enable the teacher to maintain a central point in the classroom interactions when necessary. This does not mean the teacher should lecture, but rather guide the classroom with the help of technology. To reduce the burden of awareness orchestration, the learning environment should provide the teacher with constant knowledge of each student's condition. Data should be aggregated on the temporal and/or social axis in a single graphic (Alcoholado et al., 2011; Moraveji, Kim, Pawar, Ge, & Inkpen, 2008). Flexibility orchestration burden can be reduced by creating a learning environment that is adaptable to changes in the scenario's development such as changes in students' states, or time constraints. The design should also consider unforeseen events and how the teacher can modify lesson plans accordingly. Minimalism orchestration load decreases if the learning environment only provides necessary information and functionalities at any given time.

Nussbaum and Diaz (2013) proposed strategies for the integration of digital and non-digital resources. They argue that teachers should have the tools to structure their classes, they should be empowered beyond the training process. Every aspect of the class and the actions that the teacher must perform in order to apply the proposed strategies for the integration of digital and non-digital educational tools should be detailed precisely. Adequate orchestration helps to guide the teacher through the work to be performed in the classroom, allowing a shift from an instructor-centered arrangement, in which the teacher radiates knowledge before a passive class of students, to one where the students actively participate, with the teacher acting as a mediator. In defining what the classroom work should be, Nussbaum and Diaz (2013) specify three elements. The first two, context and aim, determine the orchestration conditions, while the third, specification, defines the orchestration, with examples presented in their work.

Overall, the given definitions and the underlying conceptual models of orchestration address that orchestrating technology enhanced learning is a complex practice which is, according to Prieto, Dimitriadis, Villagrá-Sobrino, Jorrín-Abellán, and Martínez-Monés (2011), composed of at least three elements: awareness mechanisms which the teacher uses to assess the progress of the activity and decide on potential interventions; mechanisms for class management, such as social and technological regulation mechanisms, to ensure that the design of the activity is followed; and adaptation or dynamic re-design of the activity, in response to emergent events during the activity (time and group management, tool usage and management, task/workflow modifications, etc).

As opposed to learning theories that focus on cognitive aspects, orchestration is concerned with practical issues and tasks that are not directly linked with learning but can shape learning. It emphasizes attention to the challenges of classroom use of technology, with a particular focus on supporting educators with the challenges associated with technology use within the classroom (Roschelle et al., 2013). Classrooms are complex environments and unpredictable. Orchestration emphasizes attention to the challenges of classroom use of technology, with a particular focus on supporting teachers' roles. Coordination has been highlighted as being an integral part of orchestration. There seems to be an encouraging shift in educational research, toward balancing attention between more idealistic research and practical problems, and toward finding ways to design learning tools that are theoretically motivated, practically applicable, and useful, as well as for the practical classroom contingencies that call for adaptable teaching methods.

2.6 Conceptual framework – concluding remarks

The conceptual framework of the study draws on theories of embodied cognition and embodied learning and on models of classroom orchestration with an emphasis on technology-enhanced embodied learning. There are frameworks and taxonomies guiding the work on embodied learning from the perspective of designing the learning experience. There is less theoretical work guiding the integration of embodied learning in the classroom, from the perspective of classroom orchestration. The conceptual framework presented aims to guide the design of the interventions and learning environments in this study, building on knowledge from theory on embodied cognition and embodied learning, as well as practice on the design of technology-enhanced embodied learning environments and practical models of classroom orchestration.

3 BACKGROUND WORK

The purpose of this chapter is to identify and examine previous empirical research on technology-enhanced embodied learning and orchestration of technology-enhanced embodied learning environments. The chapter relieves gaps in the literature that the present study aims to address.

3.1 Empirical work on technology-enhanced embodied learning

The research in the field of technology-enhanced embodied learning is relatively new and it covers various fields, such as mathematics (Arroyo, Micciollo, Casano, Ottmar, Hulse, & Rodrigo, 2017; Tran, Smith, & Buschkuehl, 2017; Ruiter, Loyens, & Paas, 2015; Dackermann, Fischer, Nuerk, Cress, & Moeller, 2017; Abrahamson, & Sánchez-García, 2016), physics (Anderson, & Wall, 2016; Han, & Black, 2011; Anastopoulou, Sharples, & Baber, 2011; Grønbæk, Iversen, Kortbek, Nielsen, & Aagaard, 2007; Johnson-Glenberg et al., 2011; Johnson-Glenberg et al., 2014; Lee, Huang, Wu, Huang, & Chen, 2012; Lim, Leichtenstern, Kriegel, Enz, Aylett, Vannini, & Rizzo, 2011; Enyedy, Danish, Delacruz, & Kumar, 2012), chemistry (Johnson-Glenberg et al., 2014; Tolentino et al., 2010), biology (Andrade, Danish, & Maltese, 2017), science (Adachi, Goseki, Muratsu, Mizoguchi, Namatame, Sugimoto, & Takeda, 2013; Carreras, & Parés, 2009), vocabulary and language acquisition (Kosmas, Ioannou, & Zaphiris, 2019; Pulvermüller, & Fadiga, 2010; Hsiao, & Chen, 2016; Wellsby, & Pexman, 2014), reading comprehension (Glenberg et al., 2004; Glenberg, 2011), sound concepts (Bakker, Van Den Hoven, & Antle, 2010; Parés, Durany, & Carreras, 2005; Hashagen, Büching, & Schelhowe, 2009) and special education (Lee-Cultura, Sharma, Aloizou, Retalis, & Giannakos, 2020; Agosta, Borghese, Brandolese, Clasadonte, Fornaciari, Garzotto, & Valla, 2015; Altanis, Boloudakis, Retalis, & Nikou, 2013; Hsiao & Chen, 2016; Kourakli, Altanis, Retalis, Boloudakis, Zbainos, & Antonopoulou, 2017; Li, Lou, Tsai, & Shih, 2012; Vernadakis, Papastergiou, Zetou, & Antoniou, 2015).

Most of these studies have examined the efficacy of embodied learning and have partially confirmed embodied learning theories, namely the advantages of learning via active engagement in conceptual anchoring (Malinverni, & Pares, 2014; Georgiou, & Ioannou, 2019). That is, through the embodied interaction, learners actively engage with the learning environment and use their bodies to anchor new concepts to existing knowledge. Those studies suggest that learners use their bodies as tools for thinking and that learning is a process of actively constructing meaning through bodily experience (Malinverni, & Pares, 2014; Georgiou, & Ioannou, 2019).

3.1.1 Part-bodily embodied learning

Several studies have shown the beneficial effects of technology-enhanced part-bodily motion on learning, such as students' hand gestures (Alibali, & Nathan, 2012; Goldin-Meadow, Cook, & Mitchell, 2009), finger tracing (Agostinho, Tindall-Ford, Ginns, Howard, Leahy, & Paas, 2015), finger counting (Domahs, Moeller, Huber, Willmes, & Nuerk, 2010), or arm movements (Lindgren, & Johnson-Glenberg, 2013; Smith, King, & Hoyte, 2014). A substantial amount of research demonstrates that youngsters acquire new concepts more effectively when they utilize gestures rather than just speaking, especially when such gestures represent the appropriate solution to a problem (e.g., Cook, Mitchell, & Goldin-Meadow, 2008; Goldin-Meadow, Cook, & Mitchell, 2009). Research has shown that learners can be prompted to perform gestures and enact their emerging understanding of STEM ideas in ways that promote new learning (Goldin-Meadow, 2011; Stieff, Lira, & Scopelitis, 2016). Chu and Kita (2011) showed that students who are encouraged to produce gestures perform better on tests of mental rotation than students who are instructed not to produce gestures. Moreover, children have been proven to benefit from watching teachers use gestures in the subject of mathematics education since it makes them more likely to employ gestures themselves (Cook, & Goldin-Meadow, 2006). Gestural cues influence learners' construction of mental representations in mathematically relevant domains, including spatial problem solving (Chu, & Kita, 2011), mathematical equivalence (Perry, Church, & Goldin-Meadow, 1988), and counting (Alibali, & DiRusso, 1999). In the field of language learning, experimental research conducted with young children demonstrated the close relation between gesturing and language learning (Iverson, & Goldin-Meadow, 2005; De Nooijer, Van Gog, Paas, & Zwaan, 2013; Toumpaniari, Loyens, Mavilidi, & Paas, 2015) particularly in language development and comprehension (Kosmas, & Zaphiris, 2019). Findings of Cassar and Jang (2010) demonstrated that the embodied learning activities improved the literacy skills of elementary students, while the study of Chang, Chien, Chiang, Lin, and Lai (2013) showed that the embodied interaction enhanced the verbal information of students.

The advantages of pointing over teaching strategies that simply focus on children's verbalization could be explained by the ease with which knowledge structures in long-term memory can be created (Cook, Mitchell, & Goldin-Meadow, 2008). Specifically, incorporating gesture into the act of learning strengthens memory traces (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Goldin-Meadow, 2011). When children learn with their hands, they build brain connections and knowledge through this movement, and they are better able to transfer learning to new domains (Black, Segal, Vitale, & Fadjo, 2012). It's possible that increasing the number of learning modalities (beyond the standard visual and auditory ones) will continue to strengthen the memory trace. Hu, Ginns, & Bobis, (2015) found that the indexing or pointing gesture, whether it touches an object or surface or not, influences how students process information and helps them better understand abstract ideas. Young children can model and spatially represent an object by using hand gestures that symbolize learning concepts, which will aid in their processing of the information offered (Fischer, & Hoellen, 2004). For instance, instructional gestures, such as asking students who are solving mental rotation problems to use their hands to represent how they would move the pieces to form certain shapes, change their perceptions, resulting in better performance on the task (Goldin-Meadow, & Beilock, 2010). These results were also supported by the Smith et al., (2014); their study investigated the effects of gestures that mimicked angle measurements on students' comprehension in a motion-controlled learning environment. The researchers looked at how well 20 elementary school pupils understood angles. After completing the body-based angle task, test results showed that there was an immediate connection between students' physical experiences and the abstract visual representation of angles, which helped students better understand angle measurement. Additionally, the gesture-based multimedia presentation had a positive impact on participants' understanding and their performance improved by 15%. Importantly, gesturing is not only relevant at a young age but remains an important aspect of embodiment-based learning during later years (Kontra, Goldin-Meadow, & Beilock, 2012).

3.1.2 Whole-body embodied learning

Instructional contexts that involve learners' entire bodies are a major focus of embodied learning research (e.g., Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014; Lindgren, Tscholl, Wang, & Johnson, 2016). A number of studies in mathematics education (e.g., Abrahamson, & Lindgren, 2014; Alibali, & Nathan, 2012; Lakoff, & Núñez, 2000; Nathan, & Walkington, 2017; Tran, Smith, & Buschkuehl, 2017) and language acquisition (e.g., Glenberg, & Kaschak, 2002; Gallese, & Lakoff, 2005; Lakoff, & Johnson, 2008; Kosmas, & Zaphiris, 2018) provided empirical evidence that body movement can impact our processes of learning, and that having students move in prescribed ways can benefit learning and performance for both children and adults. These studies indicate that children show improved learning when they are physically and actively engaged in the learning material via full-body movements. This is consistent with several reviews that reinforce the bolstering role of embodied cognition (motor movements being integral to cognition; Madan, & Singhal, 2012) and full-bodied, active participation (Gallagher, & Lindgren, 2015) in learning. Incorporating body movements into students' learning experiences activates their cognitive processing and provides an interactive learning experience where students are physically engaged in the learning tasks (Kosmas, Ioannou, & Retalis, 2017; Smith et al., 2014).

Further studies on language instruction indicate that using kinaesthetic activities in the learning process might support students' vocabulary retention. For instance, the study of Kosmas et al., (2017) investigated how to employ a motion-based embodied learning game to improve students' memory performance when learning a second language. The system was evaluated through a four-month comparative study involving 52 elementary school children. Pre and post assessments were used to collect data on participant performance in learning and short-term memory. The findings showed that, in comparison to participants learning through a mouse-based interaction (Mean = 6.2), students' retention skills improved with sensorimotor experience. The study by Kourakli et al., (2017) examined the effects of embodied learning games on primary school students' language retention. A pre- and post-test questionnaire used to evaluate the proposed system revealed that using motion-based technology to interact with the learning content increased students' cognitive capacities and performance by a mean value of 3.64. Further studies proposed the implementation of immersive learning environments. For instance, in order to teach pupils Newtonian physics, Lindgren and Johnson-Glenberg (2013) investigated full-body contact in smart environments. A controlled comparative study involving 113 seventh graders was carried out. The results showed that students' learning performance improved (Mean = 4.92) as compared to group learning using a computer-based program (Mean = 4.45).

An embodied immersive space was developed more recently by Gelsomini, Leonardi, and Garzotto (2020) to support young pupils' factual understanding. The manipulation of the learning content mandated the use of an IR-depth camera to record students' hand and body movements. Through pre- and post-testing, the researchers assessed how the immersive environment affected the students' capacity for memory. The findings showed that students' retention skills had improved as children exposed to embodied engagement scored on average 18 concepts on a scale of 20 at the long-term level, compared to 7 concepts for students learning in a traditional classroom. Five empirical studies of students engaged in kinesthetically enhanced learning activities with digital technologies have shown benefits in terms of knowledge retention as indicated by delayed tests (Kuo, Hsu, Fang, & Chen, 2014; Jagodziński, & Wolski, 2014; Yang, Chen, & Jeng, 2010; Hwang, Shih, Yeh, Chou, Ma, & Sommool, 2014; Johnson-Glenberg et al., 2014). Johnson-Glenberg et al., (2016) posit that better retention of certain types of knowledge can be seen over time when more embodiment is present during the encoding phase (Johnson-Glenberg, Megowan-Romanowicz, Birchfield, & Savio-Ramos, 2016). For example, a study on students using their bodies to learn about centripetal force through computer simulation revealed that participants in the "high embodiment" condition (swinging a trackable object over their "heads") demonstrated higher long-term learning gains in physics compared to students in the "low embodiment" condition (initializing a simulation using a mouse) (Johnson-Glenberg et al., 2014).

Glenberg (2011) conducted an experimental design study with seventy-one 9th graders, examining whether embodied learning using XR was more effective than traditional classroom learning. Results indicated that the embodied environment led to greater knowledge gains. In a follow-up study, they examined if the XR embodied learning environment was more effective than a desktop simulation, and they found that embodied learning yielded significant learning gains for chemistry and disease transmission (Johnson-Glenberg et al., 2014), as well as in the abstract domain of the electric field

(Johnson-Glenberg, & Megowan-Romanowicz, 2017). Lindgren et al., (2016) also evaluated the effects of embodied interaction on conceptual understanding and learning engagement, and their results corroborated those of Johnson-Glenberg's et al., (2014) desktop simulation and embodied learning findings. Specifically, Lindgren et al., (2016) argued that the embodied learning simulation that was designed to teach critical concepts in physics led to positive results in terms of students' learning gains, engagement, and attitudes towards science.

Several studies on whole-body engagement have also reported on students' outcomes in the affective domain. Most of the reviewed studies reported on students' engagement with the learning process (e.g., Ibánez, & Wang, 2015; Lindgren et al., 2016; Tolentino et al., 2010; Johnson-Glenberg et al., 2014) as well as on students' increased motivation for participation in the task (e.g., Hwang et al., 2014; Yang et al., 2010). A limited number of studies reported on the contribution of technology-enhanced embodied learning environments to students' attitudes and dispositions (e.g., Silva, Ferreira, Andrade, Nunes, & da Luz Carvalho, 2015) or students' social behaviors, such as positive social interactions and collaboration (e.g., Mora-Guiard, Crowell, Pares, & Heaton, 2017; Roschelle, Rafanan, Bhanot, Estrella, Penuel, Nussbaum, & Claro, 2010).

3.1.3 Other findings on embodied learning

There have been studies indicating that not only participating in full-body interaction but also watching embodied interaction can be helpful. Giving students the chance to observe or influence the movements of people or things instead of having them move themselves might also help them learn concepts better, which indicates, in accordance with the moderate embodiment perspective, the use of mirroring or simulation methods (De Koning, & Tabbers, 2011; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009). A large portion of the research on observing others or objects has been devoted to observing teachers' use of gestures (e.g., Singer, & Goldin-Meadow, 2005) and observing the movements of somebody or something else through video examples or animations (e.g., De Koning, & Tabbers, 2011). Fifth-grade students in the study by Bokosmaty, Mavilidi, and Paas (2017) watched a teacher demonstrate a geometry subject. After manipulating the geometric features of triangles and watching their teacher do it, the pupils had a better understanding of geometry. Influencing and observing the movements of others and objects entails other ways of bodily involvement than making movements of your own.

Despite the numerous positive outcomes of embodied learning research, a number of recent embodiment research studies in the area of multimedia learning have produced discouraging findings regarding the efficacy of body-based (and, in some cases, activity-based) forms of instruction (e.g., Post, Van Gog, Paas, & Zwaan, 2013; Song et al., 2014; Tran et al., 2017; Skulmowski, & Rey, 2017; Díaz, Nussbaum, Ñopo, Maldonado-Carreño, & Corredor, 2015). For instance, the Human SUGOROCU is a simulation game that consists of a full-body interaction system to enable elementary school students to enjoy and learn about vegetation succession (Adachi, Goseki, Muratsu, Mizoguchi, Namatame, & Sugimoto, 2013). The study was conducted with 27 elementary students (age: 11–12 years) who played the game in two conditions: as a tablet game with a touch panel interface and as a human SUGOROKU where students themselves moved on the board as pieces and played the digital game. The results indicated that the full-body interaction promoted a sense of immersion in the game, but no other learning benefits were mentioned. Another example is Sound Maker, an interactive sound making environment. It was used in a comparative study to explore the potential benefits of using embodied interaction to help children learn abstract concepts related to musical sounds (Antle, Droumeva, & Corness, 2008). In the study, 40 kids between the ages of 7 and 10 created musical sound sequences in this interactive sound environment. A version of the system that instantiated a body-based metaphor in the mapping layer, linking body movements to output noises, was used by half of the students. The environments used by the remaining kids did not instantiate a metaphor in the mapping layer. The findings showed that children could be better at performing sequences physically than they are at explaining them orally. No conclusive proof was found to show that kids understood the musical concepts represented in the system better or if kids could apply this knowledge to other contexts or fields (Antle et al., 2008).

3.2 Empirical studies on embodied learning classroom integration and orchestration

A few authors indicate that there is a gap between research and development of embodied learning environments and their applicability in schools (Schneider, Jermann, Zufferey, & Dillenbourg, 2011; Malinverni & Pares, 2014; Price, Sheridan, Falcão, & Roussos, 2008; Marshall, 2007; Xie, Antle, & Motamedi, 2008; O'Malley, & Fraser, 2004; Bossavit, & Pina, 2014). For example, Malinverni and Pares (2014) stated that the field of full-body interaction is relatively new, and research on design and assessment methods is currently incomplete and lacking in coherence. Similar claims were made by Price, Sheridan, Falcão, and Roussos (2008) as well as Schneider, Jermann, Zufferey, and Dillenbourg (2011) per their work on tangible user interfaces. Kim and Hannafin (2011) argue that evidence of implementation, effectiveness and system use suggests that teachers, students, and technology interact differently in controlled versus real-world, everyday school settings. Similarly, Stanton et al. (2001) stressed the importance of paying higher attention to the classroom in the design of pedagogical Tangible User Interfaces (TUIs) and for evaluating TUIs in classrooms rather than in a lab. According to Dillenbourg (2013) how to properly design learning interventions, and more importantly, how to adapt and deliver them for classroom implementation, is a complex task. Understanding the opportunities and barriers for deployment becomes an important part of the classroom integration process. In other words, it is important to make orchestration a key issue in the field of embodied learning.

Indeed, a few studies have provided valuable contributions into strategies, approaches, or frameworks for orchestrating embodied learning activities with technology. A careful review of the literature looking at classroom orchestration in relation to embodied learning, revealed work relevant to classroom orchestration around the use of interactive surfaces such as tabletops, interactive whiteboards, and interactive floors (e.g., Higgins, Mercier, Burd, & Joyce-Gibbons, 2012; Slotta, Tissenbaum, & Lui, 2013; Kharrufa, Balaam, Heslop, Leat, Dolan, & Olivier, 2013), classroom orchestration around the use of mobile devices such as phones and tablets running AR apps (e.g., Niramitranon, Sharples, & Greenhalgh, 2010; Munoz-Cristobal, Jorrin-Abellan, Asensio-Perez, Martinez-Mones, Prieto, & Dimitriadis, 2014), or other tangible tools such as educational robotics (e.g., Palaigeorgiou, & Pouloulis, 2018; Girotto, Lozano, Muldner, Burleson, &

Walker, 2016; Shahmoradi, Olsen, Haklev, Johal, Norman, Nasir, & Dillenbourg, 2019). However, there is paucity of research in the area of classroom orchestration around the use of motion-tracking technologies, especially those engaging learners in full body interaction technologies (e.g., VR or Kinect/Wii tools). In fact, the interplay of classroom orchestration and the enactment of technology-enhanced embodied learning in authentic classrooms is a largely unexplored field while coherent frameworks to guide implementation have yet to emerge.

To extent the discussion, research on the orchestration of interactive surfaces has reported on how multi-touch technology can be used to support collaborative and constructivist learning in classroom settings (Higgins, Mercier, Burd, & Joyce-Gibbons, 2012; Slotta, Tissenbaum, & Lui, 2013) while also providing data to enhance teachers' awareness of students' progress (Martinez-Maldonado, Dimitriadis, Martinez-Monés, Kay, & Yacef, 2013). Martinez-Maldonado et al., (2013a;2013b) designed a multi-tabletop ecology to help teachers orchestrate the classroom and enhance their awareness of each group strategies by analyzing data captured from collaborative interactions. Similarly, Slotta, Tissenbaum and Lui (2013) research incorporates tangible and embodied interactions with the environment which employ learning analytic techniques to allow students' physical interactions and spatial positioning within the room to play a strong role in scripting and orchestration. Furthermore, Kharrufa et al.'s (2013a;2013b) research on the deployment of digital tabletops in a classroom highlights the importance of supporting teachers through flexibility or making the system flexible enough to adjust to teachers' plans, and awareness, or making teachers aware of students' progress.

Furthermore, in the context of orchestration, research on mobile devices running simulations or AR apps also elaborated how computer-supported collaborative learning (CSCL) could pay more attention to design features that allow teachers to manage multiple classroom constraints (Dillenbourg, Zufferey, Alavi, Jermann, Do-Lenh, & Bonnard, 2011). Magana, Chiu, Ying Seah, Bywater, Schimpf, Karabiyik, ... & Xie, (2021) study include how learning experiences with engineering and science simulations should be designed so that teachers can adopt and adapt materials for their specific audiences, contexts, and settings. The research by Munoz-Cristobal et al., (2014) evaluates the effectiveness of GLUEPS-AR, a system designed to assist teachers in coordinating learning activities across different spaces in ubiquitous learning environments (ULEs), using a case study where a pre-service teacher designed an authentic learning situation in a primary school aimed at fostering orienteering skills. The evaluation found that GLUEPS-AR was helpful in managing the orchestration of the learning activities across multiple devices and technologies, although there was room for improvement in terms of the teacher's awareness during outdoor activities.

More research on technology-enhanced learning and classroom orchestration can be found around the integration and use of tangible tools such as educational robotics. Shahmoradi, et al., (2019) present the opportunities and challenges of orchestrating Educational Robotics (ER) activities in classrooms framing the challenges that need to be addressed to realistically scale-up usage of ER in classrooms. Moher (2006) proposed introducing tangible learning environments into classrooms by first integrating "embedded phenomena", which involves bringing technologies out of desktop computers and into the classroom (e.g. simulations). While the paper primarily discusses how students interact with this technology, the author recognizes that teachers' understanding of their individual students is crucial in ensuring effective learning from the simulations. Lui, Kuhn, Acosta, Quintana, & Slotta, (2014) also described the integration of immersive simulations in the classroom and emphasized the necessity of iterative design and co-design with teachers. To minimize barriers faced in the classroom, while optimizing the classroom orchestration, and thus maximizing the value in robo-tangible systems, Girotto et al., (2016) proposed four design recommendations for the deployment of non-traditional interface systems in a school setting: 1) target multiple learning objectives, 2) emphasize the collaborative affordances, 3) optimize for training, and 4) innovate the use of known system components. Stanton et al., (2001) stressed the importance of paying higher attention to the classroom in the design of pedagogical Tangible User Interfaces (TUIs) (Cuendet, Bonnard, Do-Lenh, & Dillenbourg, 2013) and for evaluating Tangible User Interfaces (TUIs) in classrooms rather than in a lab.

Closing, one of the best practices for integrating and orchestrating a new technology is remediation i.e., the practice of taking techniques and practices that work in one domain and applying them to the new domain. There is plenty of work in the field of technology integration and orchestration, although not focused on embodied learning environments. Remediation can therefore be used to integrate and orchestrate technology-enhanced embodied learning based on previous knowledge, techniques, and practices from the general research in the field.

3.3 Background work – concluding remarks

Overall, a few studies of embodied learning seem to report mixed or negative findings regarding the effectiveness of body-based (and in some cases) forms of instruction (e.g., Hung, & Chen, 2018; Johnson-Glenberg, & Megowan-Romaniwicz, 2017; Lan, Fang, Hsiao, & Chen, 2018; Nathan, & Walkington, 2017). This suggests that technology-enhanced embodied learning does not always result in better learning effects compared to non-embodied learning, and implementations suggest variable enactment and inconsistent impact. According to Díaz, Nussbaum, Ñopo, Maldonado-Carreño, & Corredor (2015), despite growing investments in educational technology, studies have not yet shown that learning has significantly improved. Findings on the effectiveness of technology-enhanced embodied learning are inconsistent especially between studies conducted in laboratories settings and studies conducted in the authentic educational contexts (Maliverni, & Pares, 2014; Karakostas, Palaigeorgiou, & Kompatsiaris, 2017).

While several technology-enhanced embodied learning environments have received positive evaluation in high-controlled laboratory settings (e.g., Homer et al, 2014; Lindgren, Tscholl, Wang, & Johnson, 2016), studies conducted in authentic school classrooms had not been as successful as initially expected in promoting students' learning gains (e.g., Anderson, & Wall, 2016; Hung, Lin, Fang, & Chen, 2014). The review of the literature in this dissertation reveals that a comprehensive, yet pragmatic, framework that describes when and under which conditions pedagogical strategies for embodied learning can be employed in everyday classroom settings is lacking, especially for technology-enhanced embodied learning. In sum, the adoption, adaptation, integration, and orchestration of technology-enhanced learning into a classroom setting have not been thoroughly investigated. The efficacy and success of technology-enhanced embodied learning requires fostering a research-driven orchestration of the learning process so that both a body-minded experience and a body-minded understanding are facilitated. Overall, there is a need for practical examples and guidelines for embodied technology integration designed to be immediately adopted into the classroom. Such practical examples and guidelines will help maximize the value and benefit while minimizing the barriers to the adoption of technology-enhanced embodied learning in authentic classrooms.

4 RESEARCH METHODOLOGY

This chapter describes in detail the research methodology used in this study, known as Design-Based Research (DBR). The chapter begins with an explanation of what DBR involves. Then, the chapter provides an overview of the different stages/cycles of this DBR work and ways in which validity, reliability, and ethics are ensured. The chapter also gives information regarding the participants and procedures in each phase, including data collection and analysis. The aim of the overall DBR work was to inform theory and practice and to generate design guidelines for technology-enhanced embodied learning in authentic classroom settings.

4.1 Design Based Research (DBR)

The DBR work addresses the problem of the scarcity of research on the orchestration of technology-enhanced embodied learning in authentic classrooms. Four cycles composed of design, implementation, analysis, and redesign were employed. The implementations took place in elementary classrooms in public schools in Cyprus. DBR methodology was deemed appropriate since the context and naturalistic setting of the classroom were key components of the design being evaluated. Mixed approaches based on both quantitative and qualitative data gathering were used in order to explore the empirical problems and possibilities that arise during technology-enhanced embodied learning. In this way, we obtained a rich overview of the learners' experiences during each cycle of research.

At the start of the twenty-first century, DBR emerged and was hailed as a useful research methodology that might bridge the gap between formal education's research and practice. According to Wang and Hannafi (2005), DBR is a systematic but flexible methodology aimed at improving educational practice through theoretically driven iterative design, development, and deployment of educational activities in real-world learning contexts, developed through researcher-practitioner collaboration, with the view to informing theory and/or generating design guidelines. From a different perspective, Shavelson et al., (2003) define DBR as a sort of research that is conducted in educational settings and is heavily based on earlier research and theory. It aims to test and develop theories of teaching and learning, create instructional tools that can withstand difficulties encountered in daily practice, and trace the progression of learning in complicated, messy classrooms and schools. Similarly, Barab and Squire (2004) view DBR as a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings.

DBR is characterized by an iterative cycle of design, enactment or implementation, analysis, and redesign (DBRC, 2003). Initial problem identification, literature evaluation, intervention design and building, implementation, assessment, and the production and dissemination of theoretical and design principles are all steps in the study's progression. Researchers use both quantitative and qualitative methods to gather data. It supports educational interventions in naturalistic contexts where participants interact socially with one another and within design settings rather than in laboratory settings for producing novel learning and teaching environments (DBRC, 2003). The fact that the research is conducted in a real educational setting gives it a sense of validity and guarantees that the findings may be utilized to evaluate, inform, and improve practice in at least this one (and probably other) situation (DBRC, 2003). With this approach, it is possible to study types of learning that do not yet exist (Bakker, 2018).

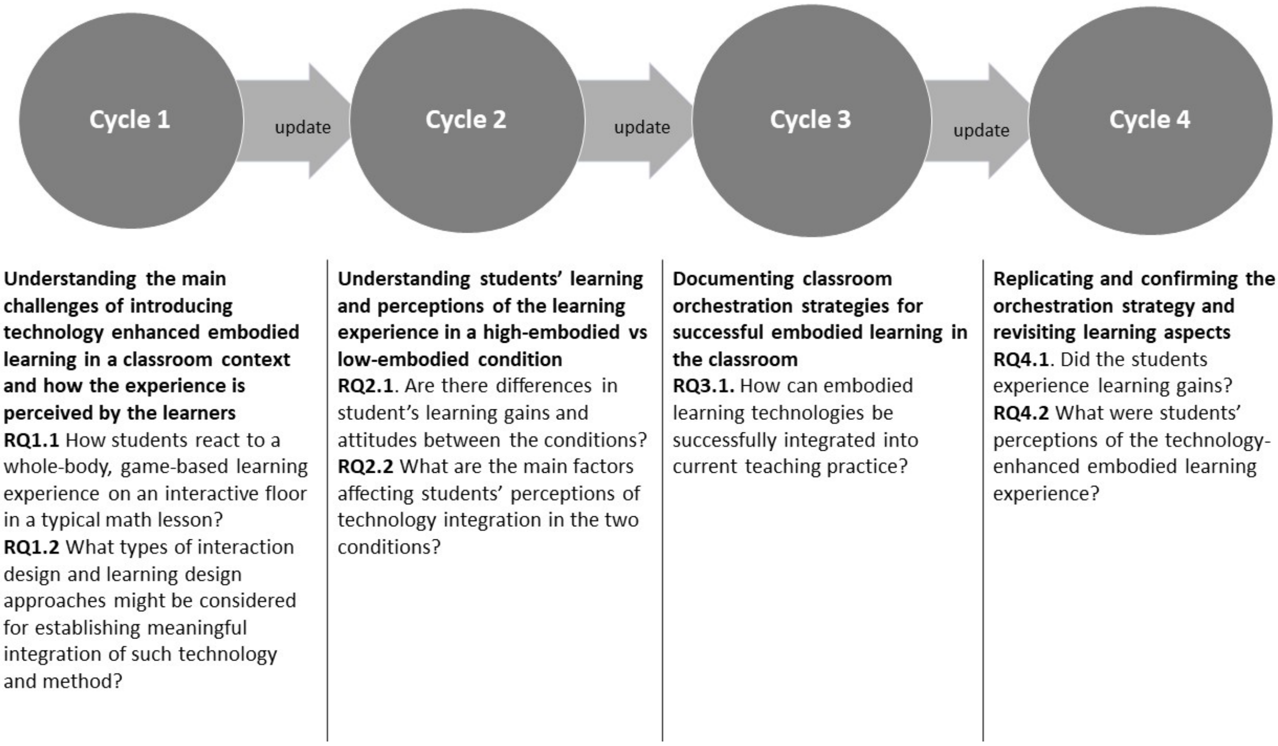
Increased impact, transfer, and translation of educational research into better practice are goals of DBR. It emphasizes the necessity of developing design principles and building theories to direct, inform, and advance practice and research in educational contexts (Anderson, & Shattuck, 2012). In design-based research, theory informs design, whose evaluation then comes back to inform theory, and over again through iterative cycles of development efforts. Researchers and practitioners work together to design and implement interventions systematically to refine and improve initial designs, and to produce meaningful change in contexts of practice (e.g., classrooms, after-school programs, teacher on-line communities) (Wang, & Hannafin, 2005). Researchers manage the design process, cultivate the relationship with practitioners, and most importantly, develop their understanding of the research context, despite the fact that boundaries between designers, researchers, and participants are blurred in design-based research processes (Bannan-Ritland, 2003). Thus, the products/outputs of DBR are design principles, learning theories, interventions, curricular products, instructional tools, and/or practical solutions/prescription (Abdallah, & Wegerif, 2014). Anderson and Shattuck (2012) describe it as a methodology that requires: addressing complex problems in real educational contexts, involving a collaborative partnership between researchers and practitioners; combining technological affordances with known and speculative design principles to generate workable solutions to these complex problems; conducting rigorous and reflective inquiry through multiple iterations to test and refine innovative learning environments as well as to define new reusable design principles; using mixed methods with a variety of research tools and techniques.

DBR has been embraced as a flexible methodology that enables academics to connect theory to practice, philosophy to reality, and abstract concepts to concrete circumstances. However, design-based research requires significant literature review and theory formulation, involves formative evaluation as a research approach, and utilizes numerous data collection and analytic methodologies widely used in quantitative or qualitative research (Wang, & Hannafin, 2005). Design experiments often lead to the collection of large amounts of data that may go unanalyzed.

DBR has been criticized because, in naturalistic research, causality can be difficult to determine and disambiguate; all potential components cannot be logistically investigated equally; and it is generally difficult to precisely replicate an intervention. Concerning research validity, Barab and Squire (2004) argued that "if a researcher is intimately involved in the conceptualization, design, development, implementation, and research of a pedagogical approach, then ensuring that researchers can make credible and trustworthy assertions is a challenge" (p. 10). Advocates of DBR argue that this problem is shared by many types of qualitative research, including anthropological research, in that none of these techniques can or does make the claim that the researcher's bias is eliminated from the study process. Good research requires "skepticism, commitment, and detachment" in order to walk this narrow line between objectivity and prejudice. A challenging and distinguishing trait of high-quality DBR is the ability to hold all these attitudes simultaneously. DBR requires objectivity, dependability, and validity to be considered scientifically sound, but these traits are handled very differently from controlled experiments (e.g., Barab, & Kirshner, 2001). DPR relies on techniques used in other research paradigms, like thick descriptive datasets, systematic analysis of data with carefully defined measures, and consensus building within the field around interpretations of data. It is possible to employ specific research methods to question the designer researcher’s tacitly held assumptions. Reliability of findings and measures can be promoted through triangulation from multiple data sources, repetition of analyses across cycles of enactment, and the use (or creation) of standardized measures or instruments. The challenge for DBR is to develop more globally usable knowledge for the field.

4.2 DBR cycles – aims, RQs and major findings

The overarching goal of this work was to address technology-enhanced embodied learning in authentic classroom contexts and to develop design guidelines that will ground and expand the implementation of embodied learning experiences in the classroom. Based on the overarching goal of the work, a set of research questions were formulated to be addressed in four cycles. Each of these cycles operates with one another to inform the theory and practice and inform the design of practical guidelines. Below, we elaborate on the researcher's decision for four cycles of work, i.e., the decision to "continue or quit the iterative design" (Dede, 2004), considering the overarching goal of the work to address technology-enhanced embodied learning in authentic classrooms and to develop design guidelines that will ground and expand the use of embodied learning. Figure 7 is a schematic representation of the research questions used in the four cycles of DBR work.



Understanding the main challenges of introducing technology enhanced embodied learning in a classroom context and how the experience is perceived by the learners
RQ1.1 How students react to a whole-body, game-based learning experience on an interactive floor in a typical math lesson?
RQ1.2 What types of interaction design and learning design approaches might be considered for establishing meaningful integration of such technology and method?

Understanding students' learning and perceptions of the learning experience in a high-embodied vs low-embodied condition
RQ2.1. Are there differences in student's learning gains and attitudes between the conditions?
RQ2.2 What are the main factors affecting students' perceptions of technology integration in the two conditions?

Documenting classroom orchestration strategies for successful embodied learning in the classroom
RQ3.1. How can embodied learning technologies be successfully integrated into current teaching practice?

Replicating and confirming the orchestration strategy and revisiting learning aspects
RQ4.1. Did the students experience learning gains?
RQ4.2 What were students' perceptions of the technology-enhanced embodied learning experience?

Figure 7: DBR cycles and RQs of the study

4.2.1 DBR Cycle 1 – Understanding the main challenges

DBR Cycle 1 was an exploratory case study of embodied learning using an interactive floor application in the context of math education. In praxis, the environment supported kinesthetic learning around a math game, where the learner physically interacted with content on fractions. An interactive floor can be categorized across immersion levels 3-4, based on the Johnson-Glenberg et al.'s taxonomy, which includes motoric engagement, gestural congruency, and immersive experience. Motoric engagement was achieved with full-body interaction on the interactive floor, however, gestural congruency required in immersion level 4 per Johnson-Glenberg taxonomy was not achieved in this exploratory investigation. Aspects of immersion were not examined in DBR Cycle 1.

Judging from the preliminary results of this study, these types of learning experiences appear to have value in terms of students' positive emotions; excitement and participation were overwhelmingly evident. Yet, the experience was not without drawbacks. Rather, many aspects of the learning experience design could be improved, including a gameful design preventing random choices at no cost, gestural concurrency and closer coupling in the game design, collaboration and social interaction in the game design, inquiry learning approach to lesson design, newer technologies tracking and responding to body or hand position more accurately. Overall, DBR cycle 1 triggered our greatest attention in pedagogical design aspects that should be considered for establishing meaningful integration of embodied learning technology in the classroom, particularly where collocation, collaboration, kinesthetic learning, and closer coupling of physical activity and digital representations are valued.

4.2.2 DBR Cycle 2 – Perception of the learning experience / High-embodied vs low-embodied experience

DBR Cycle 2 aimed to provide a richer embodied learning experience and to document gains in the learning domain, in addition to revealing positive emotions evident in DBR Cycle 1. Also, drawing on DBR Cycle 1 outcomes, we sought to understand what pedagogical elements might be considered for establishing meaningful integration of embodied learning technology in the classroom, around complete lessons. In doing so, first, we developed different pedagogical strategies to involve student groups in the learning process and encourage collaboration. Second, we sought to enforce the relationship between motoric engagement, gestural congruency, and immersion in a highly embodied learning experience. Third, considering the technical challenges (camera inaccuracies) of DBR Cycle 1, we obtained a different technological set-up in DBR Cycle 2. Namely, Kinect-based technology was used, corresponding to level three of Johnson-Glenberg et al.'s (2014) embodiment taxonomy. For comparison, a desktop-based version of the same educational game was also employed which provides the lower level of embodied experience according to the taxonomy. Last, an inquiry-based learning approach was adopted; a lesson unit about healthy food choices was designed and an embodied learning game was integrated in the lesson as one of students' hands-on activities. Overall, guided by two research questions (see Figure 7), DBR Cycle 2 extended our understanding of students' learning and perceptions of the learning experience in a high-embodied, Kinect-based educational game (Condition1, n=24 students), in comparison with a low-embodied, desktop-based version of the same game (Condition2, n=18 students).

Results from DBR Cycle 2 demonstrated high levels of engagement and motivation, enhancing the promise of enacting technology-enhanced embodied learning in authentic classrooms. Yet, in terms of level of embodiment, learning gains were higher for students who employed the desktop-based game (low-embodied) in comparison with their counterparts who employed the kinect-based game (high-embodied). In other words, motoric engagement and gestural congruency in the high embodied condition were not proven beneficial as hypothesized. A series of contextual factors deemed to have contributed negatively to students' learning experience. For example, collaborative learning and teamwork in DBR Cycle 2 was notoriously difficult to embed in this embodied learning environment and issues such as dominance within groups and unequal participation were identified during the implementation of the learning experience. Overall, while being enjoyable and engaging, the embodied learning experience in a typical classroom may not always produce significant learning gains. There is a need for a scaffolded approach that helps students understand the learning content and enables gains in the learning domain. Also, meta-cognitive activities, such as reflective opportunities, should be integrated into the inquiry experiences to reinforce concepts being presented. Another key component of effective implementation is planning activities such that the greatest number of students are actively engaged in their education and location; this would help to eliminate issues of dominance and unequal participation. The series of factors affecting the technology-enhanced embodied learning experience is presented in DBR Cycle 2. Most of these factors seem to suggest issues related to classroom orchestration that are worth investigating further. It became apparent that the implementation of technology-enhanced embodied learning in authentic classrooms requires special attention to issues of classroom orchestration, referring to the way teachers design and manage the classroom which involves activities and constraints in real-time.

4.2.3 DBR Cycle 3 – Orchestrating the classroom experience

In DBR cycle 3, we applied initial design principles for orchestrating the technology-enhanced embodied learning classroom, guided by the published framework of Prieto, Holenko Dlab, Gutiérrez, Abdulwahed, & Balid, (2011). We designed classroom experience for embodied learning using high-embodied, Kinect-based educational games (level three in Johnson-Glenberg et al.'s, 2014 embodiment taxonomy) along with conventional paper-and-pencil tools. We succeeded in enacting technology-enhanced embodied learning in the classroom that reached the third level of immersion per Johnson-Glenberg et al.'s, (2014) taxonomy, via the use of a large display and full-body interactions using motion-tracking devices. A lesson about means of transport was designed for the intervention. The Learning Station Rotation Model was adopted, which allows students to rotate through learning stations on a fixed schedule (Aydogmus, & Senturk, 2019). The set-up was designed to enable different teams to operate autonomously, i.e., without the need for much support from a teacher. Moreover, in this cycle, we emphasized teacher professional development, which helped teachers to better understand processes as well as implications of enacting technology-enhanced embodied learning in the classroom. The essential contribution of this work is the presentation of an experience report about implementing an orchestration strategy for designing embodied learning, guided by the published framework of Prieto, Holenko Dlab, Gutiérrez, Abdulwahed, & Balid, (2011). In sum, DBR Cycle 3, presented evidence for the success of the orchestration strategies adopted. Furthermore, we presented newly generated design principles related to the real-world design setting under investigation and building on the previous framework adopted. Our findings, based on interview data with the teachers, supported the idea that our orchestration strategy can guide the successful implementation of technology-enhanced embodied learning in authentic classrooms. The following DBR cycles could further refine this strategy.

4.2.4 DBR Cycle 4 – Replicating and confirming the orchestration strategy and revisiting learning aspects

In DBR Cycle 4, we tried to replicate and confirm the orchestration strategy that derived from DBR Cycle 3 and to revisit learning aspects in technology-enhanced embodied learning which were unclear in earlier cycles of the work. A history lesson plan about archaic kingdoms was co-design between teachers and the researcher. Teachers were already trained in enacting technology-enhanced embodied learning, including the use of multi-sensory technologies, per their participation in previous cycles of the DBR. The Station Rotation Model was adopted again in this cycle as it enables different teams to operate autonomously, and it permits the teacher to rotate across learning stations and assist students as needed. All stations enacted an embodied learning experience; we employed a variety of activities with technologies (virtual reality, robot programming, tablets), each harnessing the power of embodied learning guided by Black et al.'s (2012) IEF framework. We used affordable technologies enriched with content that is aligned with the national educational curriculum. The students engaged in a virtual field trip, programmed the Bee-bot, and created storyboards. We aimed to combine the physical and digital worlds and to enable a multisensory and embodied learning experience to promote an understanding of historical information in a multidisciplinary lesson.

In DBR Cycle 4, design principles that proved successful in the previous cycle were applied and enriched. Students' performance and input revealed positive learning gains and attitudes and underlined that the learning station model, the use of technologies and manipulatives, and the design of the learning activities were successful in providing an engaging embodied learning experience. With this study, we presented a successful enactment of technology-enhanced embodied learning in the classroom, replicating and confirming the orchestration strategy that derived from DBR Cycle 3 and documenting learning aspects that were unclear in earlier cycles of the work. The study highlighted how technology-enhanced embodied learning can offer learning opportunities for students and therefore deserves major consideration as mainstream education practice.

This study showed a significant gain in student learning when technology integration and orchestration strategies were made explicit to the educators.

4.3 DBR Cycles: Participants, procedures, data collection and instrumentation

4.3.1 Participants

DBR Cycle 1 was conducted with 20 fourth-grade students (aged 9-10; 11 males, 9 females) at a public elementary urban school in Cyprus. The teacher of the classroom (author of this dissertation) was present during the intervention to manage students' behaviour, to guide them and to coordinate the intervention on the interactive floor. The teacher was both a participant and observer of students' activities and her role provided access to a wide range of data. A second observer, an experienced researcher in the field, participated in this cycle.

DBR Cycle 2 was conducted with 42 students in 4th grade (aged 9-10 years old), who were enrolled in a public primary school in Cyprus. The students were randomly assigned to the two conditions. Group1 (Kinect-based gaming condition) had 24 children (12 boys, 50%) and Group2 (Desktop-based gaming condition) had 18 children (11 boys, 61%). The teachers of the two classes were present during the intervention to manage students' behaviour, to guide them and to coordinate the lesson implementation. In this DBR cycle the author of this dissertation did not participate as a teacher in the intervention. A second observer, an experienced researcher in the field, participated in this cycle.

DBR Cycle 3 was conducted with 52 students, aged 6-7 years old, in three 1st grade classrooms of a public primary school in Cyprus. Students had no previous experience with embodied learning technologies prior to the intervention. The students were assigned in mixed-ability groups of four, based on their teachers' knowledge of students' academic background and learning needs, collaboration skills and social relationships. The participating teachers were 5 females with 10 – 20 years of teaching experiences at primary school. Three teachers teach all subjects in the age categories of 1-6th grade and two teachers work in the school's special education unit as speech therapist teacher and special education teacher. At the time of the study the participating teachers received professional development. One of the interventions in this DBR cycle was carried out by the author, who acted as both a participant and observer of the students' activities. In the other two interventions, the author was only observer as other educators, who followed the professional development program, implemented the interventions.

DBR Cycle 4 was conducted with year 4 students (N = 34, 9-10-year-olds) from two classes at a public primary school in Cyprus; 16 participants came from one class (7 girls, 9 boys) and 18 from the other (10 girls, 8 boys). The students had not previously used Google Expeditions; it was also their first-time using VR headsets at school (i.e., station 1). The students were familiar with the technology used at stations 2 and 3 (the Bee-bots and the storyboarding software). The two participating teachers (including the author of this dissertation) were already familiar with embodied learning via their participation in professional development and previous cycles of this work.

In summary, all investigations were conducted in public elementary schools with groups of school children aged 6-10 years old. All studies had been granted ethical approval by the Cyprus Ministry of Education, Culture, Sport, and Youth (see Appendix). Prior to each study, a consent form was acquired from the participating schools and schoolteachers. Pupils and pupils' legal guardians also filled out and signed informed consent forms. The consent involved agreement to participation, data collection, treatment of personal information, data processing, and the publication of anonymized data. Table 1 shows the participants involved in the four DBR cycles.

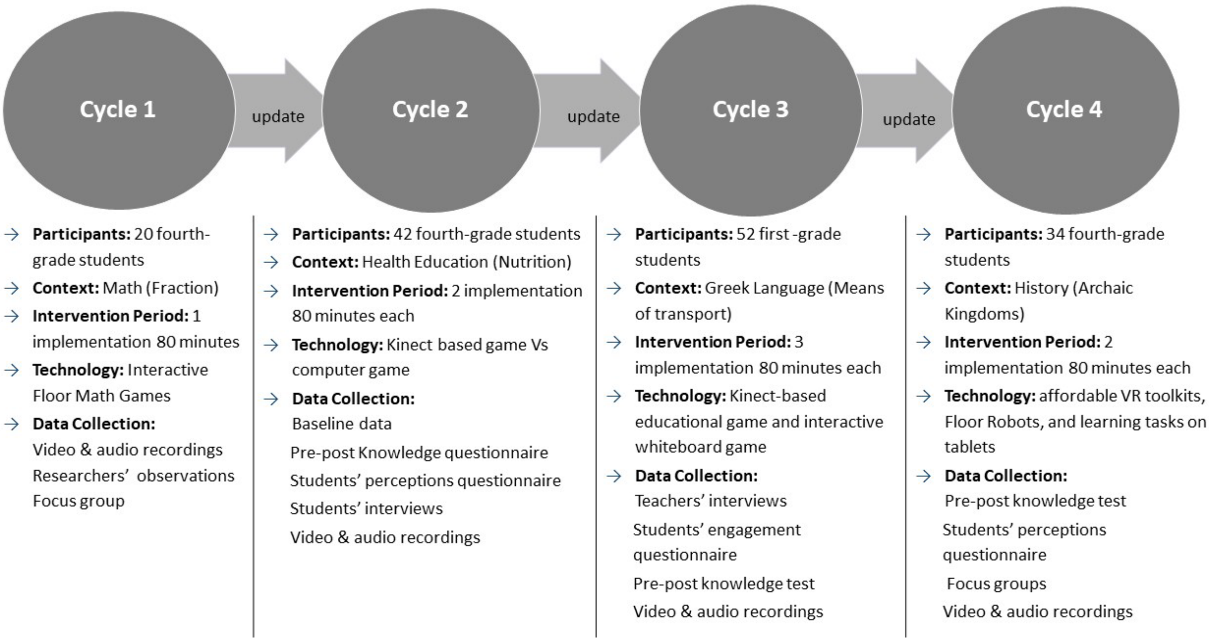


Figure 8: Participants in each DBR cycle

4.3.2 Procedures

In all four cycles, the intervention was conducted in a real classroom setting. In all cycles of work, designing the technology-enhanced embodied learning environment - technological set-up as well as learning material and assessment - was a task undertaken by teachers and an educational technologist as a co-design effort. The content of the activities came from the national curriculum on different subjects. In some cases, the author of this dissertation acted as the teacher in the classroom implementing the intervention. In other cases, the classroom teachers coordinated the lesson implementation while the researcher was present during the delivery of the lesson. A second observer, an experienced researcher in the field, participated in the first two cycles of work.

In DBR Cycle 1, the intervention took place in a large multi-purpose classroom in a primary school. The embodied learning experience consisted of three full-body activities about fractions on an interactive floor, which were designed to provide an embodied experience to students and to map to potential emotional and learning outcomes. The goal in the first app was to identify fractions as part of a whole (played individually). The goal in the second app was to recognize equivalent fractions (played in a group). The third app was about adding and subtracting fractions with common denominators (played individually). The visual output was projected on the floor and the students could move around the periphery of or directly on the visual output. Visual and auditory feedback was given on the projected display.

DBR Cycle 2 took place in two classes to allow the comparison of two conditions. We examined students' learning and perceptions of technology integration in a high-embodied condition, n=24 students (Kinect-based educational game), in comparison with a low-embodied condition, n = 18 students (desktop-based version of the same game). In both conditions, the game was contextualized as a collaborative educational activity. Students' learning gains and their perceptions about the implementation were examined. We proceed with a thematic analysis to identify the numerus factors influencing students' attitudes, namely perceptions of technology integration, within the three dimensions of our conceptual framework: "Relationship", "Personal development", and "System maintenance and change" and present them on a conceptual map.

In DBR Cycle 3 we adopted Prieto et al.'s conceptual framework of "characterizing orchestration" (Prieto, Dlab, Gutiérrez, Abdulwahed, & Balid, 2011) to guide the classroom design and implementation of the technology-enhanced embodied learning experience. The students were assigned to mixed-ability groups of four and used the Kinems platform, which consisted of movement-based educational Kinect games for special and mainstream education with kinesthetic and learning analytics. Children could interact with the learning environment with hand and body gestures. The Learning Station Rotation Model was adopted, which allows students to rotate through learning stations on a fixed schedule. Four learning stations were set up in each classroom, two of which utilized technology and the other two utilized conventional paper-and-pencil tools.

In DBR Cycle 4 we adopt the "Instructional Embodiment Framework" (IEF) proposed by Black, Segal, Vitale, and Fadjo (2012) for the enactment of embodied learning via forms of physical embodiment (direct, surrogate, and augmented) while the orchestration strategy applied was informed by DBR Cycle 3. This study took place in a multidisciplinary lesson on historical information. We employed a variety of activities with technologies (virtual reality, robot programming, tablets), each harnessing the power of embodied learning. The students engaged in a virtual field trip, programmed the Bee-bot, and created storyboards.

4.3.3 Data collection and instrumentation

Data collection in each cycle included children's perceptions as a central guide to inform design. We aimed at incorporating children's perceptions into the design of a learning environment, thereby making those environments more effective for the learners in terms of specific educational goals. The way in which children interpreted and used the technology-enhanced embodied learning environment was used to further inform and refine our learning design. Data collection and analysis was always a mixed method, driven by the researcher's pragmatic view in research and understanding that data from multiple sources increases the objectivity, validity, and applicability of research findings. Data collection details per DBR cycle are summarized below and detailed in Table 2.

In DBR Cycle 1 data was collected through both qualitative and quantitative methods. Because of the children's ages, more emphasis was placed on the qualitative rather than the quantitative part by conducting interviews and observations. Multiple video cameras were set up in the classroom to capture facial expressions, physical movement, social interactions, and verbal communication around the interactive floor. We prompted students to talk about their thinking during their participation, and in general, they were encouraged to share any immediate thoughts about their experience during their play; verbal reports were later extracted from the video data. At the end of the experience, we engaged students in a class-wide discussion (i.e., a large focus group) about their overall impressions.

In DBR Cycle 2 data collection included questionnaires evaluating students' baseline, pre and post-test evaluating knowledge gains, perceptions of technology integration, and post-activity interviews with eight students from condition 1 (33.3%) and eight students from condition 2 (44.4%).

In DBR Cycle 3 data collection included student pre-and post-knowledge tests and a questionnaire on their engagement within three subscales: (a) Cognitive engagement; (b) Emotional engagement; and (c) Social (Rimm-Kaufman, 2010). After the interventions, semi-structured group students' and teachers' interviews followed.

In DBR Cycle 4, we adopted a mixed method design, using quantitative and qualitative data as well. It included a pre- and post-test for evaluating students' understanding of historical information, and a post-test evaluating students' perception of technology integration on three dimensions: Relationships, Personal development and System maintenance and change. Data collection included focus groups with groups of 8 students from each classroom.

Table 1: Data collection details per DBR cycle

Phase	Data collecting method	Purpose
DBR Cycle 1	Focus group	Students got engaged in a class-wide discussion (i.e., a large focus group) about their overall impressions.
	Video & audio recording Researchers'observations	Multiple video cameras were set up in the classroom to capture facial expressions, physical movement, social interactions, and verbal communication around the interactive floor.

		The teacher and an experienced researcher in the field were observers of students' activities.
DBR Cycle 2	Baseline questionnaire Pre and Post Knowledge test Perceptions of technology integration questionnaire Post activity interviews with participants from each group Video & audio recording	Students' baseline in terms of computer and gaming attitudes (CAMYS, Teo, & Noyes, 2008). The test was developed by Johnson-Glenberg and Hekler (2013) for evaluating students' learning gains in the Alien Health game. Students' perceptions of technology integration in terms of "Relationship", "Personal development" and "System maintenance and change" were evaluated at the end of the experience (Wu, Chang, & Guo, 2007; Maor, & Fraser, 2005). Eight students from each condition participated in an approximately 15-minute semi-structured individual interview, which took place right after the intervention. Cameras were set up in the classroom to capture facial expressions, physical movement, social interactions, and verbal communication of the students.
DBR Cycle 3	Student knowledge test Students' engagement questionnaire Teacher interviews Video & audio recordings	A pre- and post-knowledge test about language acquisition on means of transport was administered to the student. A post-interventional questionnaire aimed at evaluating students' engagement within three subscales: (a) Cognitive engagement (b) Emotional engagement (c) Social engagement (Rimm-Kaufman, 2010). Post-activity interviews were carried out with the participating teachers about their overall experience. Cameras were set up in each classroom to capture facial expressions, physical movement, social interactions, and verbal communication of the students.

DBR Cycle 4	Pre and Post Knowledge test Perceptions of technology integration questionnaire Focus groups Video & audio recordings	Knowledge test on understanding of historical information Students’ perceptions of technology integration in terms of "Relationship", "Personal development" and "System maintenance and change" were evaluated at the end of the experience. Eight students from each classroom participated in an approximately 25-minutes focus group took place right after the intervention. Cameras were set up in each classroom to capture facial expressions, physical movement, social interactions, and verbal communication of the students

5 DBR CYCLE 1

This chapter reports the design, development, and deployment of DBR Cycle 1 – an exploratory case study of embodied learning using an interactive floor application in the context of math. Preliminary results from this exploratory case study are published in the proceedings of the 13th International Conference of the Learning Sciences (ICLS) 2018, in the form of a poster [Ioannou, M., & Ioannou, A. (2018). Playing with fractions on an interactive floor: An exploratory case study in the math classroom. In J. Kay & R. Luckin (Eds.), *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018* (Vol. 3, pp. 1635-1636). London, UK: ISLS.]

5.1 Introduction

DBR Cycle 1 was an exploratory case study of embodied learning using an interactive floor application in the context of math education. The Johnson-Glenberg, Birchfield, Tolentino, and Koziupa (2014) taxonomy levels of bodily involvement provide us with a basis to categorize our technology-enhanced embodied learning environment where students' own motion entails a direct bodily experience. An interactive floor can be categorized across immersion levels 3-4, based on the Johnson-Glenberg et al.'s taxonomy, which includes motoric engagement, gestural congruency, and an immersive experience. The interactive floor of the study simulates an interactive surface where digital information can be manipulated directly with feet and body movements, yet it does not enable the gestural congruency required in immersion level 4 per Johnson-Glenberg et al.'s taxonomy. In praxis, the environment supports kinesthetic learning around a math game, where the learner physically interacts with content. It can be hypothesized that by moving interaction from the screen to a physical space, the learning experience is extended, enabling new and richer forms of interaction (Dourish, 2004).

DBR cycle 1 aimed to advance our understanding of the main challenges of introducing technology-enhanced embodied learning in a classroom context and how the experience is perceived by the learners. More precisely, the study aimed at examining:

(i) how students react to a whole-body, game-based learning experience on an interactive floor in a typical math lesson and

(ii) what types of interaction design and learning design approaches might be considered for establishing meaningful integration of such technology and method.

5.2 Background work

Embodied cognition states that abstract representations are based on bodily experiences and movement may help children to understand abstract concepts better as it may draw on previous sensorimotor experiences, whilst the perceptual and interactive richness provides opportunities for alleviating cognitive load (Lindstedt, Kiili, Tuomi, & Perttula, 2016). Meanwhile, there is growing awareness in mathematics education of the importance of embodied action, interaction, and experience for mathematical thinking and learning (Hall, & Nemirovsky, 2012). Work exploring grounded and embodied mathematical cognition through gestures showed significant promise in prior research (Abrahamson, Gutiérrez, Charoenying, Negrete, & Bumbacher, 2012). When properly used, digital tools for education increase the educational potential through multimodality, whilst technology can support the construction of mathematical meanings (National Council of Teachers of Mathematics, 2000), allowing students to "play with" mathematics (Fey, 1989) and explore justification and proof in a visual, interactive environment (Hanna, 2000). Technology also allows students to enact mathematical tasks such as visualization, symbolization, intuition, and reasoning, providing new chances for the embodiment of mathematical ideas (Lee, 2015). In sum, it appears that the use of technology-enhanced embodied learning environments has potential to help students better understand the math concepts under study and make learning more interesting and interactive. The present exploratory investigation was enacted in the context of math education, particularly fractions.

5.3 Methodology

5.3.1 Participants

DPR cycle 1 was conducted with 20 fourth-grade students (aged 9-10; 11 males, 9 females) at a public elementary urban school in Cyprus. The intervention took place in a large multi-purpose classroom in a primary school.

5.3.2 Technology setup

A down-pointing projector was mounted on a special tripod (see Figure 8) and was connected to a laptop and a motion tracking camera (Kinect-type). The visual output was projected on the floor, and the user could move around the periphery of or directly on the visual output. Visual and auditory feedback were given on the projected display, based on the programmed game, to let players know if certain actions had succeeded or failed. The space was physically open on all sides, thus allowing students to directly communicate with peers inside and outside of the active area. We aimed to generate collaboration and interaction between the players, therefore our game was designed to accept multi-user input.

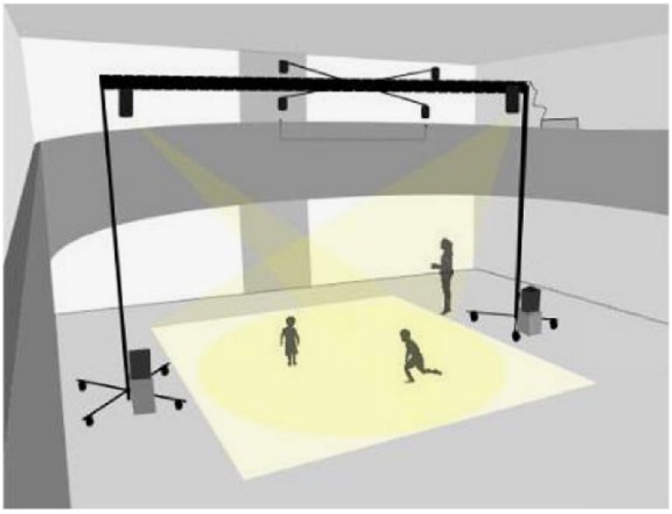


Figure 9: Interactive floor setup, a down-pointing projector mounted on a special tripod

5.3.3 Learning topic and activities

The learning topic used for this study - fractions - was identified in collaboration with the teacher based on the school curriculum set by the Ministry of Education. The embodied learning game consisted of three full-body activities. The activities were simulated on an interactive floor as follows. In the first activity, the children were tasked to identify fractions as part of a whole. They were given ten fractions and ten representations as a part of a whole. They had to move around on the interactive floor to match a fraction with its representation. Fractions and their representations were spread far apart, so that students had to look around to find a fraction's representation. For this activity, we explored the use of the embodied learning game in pairs and by individuals. In the second activity, the children had to recognize the equivalence of fractions. A visual representation of fractions was used, showing part of a pizza, and children had to move around to find its equivalent. They had to choose the simplest form from four different written representations of fractions. For this activity, the game was used by a group of four students. The third activity was for practicing adding and subtracting fractions with common denominators; it was used by individual students who had to choose the correct answer from the given options. Figure 9 presents some students interacting with the interactive floor.

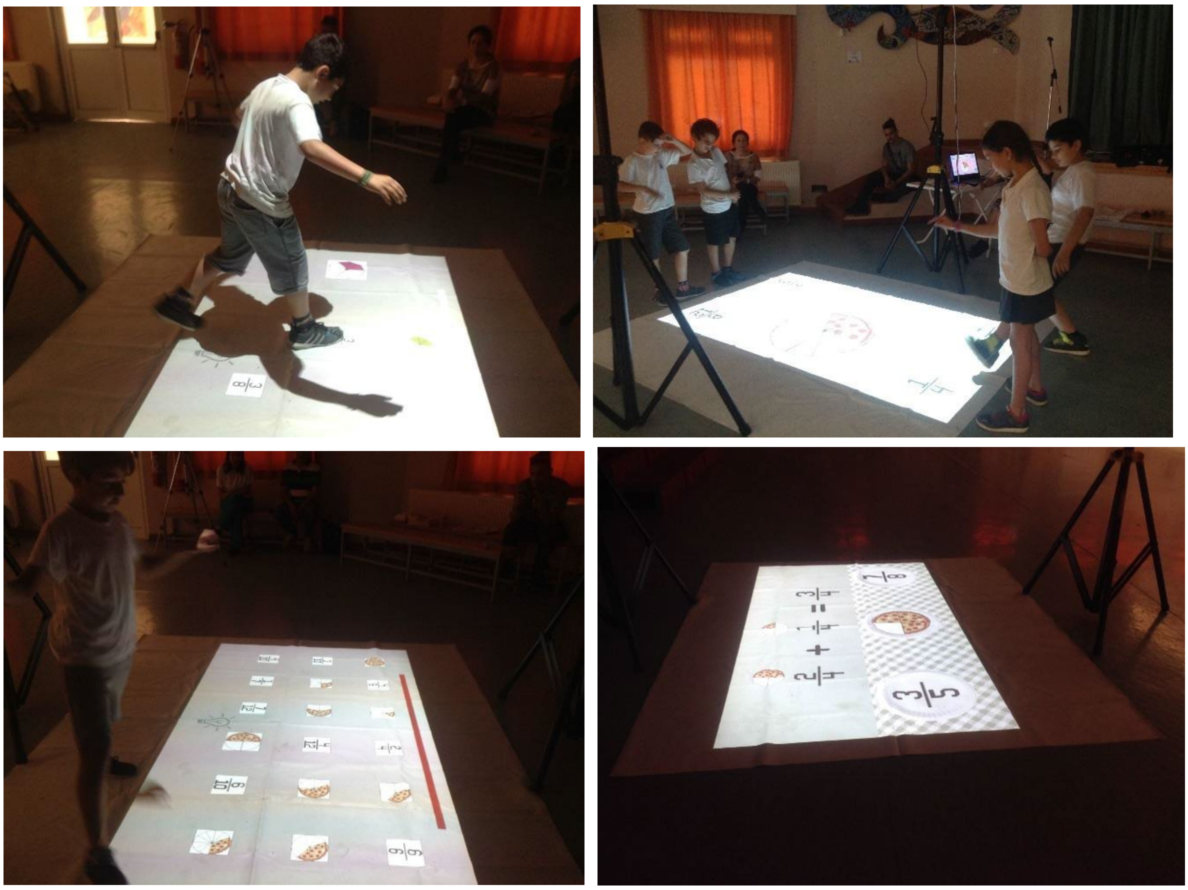


Figure 10: Students interacted with the interactive floor

5.3.4 Data collection

The study gathered qualitative data via discussion with the students and observations. Multiple video cameras were set up in the classroom space to capture physical movement, social interactions, and verbal communication around the interactive floor, which lasted for approximately one and a half hours. We prompted students to talk about their thinking during their participation, and in general, they were encouraged to share any immediate thoughts about their experience during their play; verbal reports were later extracted from the video data. At the end of the experience, we engaged students in a 30-min class-wide discussion (i.e., a large focus group) about their overall experience.

5.4 Results

We first analysed student focus group data following an open coding for themes approach. Themes related to joy and excitement, value of such games for learning and assessment, and design preferences emerged in the discussion with the students. We then analysed the video-corpus (including verbal talk) to extract further conclusions about the learner's experience. Findings from the video analysis triangulated the main themes found in the student focus groups while some more issues of concern were revealed. Overall, the learning experiences appeared to have value in terms of students' positive emotions; excitement and engagement were overwhelmingly evident. Table 3 illustrates the most persisting themes of the overall analysis and further below we elaborate with examples and student excerpts.

Table 2: Themes from the analysis of focus group data and video corpus

Positive themes	Negative themes
• Joy and excitement/ playfulness [+] • Emotional aspects/ engagement [+] • Assessment & immediate feedback [+] • Touchless interaction & bodily movement [+] • Teamwork & collaboration in pairs [+]	• Tech issues/Camera inaccuracies [-] • Sense of Immersion/presence [-] • Collaboration and teamwork [-] • Cognitive engagement [-]

Joy and excitement/playfulness [+] The students' feedback was positive. Beyond self-reported excitement, in our videos we found many instances of joy in the form of facial expressions, utterances of excitement, pleasure and thrill, active attention and participation, anticipation for their turn to play, and engagement in their activities. In a student's words:

> *"I like it a lot! It was a combination of math, gymnastics and play. It was math because we had to solve fractions. It was gym because we could move within the space, and it was sort of a game because we had lots of fun doing it." (female, student 1)*

Emotional aspects/engagement [+] We observed high levels of motivation. Students appeared engaged and motivated to participate and work with the flow. Students reported that the interactive floor experience was way more engaging than "typical lessons" e.g.,

> *"I like it more than a typical lesson because I solve problems with fractions while playing rather than writing; writing makes me tired but playing does not." (male, student 2)*

The students also expressed a desire to use the system in other content areas as well.

> *"It would be nice to have such games in other subjects. It could be a short exercise in the end of each lesson". (female, student 3)*

Assessment & immediate feedback [+] Students said that this would be a fascinating way to learn math and, potentially, other subjects. They did not report any specific learning gains but commented that the game was a fun way of assessing what they already knew about fractions and an opportunity for real-time feedback. Indeed, the games used visual and auditory feedback. Such feedback allowed the students to immediately see the outcome of their action/response or resulted in more global changes such as leveling up in the game.

> *"I like this game because we can remember things that we were already taught in math. It was a fun game, but with math. It is like a fun way of assessment". (female, student 4)*

> *“I liked the game because every time we made a mistake, ketchup was thrown at us and, in this way, we could know that our answer was wrong.” (male, student 5)*

Touchless interaction & bodily movement [+] Students enjoyed touchless interaction for learning with the embodied digital learning apps as this allowed them to be more active and engage in collaborative learning activities. This interaction was more natural for students. Also, students loved the kinesthetic aspect of the games.

> *“I like it because it is different from the game that we play on the interactive whiteboard. Here we play and we also move while on the interactive whiteboard we use the pen stylus, and we must click the answer.” (female, student 1)*
>
> *“It was nice. For the first time I see a video projector that does not need a pen stylus or a mouse to click to choose the answer and the interaction has been done by moving our body.” (male, student 2)*
>
> *“I like it because I could jump and move in the game and that was a lesson because we had to solve fractions.” (male, student 6)*

Collaboration and teamwork [-] The playful aspects of the game encouraged many students to dominate; when they knew the answer, they rushed to jump onto the surface of the interactive floor before their peers could think or act. At times, we observed parallel, independent play rather than the intended cooperation.

> *“I did not like the fact that I was always last. Every time someone else jumped into the answer before me. Some of my team members played immediately, and I had no time to think about the correct answer”. (female, student 7)*

Teamwork and collaboration in pairs [+] Along with issue of collaboration and teamwork, the students discussed that they preferred a multi-player then a single-player game, but the preference was for playing in couples rather than larger groups They argued that having two instead of four or five students in a group gave them the opportunity to play more, move better in space, and get more practice and feedback.

> *“Something else that I liked was the fact that most games were games played by groups of students. We were a group of students working together and not fighting.” (male, student 6)*

> *“What I most enjoyed was the game with pizzas and simplifying fractions. It was played by two students and not four. Being only two students in the game area was better because we had plenty of space to move and more chances to play.” (female, student 1)*

Cognitive engagement [-] A few students played the game only for fun, and their choices were incidental selections with no evidence of cognitive engagement. The students took advantage of the affordance of the game for multiple selections until the correct answer was chosen which led students to make random choices at no cost.

> *“I prefer the exercise to be more difficult, so to think more in order to find the solution.” (male, student 7)*

> *“I wanted it to be more difficult because when exercises are easy you do not learn but when they are difficult you have to think harder before acting on the floor.” (female, student 6)*

Technological issues /Camera inaccuracies [-] The implementation of our math games on the interactive floor was not flawless. We observed some tracking issues which interfered with players’ ability to smoothly interact with the game. For example, sometimes students’ moving hands were accidentally recognized as input and multiple selections were activated. On the other hand, sometimes jumping onto a "selection" was not immediately activated, and students had to insist on jumping.

> *“The only thing that I did not like was that we walked on the answer, but it was not activated. It was taking some time to be activated, and I wanted to jump into the next answer, so I had to stay there to insist until it was activated.” (male, student 6)*

> *“It needed some time for the chosen answer to be activated, and I was keep moving my foot back and forth and I was getting frustrated.”(male, student 8)*

5.5 Discussion

RQ1 – students' perceptions and behaviors. In this exploratory case study, we first previous aimed to examine how students react to a full-body, game-based learning experience on an interactive floor in a typical school setting. First, the results demonstrated that it is possible to integrate such methods in the math classroom. Judging from the preliminary results of the study, these types of learning experiences appear to have value in terms of students' positive emotions; excitement and engagement were overwhelmingly evident. These results confirm the outcomes of research that relates physical activity to positive emotions (Bianchi-Berthouze, Kim, & Patel 2007; Kosmas, Ioannou, & Retalis, 2017; Price, & Rogers, 2004). Yet, the experience was not without drawbacks. Rather, many aspects of the learning experience design could be improved and are discussed next.

RQ2 – interaction design and learning design aspects. We further sought to understand types of interaction design and learning design approaches that might help to establish meaningful integration of such technology and methods. First, we elaborate on the fact that, despite the excitement, cognitive phenomena were scarce. A few students played the game only for fun and their choices were incidental selections with no evidence of cognitive engagement. We think that our design choice which allowed for multiple selections, until the correct answer was chosen, let students make random choices at no cost. A *gameful design* (i.e., gamification) where points are earned only for correct answers on the first trial, could improve this issue. Furthermore, the students did not report any learning gains. On one hand, this result was rather expected since the game was designed to reinforce concepts and enable practice on a previously studied topic. On the other hand, this could be a result of the lack of *gestural concurrency in the game design* meaning that the movement was not closely coupled to the mathematical concepts i.e., *closer coupling* of physical activity and digital representations. In future attempts students could be asked to manipulate physical objects meaningfully, in ways that the abstract concepts that these objects aim to convey are understood.

Second, it was apparent from the results that the game should encourage collaboration and social interaction by design, which was not the case in this study. This created problems in larger-group collaboration, encouraging dominant behavior by few students. Yet, students seemed to enjoy teamwork in pairs, over individual work. We consider that an *inquiry learning approach to lesson design* -- in which students are guided to solve problems, collaborate, then interact with the floor game -- could encourage collaboration as well as cognitive engagement in this context. According to Shaer, Strait, Valdes, Feng, Lintz, and Wang (2011) inquiry-based approaches typically involve students working in groups to solve an over-arching question that necessitates multi-stage investigation. Between stages, students are required to reflect, discuss, and make decisions. The work involves teamwork, e.g., while one student is working with embodied learning technology, the other two or three can give the student instructions from the assignment sheet. According to Pirker, Holly, Almer, Gütl, and Belcher (2019) this sort of collaboration was identified as a valuable tool to engage also in VR experiences.

Third, this research cycle revealed that the technology used in this study had limitations in term motion tracking, which was spotted by the students. As newer technologies that track and respond to body or hand positions more accurately are rapidly entering the market, such issues should be resolved. A follow-up study could attempt to implement embodied learning using other types of motion tracking technologies.

Closing, the transition from traditional to technology-enhanced embodied learning includes several considerations. In terms of learning experience design, there are many design decisions that will have consequences on students' engagement and learning. Such decisions must practically be settled and in turn inform the development of best practice in technology-enhanced embodied learning. DBR cycle 1 triggered our greatest attention in pedagogical design aspects that should be considered for establishing meaningful integration of embodied learning technology in the classroom, particularly where colocation, collaboration, kinesthetic learning, and closer coupling of physical activity and digital representations are valued.

6 DBR CYCLE 2

This chapter reports on DBR Cycle 2 – an investigation of high-embodied, Kinect-based learning experience in comparison with a low-embodied desktop-based experience. A major part of the results from DPR Cycle 2 are published in the proceedings of the 13th International Conference on Computer Supported Collaborative Learning (CSCL 2019) [Ioannou, M., Georgiou, Y., Ioannou, A., & Johnson-Glenberg, M. (2019). On the understanding of students' learning and perceptions of technology integration in low-and high-embodied group learning. In *Proceedings of the 13th International Conference on Computer Supported Collaborative Learning*, 304 -311].

6.1 Introduction

DBR Cycle 2 aimed to provide a richer embodied learning experience and to document gains in the learning domain, in addition to revealing positive emotions evident in DBR Cycle 1. Also, drawing on DBR Cycle 1 outcomes, DBR Cycle 2 sought to understand what pedagogical elements might be considered for establishing meaningful integration of embodied learning technology in the classroom, around complete lessons.

In doing so, first, we developed different pedagogical strategies to involve student groups in the learning process and encourage collaboration. Second, we sought to enforce the relationship between motoric engagement, gestural congruency, and immersion in a highly embodied learning experience. Third, considering the technical challenges (camera inaccuracies) of DBR Cycle 1, we obtained a different technological set-up in DBR Cycle 2. Namely, Kinect-based technology was used, corresponding to level three of Johnson-Glenberg et al.'s (2014) embodiment taxonomy. Even though in the Kinect-based game there is motoric engagement and some amount of gestural congruency, in this study, we did not reach the fully immersive experience enacted via moving one's body within a simulation. For comparison with a less rich embodied experience, a desktop-based version of the same educational game was also employed which provides the lower level of embodied experience according to the taxonomy. Last, a collaborative learning approach was adopted using aspects of inquiry leaning; a lesson unit about healthy food choices was designed and an embodied learning game was integrated into the lesson as one of students' hands-on activities.

In the form of two sub-questions DBR Cycle 2 extended our understanding on students' learning and perceptions of the learning experience in a high-embodied, Kinect-based educational game (Condition1, n=24 students), in comparison with a low-embodied, desktop-based version of the same game (Condition2, n=18 students):

(i) Are there differences in student's learning gains and attitudes between the conditions?

(ii) What are the main factors affecting students' perceptions of technology integration in the two conditions?

6.2 Methodology

6.2.1 Participants

Participants were 42 students in 4th grade (aged 9-10 years old), who were enrolled in a public primary school in Cyprus. The students were randomly assigned to the two conditions. Group1 (Kinect-based gaming condition) had 24 children (12 boys, 50%) and Group2 (Desktop-based gaming condition) had 18 children (11 boys, 61%).

6.2.2 Research design

This study followed an explanatory sequential design, composed of two sequential phases (Creswell & Clark, 2017). In phase 1, we adopted a two-group quasi-experimental design for investigating students' learning gains and perceptions of technology integration in both conditions. In phase 2, we proceeded with qualitative data collection to deepen our understanding of the factors relating to students' perceptions of technology integration.

6.2.3 The digital game and high/low- embodied interaction

We employed the "Alien Health" digital game, which was designed to teach 4th-12th grades about nutrition and healthy food choices. The game is well-related to the school curriculum whilst findings from previous studies of "Alien Health" indicated its acceptability by the children and its affordances to improve content knowledge (Johnson-Glenberg, & Hekler, 2013). Children's mission in the game is to make the right nutritional choices for the alien to make him feel better as he oversees stopping the collision of an asteroid with the Earth. During the gameplay, children are presented with combinations of food and are requested to make choices within predefined timeframes, considering a constellation of five nutrients per food (protein, fats, carbohydrates, fiber, and vitamins/minerals). The digital game became available in both a low embodied (desktop-based) and in a high embodied (Kinect-based) version. In high embodied, congruent gestures using hands were used to manipulate the content on screen in the high embodied condition in order to facilitate learning. The learner would grab and move, via gesture, the food on the plate. Congruency across this condition was easily achieved as children's actions drew their attention to naturally occurring relationships in the physical world. On the other hand, in low-embodied condition, manipulating a computer mouse with the micro-movements of one's hand entailed a much lower degree of embodiment (Johnson-Glenberg et al., 2014).

6.2.4 The interventions

A collaborative learning approach was adopted using aspects of inquiry learning; a lesson unit about healthy food choices was designed and an embodied learning game was integrated into the lesson as one of students' hands-on activities. An 80-minute intervention was developed for each condition. Children in the low embodied (desktop) condition were divided in dyads and used the desktop-based version of the digital game. In this version children used the mouse and the keyboard for making a choice and feeding the alien (see Figure 10). Children in the high embodied (Kinect-based) condition were divided into groups of four (the limited classroom space allowed only six Kinect workstations of the game) and used the Kinect-based version of the game. In this case, the game was projected on a big screen and there was touchless interaction via the Kinect camera which can identify children's arm/hand movement hovering over a single food item and moving it into the Alien's mouth (see Figure 10). In both conditions the game was part of the collaborative learning activity; the children took turns in playing (game affords only single player mode); the other child(ren) of the group was/were asked to provide feedback to the player, discuss the selections made, and record their food choices on a structured worksheet.

Figure 11: A group of students in low-embodied and high-embodied condition

6.2.5 Data collection and analysis

Data collection included questionnaires evaluating students' baseline, knowledge gains, perceptions of technology integration, and post-activity interviews with eight students from Condition1 (33.3%) and eight students from Condition2 (44.4%).

6.2.5.1 Baseline data

We aimed at establishing the equivalency of the two conditions in terms of computer and gaming attitudes. We used the Computer Attitude Measure for Young Students questionnaire (CAMYS, Teo, & Noyes, 2008), which is composed of 12 items on a five-point Likert scale and has a documented reliability alpha coefficient of .85. Gaming attitudes were measured using an 11-item Likert scale (Cronbach's alpha=0.73) validated in the study of Bressler and Bodzin (2013). Differences between the two conditions were examined using the Mann-Whitney U test, given the small sample size of participants in each condition and the lack of normal distribution in the data.

6.2.5.2 Knowledge test

A knowledge test was administered in pre-post format. The test was developed by Johnson-Glenberg and Hekler (2013) for evaluating students' learning gains in the Alien Health game.

6.2.5.3 Technology integration survey

Students' perceptions of technology integration were evaluated at the end of the experience. The questionnaire was composed of five subscales guided by Moos (1987)'s conceptual framework of technology integration, later used by Wu, Chang and Guo

(2007) and Maor and Fraser (2005) to derive subscales for its three dimensions: "Relationship", "Personal development" and "System maintenance and change" as in Table 4.

Table 3: Questionnaire Dimensions, Subscale Details and Individuals Items

DIMENSION 1: Relationships	**Student Negotiation (SN): a 5-item subscale assessing the extent to which students have opportunities to discuss their questions and their solutions to questions (adapted from Maor & Fraser, 2005)**	
	SN-1	I get the chance to talk to other students
	SN-2	I discuss with other students how to conduct investigations
	SN-3	I ask other students to explain their ideas
	SN-4	Other students ask me to explain my ideas
	SN-5	Other students discuss their ideas with me
	Student Cohesiveness (SC): a 6-item subscale assessing the extent to which students are supportive to each other (adapted from Wu, Chang & Guo, 2007)	
	SC-1	Students are friendly to each other
	SC-2	Students are willing to help each other
	SC-3	It is easy to find members for grouping
	SC-4	Students share information with each other
	SC-5	Students have opportunities to discuss questions with classmates
	SC-6	Group members complete assignments together in class
DIMENSION 2: Personal Development	**Competition & Efficacy (CE): a 6-item subscale assessing the extent to which students are motivated and confident to compete each other (adapted from Wu, Chang & Guo, 2007)**	
	CE-1	Students care about their own performance
	CE-2	Students work hard to outperform others
	CE-3	Classmates' performances push students to be more diligent
	CE-4	Students set up study goals on their own
	CE-5	Comparisons among groups occur
	CE-6	Students are confident of learning this subject well
	Reflective Thinking: a 5-item subscale assessing the extent to which students have opportunities to discuss their questions and their solutions to questions (adapted from Maor & Fraser, 2005)	
	RT-1	I get to think deeply about how I learn
	RT-2	I get to think deeply about my own ideas

	RT-3	I get to think deeply about new ideas
	RT-4	I get to think deeply how to become a better learner
	RT-5	I get to think deeply about my own understandings
DIMENSION 3: System Maintenance and Change	**Complexity: a 5-item subscale assessing the extent to which the program is complex and represents data in a variety of ways (adapted from Maor & Fraser, 2005)**	
	C1	It has an interesting screen design
	C2	It is easy to navigate
	C3	It is fun to use
	C4	It is easy to use
	C5	It takes only a short time to learn how to use

6.2.5.4 Post-activity interviews

Eight students from each condition participated in an approximately 15-minute semi-structured individual interview, which took place right after the intervention. The students were asked to talk about their learning experience with Alien Health, as well as their use and perceptions of the technology utilized. Driven by Moos (1987)'s conceptual framework of technology integration and its three dimensions, the students were particularly probed to discuss the factors affecting their experience in terms of: (a) Personal development (e.g., What were the main factors that help you learn during your participation in this digital game?), (b) Relationships with others (e.g., How was the collaboration among team members structured around the digital game employed?), and (c) Technology use (e.g., Did you encounter any problems while using the digital game? How did those problems affect you?). All interviews were transcribed and coded within the three dimensions of our conceptual framework.

6.3 Findings

6.3.1 Setting the baseline

A Mann-Whitney U test was used to identify any potential differences between groups in students' attitudes towards computers and digital games (Table 5). Results showed that there were no statistical differences in the student's gaming attitudes ($U(40)=198.5$, z=-.45, $p>.05$) and attitudes towards computers ($U(40)=183$, z=-.84, $p>.05$) between the groups.

Table 4: Baseline assessment of students' gaming attitudes and attitudes towards computers

	Condition 1 Kinect-based game		**Condition 2** Desktop-based game		Z
	Mean	SD	Mean	SD	
Gaming attitudes	3.38	0.65	3.28	0.52	-0.45
Computers attitudes	3.93	0.70	3.69	0.84	-0.84

Note. *p≤.05, **p≤.01. ***p≤.001

6.3.2 Knowledge gains

A Mann-Whitney U test was used to identify any potential differences between groups in student' pre- and post-test scores (Table 6). Results showed that there were no statistical differences in the student's pre-test scores (*U*(40)=212, *z*=-.11, *p*>.05). However, focusing on the post-test scores, students in Condition 2, who employed the desktop-based game, outperformed their counterparts in Condition 1, who employed the kinect-based game, and this difference was statistically significant (*U*(40)=139.5, *z*=-1.96, *p*≤..05) between the groups.

Table 5: Pre-test and Post-test scores

	Condition 1 Kinect-based game		**Condition 2** Desktop-based game		Z
	Mean	SD	Mean	SD	
Pre-test scores	1.33	1.49	1.39	1.69	-0.11
Post-test scores	5.52	2.99	7.14	2.75	-1.96*

Note. *p≤.05, **p≤.01. ***p≤.001

6.3.3 Perceptions of technology integration

A Mann-Whitney U test was used to identify any potential differences in students' perceptions of technology integration across conditions. The results showed that students in Condition 2 had better perceptions of technology integration regarding "Student Negotiation" subscale. Yet, there were no statistical differences between the groups on all other subscales (see Table 7).

Table 6: Technology integration perceptions

	Condition 1 Kinect-based game		**Condition 2** Desktop-based game		Z
	Mean	SD	Mean	SD	
Student Negotiation	3.36	1.01	3.97	0.60	-2.20*
Student Cohesiveness	3.85	0.97	4.08	0.70	-0.61
Reflective Thinking	3.41	0.95	3.81	0.79	-1.24
Competition & Efficacy	3.53	0.81	3.59	0.93	-0.06
Complexity	4.03	0.93	4.13	0.72	-0.05

Note. *p≤.05, **p≤.01. ***p≤.001

6.3.4 Factors contributing to students' perceptions of technology integration

The thematic analysis led to the identification of numerus factors (codes) influencing students' attitudes, namely perceptions of technology integration, within the three dimensions of our conceptual framework: "Relationship", "Personal development" and "System maintenance and change". A conceptual map was the result of further organizing the emerging factors into basic themes: (a) Content-related factors, referring to the features of the gaming content, (b) Interface-related factors, referring to the affordances of the gaming platform, (c) Activity-related factors related to the pedagogical setting in which the game was contextualized and (d) Context related factors, referring to the characteristics of the physical environment in which the activity was enacted. All factors were evaluated as positive or negative in relation to their impact on students' perceptions (see Table 8).

Table 7: Categorization of factors reported as affecting students' perceptions on technology integration

		High-embodied condition [Kinect-based game]		**Lowly-embodied condition [Desktop-based game]**	
Framework Dimensions	**Basic themes**	**Positive factors (+)**	**Negative factors (-)**	**Positive factors (+)**	**Negative factors (-)**
Personal development	**Content related factors**	Learning content	Textual information	Learning content	Textual information
		Gaming features		Gaming features	

		Narrative plot		Narrative plot	Repetition of gaming stages
		Integrated scaffolding		Integrated scaffolding	
	Activity related factors	Worksheets	Gaming nature	Worksheets	Gaming nature
	Interface related factors	Embodied interactions	Locomotion		
	Context related factors		Classroom noise		Classroom noise
			Other group interventions		Other group interventions
Relationship	**Activity related factors**	Team-based mode	Large groups	Team-based mode	
		Collaborative writing task	Unstructured collaboration	Collaborative writing task	
		Peer feedback strategies	Waiting time	Peer feedback strategies	
	Interface related factors		Single-player mode		Single-player mode
System Maintenance and Change	**Interface-related factors**	Novel interface	Gaming controls	Gaming controls	Small projection
		Large projection	Synchronization issues		Low graphics interface
		Bodily movement			
		Touchless interaction			

6.3.4.1 Personal development

Students in both conditions reported how a set of content-related factors such as the *learning nature of the game*, the *gaming features* (e.g. stages, points, rewards), the *narrative plot* on which the game was structured, as well as the *integrated scaffolding* (e.g., hints and prompts) had a positive contribution to their personal learning development. E.g.

> *"I liked the game's narrative plot as there was an alien trying to go back to his planet. We had to feed the alien with healthy foods. I liked the fact that every new planet was a new stage in the game with a new activity to do. It was an educational game because you could learn about nutrients in food." [#Girl -L-, Desktop-based version]*

However, students in the high-embodied cognition highlighted that there was *too much textual information*, while students who worked in the lowly-embodied condition also added that there was a *repetition of the gaming stages*, which in turn had a negative impact on their interest. E.g.

> *"A negative factor in the game that I can think of was the large text. A box popped up in every new stage writing a lot of text. Text could be limited." [#Girl -E-, Kinect-based version]*

Focusing on the activity-related factors, students, in both conditions, added that while the *worksheets* that they were required to complete contributed positively to their personal development, the *gaming nature* sometimes inhibited the learning process, as in many cases the students would deal with the activity as a playful rather than as an educational experience. E.g.

> *"We were carried away when playing the game and were oftentimes forgetting to complete our paper assignment. It was difficult to remember later on what to write." [#Girl -L-, Desktop-based version]*

Focusing on the interface-related factors, students in the high-embodied condition reported that while the activity allowed for *embodied interactions* which were valuable for their learning and personal development, *locomotion* was in some cases a negative aspect. In particular, as some of the students admitted, in some cases they would be more focused on coordinating their body movements, rather than on the learning content. E.g.

> *"Moving my body did not help me concentrate but I had a lot of fun. If I was stable in front of a computer, I would have been more concentrated because I would focus on the screen and click the correct answer, rather than trying to coordinate my body." [#Girl -E-, Kinect-based version]*

Finally, students in both conditions reported how the classroom noise and other groups' interventions while working, were two main context-related factors negatively affecting their personal development.

6.3.4.2 Relationship

Students in both conditions reported how a set of activity-related factors such as the *team-based mode* in which the activity was enacted, the *collaborative writing* task that was assigned (one worksheet to be completed by each group) and the *peer feedback strategies* that were followed, had a positive impact on their collaboration. More specifically, as the students mentioned, all these factors promoted productive social interactions, such as exchange of views and ideas, peer scaffolding and assistance. E.g.

> *"I liked working in my group to complete the paper assignment. We worked collaboratively and we helped each other. We were helping our co-players to choose the correct answer, we were giving instructions and we were encouraging each other to try harder." [#Girl -E-, Kinect-based version]*

However, students in the high-embodied condition also negatively elaborated on how a set of activity-related factors, such as working in *large groups* (of 4 students) in combination to the *unstructured collaboration*, affected their relationships negatively. In particular, as the students admitted, both of these factors prohibited their effective collaboration, as it was more difficult to agree on a common strategy and plan their next steps, while there were also many disagreements with children often fighting over turn-taking and roles in the group. E.g.

> *"I wanted to play more but the other members in my team urged me to finish so they could play. There was also a boy taking my turn in the game. He wanted to play instead of me. I couldn't concentrate because my team members were telling me the correct answers, or they were trying to show me how to move. I got confused!" [#Boy -M-, Kinect-based version]*

Finally, students in both conditions, highlighted that in terms of the interface-related factors, the single-player mode of the game transformed the non-player(s) as spectators, and this had also a negative effect on students' relationships. Importantly in the high-embodied condition, this factor had an increased negative effect given the increased waiting time between turns, which resulted in off-task discussions and behaviors amongst the members of the group. E.g.

> *"The game was for a single player. All the other members of the group stayed aside, they had conversations with each other about topics unrelated to the game's content and they were not concentrated in their team members' actions nor on contributing to the group's collaboration." [#Girl -A-, Kinect-based version]*

6.3.4.3 System maintenance and change

According to the students of the high-embodied condition, the *large projection* (bigger screen providing more heightened sensory stimuli), the *interface* (with the use of novel technologies), as well as the affordances of the gaming platform for promoting *bodily movement* (via gesture-based interactions), contributed to their experienced immersion and this had a positive impact on their perceptions of technology use. E.g.

> *"There was a large screen which seemed nicer and easier. I could see everything on that big screen. I could have better control of the game and I could feel like being in the game!" [#Boy -I-, Kinect-based version]*

However, the students of the high-embodied condition reported that the *controls of the game* which were rather different from traditional gaming controls, some s*ynchronization issues* often presented between students' movements and their belated projection on the screen, as well as some *technical bugs* (provoked by students' proximity to the Kinect), affected their perceptions of technology in a negative way. E.g.

> *"Sometimes there were problems with the technology. The game was blocked, and our hand signal was not appearing on the screen or was presented in the wrong position. This cost us time as we had to wait for the problem to be resolved!" [#Boy -I-, Kinect-based version]*

Finally, students in the low-embodied cognition reported that the small projection (limited desktop screen) and the low graphics *interface* had a negative effect on their perceptions about technology use. However, students in the low-embodied condition explained that the game had familiar *gaming controls* (keyboard and mouse) and thus, was more easily integrated in the lesson.

6.4 Discussion and conclusion

Results from DBR Cycle 2 demonstrated high levels of engagement and motivation, enhancing the promise of enacting technology-enhanced embodied learning in authentic classrooms. Yet, in terms of level of embodiment, learning gains were higher for students who employed the desktop-based game (low-embodied) in comparison with their counterparts who employed the kinect-based game (high-embodied), in other words motoric engagement and gestural concurrency in the high embodied condition were not proven beneficial as hypothesized. Given these findings, contradictory to studies that mostly announce positive and advantageous learning effects, e.g., Johnson-Glenberg, 2018; Hung & Chen, 2018; Johnson-Glenberg & Megowan-Romanowicz, 2017; Nathan & Walkington, 2017), it become apparent that other factors had contributed to the learning experiences.

RQ1 (differences in students' learning outcomes and attitudes between the conditions). In the present work, there was no difference in most dimensions of students' attitudes, namely, perception of technology integration, across conditions. Yet, the opportunity for "student negotiation" was deemed higher in the low-embodied condition. Also, students in the low-embodied condition presented increased knowledge gains in comparison to their counterparts in the high-embodied condition. In general, the results contradict the findings of prior research, mostly conducted in laboratory settings, in which the prevalence of high-embodied, over low-embodied games, in students' learning is presented (Homer, Kinzer, Plass, Letourneau, Hoffman, Bromley, ... & Kornak, 2014). The present study supports previous evidence (from a limited number of studies conducted in authentic school classrooms) that the high-embodied experience has not been as successful as initially expected in promoting students' learning compared to low-embodied, desktop-based environments (e.g., Anderson, & Wall, 2016; Hung, Lin, Fang, & Chen, 2014).

RQ2 (main factors affecting students' perceptions of technology integration). The analysis of students' post-activity interviews shed light to our findings; a series of contextual factors were mentioned by students to have affected their perceived experience in a negative way. For example, common technical issues or a noisy classroom environment, may detract from, rather than enhance student learning, which is not a surprising result (e.g., Darling-Aduana, & Heinrich, 2018). Indeed, the classroom setting imposed several constraints; having a number of students in groups interacting with Kinect cameras created undesirable noise and interference. Furthermore, like in DBR Cycle 1, collaborative learning and teamwork in DBR Cycle 2 was notoriously difficult to embed in this embodied learning environment; issues of unequal participation or dominance (one learner only as observer) were reported in this study and are also frequently identified as factors associated with disengagement from the learning process (e.g., Blatchford, Kutnick, Baines, & Galton, 2003; Yuill, Pearce, Kerawalla, Harris, & Luckin, 2009). In fact, some of these issues are inherent to a functioning classroom environment. Namely, the overall time for the activity in the study was fixed by the school timetable which did not allow much time for familiarization with the game mechanisms, especially in the high-embodied (Kinect-based) condition, and this may have unavoidably contributed to the negative experience.

To conclude, while being enjoyable and engaging, the embodied learning experience in a typical classroom may not always produce significant learning gains. There is a need for a scaffolded approach that helps students to understand the learning content to then enable gains in the learning domain. Also, meta-cognitive activities, such as reflective opportunities, should be integrated into the inquiry experiences to reinforce concepts being presented. Another key component of effective implementation is planning activities such that the greatest number of students are actively engaged in their education and locations; this would help to eliminate issues of dominance and unequal participation. The table of factors affecting the technology-enhanced embodied learning experience in long, as presented in DBR Cycle 2. Most of these factors seem to suggest issues related to classroom orchestration that are worth investigating in follow-up studies.

7 DBR CYCLE 3

This chapter reports on DBR Cycle 3 – Orchestrating the classroom experience. A major part of the results from DPR Cycle 3 are published in the proceedings of the 14th International Conference of the Learning Sciences (ICSL) [Ioannou, M., Ioannou, A., Georgiou, Y., & Retalis, S. (2020). Designing and Orchestrating the Classroom Experience for Technology-Enhanced Embodied Learning. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020,* Volume 2 (pp. 1079-1086). Nashville, Tennessee: International Society of the Learning Sciences.]

7.1 Introduction

DBR Cycle 3 aimed to contribute to the dialogue on classroom orchestration strategies for successful embodied learning in the classroom, highlighting the essential need to consider learning design when bringing technology into the classroom, as it is not a simple process to shift laboratory success to real-world learning gains. This phase, built on DBR Cycle 2 in which it became apparent that the implementation of technology-enhanced embodied learning in authentic classrooms requires special attention to issues of classroom orchestration, referring to the way teachers design and manage the classroom which involves activities and constraints in real-time.

As embodied learning technology is finding its way into the classroom, understanding the opportunities and barriers of its deployment, becomes an important part of the learning design process. The way teachers manage technology-enhanced classrooms and the involved activities and constraints in real-time is known as "classroom orchestration" and it is a crucial aspect for the materialization of students’ learning experiences (Dimitriadis, 2012; Prieto et al., 2011). Classroom design for technology-enhanced embodied learning requires new classroom orchestration strategies. Research is still lacking a model of enacting and orchestrating the technology-enhanced embodied learning classroom. It also lacks a clear focus on investigating technology-enhanced embodied learning in classrooms of 20+ students with diverse abilities and needs. Technology-enhanced embodied learning has been mainly developed and tested in highly controlled and idealized laboratory settings or in special classrooms using a one-to-one- model of teaching (Georgiou, & Ioannou, 2019b). Thus, it remains unclear how, and under what conditions, students can benefit and gain knowledge and skills in such dynamic learning environments.

In this spirit, this cycle of work aims to spark the dialogue on how technology-enhanced embodied learning in authentic school classrooms may be successfully implemented. First, we sought to analyze the classroom embodied learning experience in order to capture what might be construed as successful orchestration patterns. Second, we aimed to fill gaps in the current understanding of classroom orchestration in technology-enhanced embodied learning environments. Third, we aimed to conduct this study in an authentic classroom with all the constraints that a classroom environment imposes. We sought to answer the research question: "*How can a classroom orchestration strategy enable technology-enhanced embodied learning to be successfully enacted in an authentic classroom?*". The essential contribution of this cycle is the presentation of the implementation of an orchestration strategy for technology-enhanced embodied learning, guided by an existing conceptual framework on classroom orchestration.

7.2 Conceptual framework

We adopted Prieto et al.'s conceptual framework of "characterizing orchestration" (Prieto, Holenko Dlab, Gutiérrez, Abdulwahed, & Balid, 2011) to guide the design and implementation of the study (see Figure 11). The "characterizing orchestration" dimensions of this framework, along with our previous experiences, with technology-enhanced embodied learning implementation in the classroom (Ioannou, Georgiou, Ioannou, & Johnson-Glenberg, 2019), guided our refinement of strategies for the present implementation.

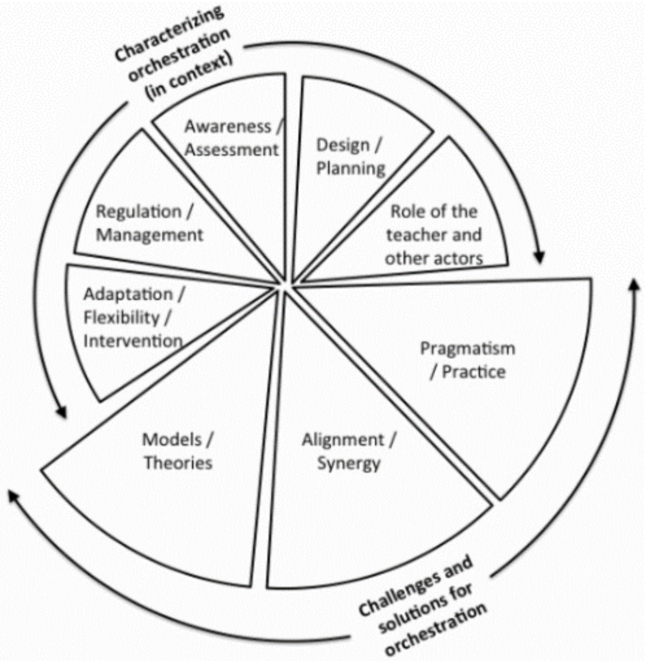


Figure 12: Graphical representation of the "5 & 3" framework presented from Prieto, Dlab, Gutiérrez, Abdulwahed, & Balid (2011)

According to Prieto et al., (2011), "Orchestration is […] coordinating a teaching/learning situation from the point of view of the teacher. Orchestration aims to manage (or subtly guide) the different activities occurring in different educational contexts and social levels, using different resources and tools in a synergic way. Orchestration is […] often guided by a design (in the form of a script or not) that may be flexibly modified during the enactment (automated or not) of the activity, in response to emergent occurrences." Their definition relies on the "5 þ 3" framework presented graphically in figure 1. The framework characterizes orchestration into eight aspects, five of which provide a descriptive view of orchestration and three of which are key factors describing how orchestration should be done (Prieto et al., 2011). In terms of the "view of orchestration" the aspects described are (1) design/planning of the learning activities, (2) regulation/management of these activities, (3) adaptation/flexibility/intervention (adaptation of the learning flow to emergent events), (4) awareness/assessment of what happens in the learning process, and (5) the different roles of the teacher and other actors. In terms of "how the orchestration should be done" the aspects described are (6) pragmatism/practice, (7) alignment/synergy to the intended learning outcomes, and (8) models/theories that guide the learning orchestration. The evaluation results of this framework suggest its usefulness, understandability, and suitability as a basis for considering vital factors during the design and evaluation of learning technologies (Prieto, Dimitriadis, Asensio-Pérez, & Looi, 2015).

7.3 Methodology

7.3.1 Participants

Participants were 52 students, aged 6-7 years old, in three 1st grade classrooms of a public primary school in Cyprus. Students had no previous experience with embodied learning technologies prior to the intervention. The students were assigned to mixed-ability groups of four based on their teachers' knowledge of the students' academic background and learning needs, collaboration skills, and social relationships. The student population of this study included eleven students with Autistic Spectrum Disorder (ASD), Comorbid Learning Disorders, and Attention Deficit Hyperactivity Disorder (ADHD) as diagnosed by pediatric neurologists and neuropsychologists prior to enrolment and mentioned in their school record.

The participating teachers were 5 females with 10 – 20 years of teaching experiences at primary school. Three teachers teach all subjects in the age categories of 1–6th grade, and two teachers work in the school's special education unit as speech therapist teachers and special education teachers. At the time of the data collection, three of the teachers (a general teacher, a speech therapist, and a special education teacher) were participating in an Erasmus+ professional development program, named INTELed (INnovative Training via Embodied Learning and multi-sensory techniques for inclusive Education), and through the program, they had already developed some expertise in working with embodied learning technologies in dynamic classroom contexts (Georgiou & Ioannou, 2019).

7.3.2 Procedures, data collection & analysis

The classroom learning experience took place in an 80-minute learning session in each of the three participating classrooms. The Learning Stations Rotation Model was adopted, allowing students to rotate through learning stations on a fixed schedule (see classroom orchestration strategy section). The technology-enhanced embodied learning environment made use of the Kinems games. Kinems (https://www.kinems.com/) is a suite of embodied learning digital games for special and general (mainstream) education, supporting students' learning in language and mathematics among others. In Kinems games children can interact with the learning content via hand-gestures and/or full-body movements and receive unobtrusive feedback. The Kinems games were found to be effective in one-to-one sessions with special education students (Kosmas, Ioannou, & Retalis, 2018) and in mainstream classrooms (Kosmas, Ioannou, & Zaphiris, 2019). Data collection involved post-activity interviews with the participating teachers about their overall experiences as well as videotaped observations from the classroom sessions. These data were analyzed qualitatively and were mapped to the orchestration framework suggested by Prieto et al., (2011). In addition, the participating students were asked to complete a pre-post knowledge test based on the vocabulary of the thematic unit being taught (with a maximum score of 10 marks). The analysis of the pre-post knowledge test was based on a paired sample t-test. Finally, students were asked to complete a post-interventional engagement survey composed of 13 items on a Likert scale 1-4 (Rimm-Kaufman, 2010), which provided insights on their engagement in the learning environment across three subscales: (a) Cognitive engagement, (b) Emotional engagement, and (c) Social engagement. The analysis of the engagement survey was based on descriptive statistics. Below, we present our classroom orchestration strategy as well as our findings from classroom implementations.

7.4 Findings

7.4.1 Learning Design – codesigning the experience and professional development

Through a co-design process, the researcher and educators endeavored to design a technology-enhanced embodied learning environment for an authentic school classroom with mixed-ability students (Martínez-Monés et al., 2019). The co-design involved the transformation of the existing classroom, setting up technology infrastructure with direct links to the official school curriculum and assessment expectations, and evaluating the curriculum enactment. Evidence from the teacher interviews provided support for the success of the design and planning strategy. Teachers evaluated the co-designing process as a positive factor contributing to the success of the technology-enhanced embodied learning experience. E.g.

> *"It was successful because it was designed by a group of teachers, not only mainstream teachers but also special education teachers and speech therapist teachers. We were a group of teachers, contributing our ideas, taking into account our working experience.". [#Teacher 1]*

Other positively evaluated factors contributing to the success of the classroom orchestration mentioned by the teachers were the deployment of a variety of activities (technological and non-technological) as well as the teachers' professional development. Indeed, in this cycle, we emphasized teacher professional development, which helped teachers to better understand processes as well as implications of enacting technology-enhanced embodied learning in the classroom, e.g.

> *"The initial stage, when we participated in the professional development workshops about embodied learning, as well as the support we received during the planning of the implementation, were some other factors that worked positively." [#Teacher 3]*

7.4.2 Regulation/management – applying a learning station rotation model

The Station Rotation Model was adopted, which allows students to rotate through learning stations on a fixed schedule. The set-up was designed to enable different teams to operate autonomously, i.e., without the need for much support from a teacher. Four learning stations were set up in each classroom (see Figure 12).

Two of the learning stations utilized technology, and the other two utilized conventional paper-and-pencil tools (Minocha, Tudor, & Tilling, 2017; Díaz, Nussbaum, & Varela, 2015). The design work was informed by previous work (Ioannou, Georgiou, Ioannou, & Johnson-Glenberg, 2019), which demonstrated that having an embodied learning technology station for each group was intrusive both for the learner and the instructor. The technological stations comprised of two different learning language games: one was Kinect-based (see game "Lexis" from the https://www.kinems.com educational platform) and was projected on a portable screen-surface, whilst the other one was a touch-based game played on the interactive whiteboard, which was already fixed in the classrooms (see figure 13). In both games a missing letter tasked the students to practice their skills on the spelling of words of different length by dragging the letters using their hands, via touchless motion (Kinect-based) or direct touch (touch-based).

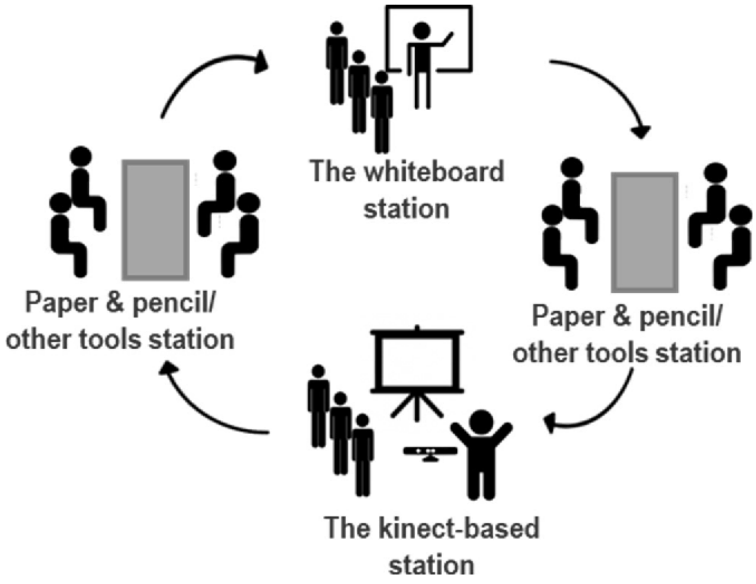


Figure 13: The Learning Station Rotation Model for embodied learning in the classroom

The Kinect-based station was set up (a) in the back space of the classroom, allowing enough space for students to move when playing and isolating the "playing" group from other students who could intervene, and (b) away from windows, as direct sunlight could cause the system to error. The other two learning stations were set for paper-and-pencil assignments, including crosswords, spelling games, and matching games, contributing to the same learning objectives to create a multi-modal experience (Minocha, Tudor, & Tilling, 2017). We succeeded in enacting technology-enhanced embodied learning in the classroom that reached the third level immersion per Johnson-Glenberg et al., (2014) taxonomy, via the use of a large display and full-body interactions using motion-tracking devices. Students in the "playing" groups played in turns, with only one student acting within the playfield, while the others stayed aside to provide support, for example:

> *A student came into the playfield. It was his turn, but he looked quite confused as on the big screen he was seeing two buttons "continue" and "stop the game". The members of his team realized that he was confused (even though he did not say anything) and they instructed him: "Name,*

> *you have to choose the "continue" button in order to play… Leave your hand for a few seconds there to become red and you can continue the game." [Episode #1, Classroom 1, Station 1: KINEMS game]*

At a previous class session, a day before, the teachers had introduced the use of the Kinect camera (new to the students) and the embodied game (how to grasp items), while also providing time for the kids to get familiar with the gaming controls. Students in the non-technological stations collaborated on games such as crosswords and spelling games on paper and pencil. The teacher assigned roles to the members of each group in order to avoid fights over turn-taking and promote more independent student group work, for example:

> *Teacher: Every member of this team will be a leader. You will take turns being the leader. The leader will be distinguished by having this flag (i.e., a medal with happy smileys). The leader is responsible for selecting a picture and showing it to the members of his/her team. Together, you will decide what the picture shows. If you don't know what the picture shows the leader will read it aloud - the word is written on the backside of the card. The leader should grab letters from this box and hang them as if they were laying clothes. The rest of you should write the word correctly. You don't have to worry if you spell the word wrong because the leader will write it correctly and then you will correct it. Okay? Who will come first?*
>
> *Boy 4: (pointing) It's Mario's turn to be the leader.*
>
> *Teacher: OK. Come on, Mario. Choose which picture you would like to show to the members of your team. Do you know this word? It is a vehicle that carries liquids. It is a big ....*

[Episode #3, Classroom 1, Station 2: Paper and Pencil]

Evidence from the teachers' interviews provided support for the success of the strategy with respect to regulation and management, acknowledging the quality of the intervention developed during the planning phase, which also addressed the restrictions imposed by the classroom realities, for example:

> *"The intervention was very well organized. There was added value in the whole technology integration process. Students successfully completed all*

> *the activities, and they enjoyed them too. We were prepared to face all kinds of failures, but we did not face any." [#Teacher 2]*
>
> *"This intervention demanded a lot of preparation. Classroom space sets restrictions. It does not allow you to have more than two technology stations, you need equipment, space, and appropriate lighting. These are some of the main limitations of the classroom reality, which we managed to overcome". [#Teacher 1]*

Figure 14: The Kinect station for embodied learning was set in the back of the classroom (left); children playing the vocabulary game on the interactive whiteboard (right)

7.4.3 Teachers/Other actors – moving from group discussion to quick debriefing at plenary

There was only one teacher in the classroom, which demonstrates the possibility to enact an embodied learning classroom experience in a typical school context. The teacher rotated through the stations and encouraged peer learning by encouraging students to provide feedback to their peers. Informed by a previous study focusing on the integration of embodied learning technologies (Ioannou, Georgiou, Ioannou, & Johnson-Glenberg, 2019), the completion of worksheets was part of the experience, helping to keep the learners focused and on-task along with play. Between those transitions, the teachers dedicated time to summarize and reflect on the learning activity so far, moving from the small group level to the discussions at the classroom plenary. The overall session lasted approximately 80 minutes. The scenario was replicated in the three different classrooms, (i.e., a total of 52 students).

> *Teacher: Ok. Come on [student 1]. Choose which picture you would like to show to the members of your team. Do you know this word? It is a vehicle which carries liquids. It is a big…*
>
> *Student2: It was in our test [meaning pre-test]*
>
> *Teacher: Yes, it was in your pre-test.*
>
> *Student2: Yeah! I didn't write it.*
>
> *Teacher: Your team members will help you. Now you will learn this new word [the teacher speaks to the other members of that team] [name] didn't know it and she didn't write it. But now we will learn it and write it. Can you tell her what vehicle this is?*
>
> *Student 1: Tanker (he reads the word behind the flash card).*
>
> *Teacher: Well done. It's a tanker.*
>
> *Teacher: [speaks to the whole class] Well kids. Can I have your attention please? This is a new word and you will probably find it in your games. Can you recognize what vehicle this is?*
>
> *Kids: Tanker!![The kids from this team were very excited to share their knowledge].*
>
> *Teacher: Well this vehicle is called "tanker" and it carries liquids, like milk or petrol.*

[Episode #4, Classroom 2, Station 2: Paper and Pencil]

The teacher interview data provided evidence for the details and success of the chosen strategy. The participating teachers explained that they work in the classroom as facilitators of students' collaboration. They assumed the role of the coach, coordinating and supporting students in a real student-centered lesson (teacher 2), providing help when needed (teacher 3), and helping students stay on track and focused on the task if they were distraught (teacher 1). All three teachers acknowledged the importance of the discussion at the plenary, summarizing the conclusions of the task.

7.4.4 Adaptation/Flexibility/Intervention – coaching with flexibility and adaptability

One of the greatest challenges of this intervention was to support teachers in their enactment of the lesson. Teachers invested a total of 25 hours in professional development workshops in the context of the Professional Development program to learn how to design lessons and be flexible and adaptable in this dynamic learning environment. Lesson plans were written in a form that they could integrate more effectively multi-sensory and embodied learning technologies in the classrooms and were designed for an inclusive educational setting to include students with and without disabilities; as such, various grained-size activities were designed. A student spontaneously said when she had just finished her embodied play, *"I liked this game more because it was more difficult to find the word than in the previous game."[#Helen]*

7.4.5 Awareness/assessment – enabling formative assessment tasks all the way

By creating student-centered activities, the teachers did not resort to transmitting knowledge. The deployment of different tools (technological or non-technological) allowed students to construct knowledge and support their inquiries (Minocha, Tudor, & Tilling, 2017; Díaz, Nussbaum, & Varela, 2015). Students' misconceptions were also addressed through just-in-time feedback by the game, by their peers, or by the teacher. In this way, there was an elevated awareness of the students' quality of understanding, thus enabling the teacher to orchestrate what domain concept to focus on when facilitating discussion at the classroom plenary. All the observed activities contained formative assessment tasks for the students as well as a general aim to assess the progress of the class after the implementation of the experience, for example:

> *The student chooses the card with the aerial tramway.*
>
> *Teacher: Look at your card, Sebastian, and tell your team members what letters you need to write the word. They are scrabble written in your flash card.*
>
> *Sebastian: I need "t".*
>
> *Kostas: What else?*

Sebastian: I need "e" and "l".

The kids in the group look for the letters and give them to their classmates. When they finished, the teacher encouraged them to look and evaluate if their classmate had formed the word correctly.

Teacher: What do you think kids? Is this word written correctly?

Sofia: Yes, but he placed the aerial tramway flash card wrong. It should be placed in the air.

[Episode #5, Classroom 1, Station 4: Paper and Pencil]

Student knowledge testing and a questionnaire on their engagement provided evidence for success of the chosen strategy. A pre- and post-knowledge test was administered to the students to explore knowledge acquisition. A paired-samples t-test indicated significant learning gains from pre (*M* = 6.63, *SD* = 2.39) to post testing (*M* = 7.75, *SD* = 2.32), *t(*30) = 4.70, *p*<.001, with a large effect size (d = 0.85). A post-interventional questionnaire aimed at evaluating students' engagement within three subscales: (a) Cognitive engagement (e.g., Today in math class I worked as hard as I could) (b) Emotional engagement (e.g., I enjoyed thinking about math today) and (c) Social engagement (e.g., Students in my math class helped each other learn today) (Rimm-Kaufman, 2010). To calculate the three Engagement variables (Cognitive engagement, Emotional engagement, Social engagement), scores were computed for every student by calculating an un-weighted mean score for the items in each of the three scales. As table 9 shows, these mean-scores were well above the midpoint of the scale, especially for cognitive and emotional engagement, demonstrating the success of the strategy in engaging the learners. However, the social engagement variable, referring to students' social interactions and collaboration was lower as the setting of the embodied games did not provide the space needed for this.

Table 8: Students' engagement (N=52)

Engagement variables	Mean	SD
Cognitive engagement	3.46	0.66
Emotional engagement	3.30	0.65
Social engagement	2.81	1.04

Evidence from the teachers' interview data provided further support for the success of the strategy with respect to students' engagement, for example,

> *"I believe that the integration of technology into the mainstream classroom has worked very well. I didn't expect group work in stations to be so successful. There was a learning climate in the class and not just voices and excitement, as initially expected. That learning atmosphere was something I did not expect." [#Teacher 2]*
>
> *"Some kids thanked me for the nice lesson we had done!" [#Teacher 3]*

7.5 Discussion

We, next, discuss the major findings derived from this design-based research study, responding to our RQ *(How can a classroom orchestration strategy enable technology-enhanced embodied learning to be successfully enacted in an authentic classroom?)*. The discussion of our findings is framed by the three characterizing components of how orchestration should be done, per orchestration model of Prieto et al. (2011).

7.5.1 Pragmatism/Practice

Regarding the pragmatism/practice aspect of how the orchestration should be done, a main issue of research on technology-enhanced embodied learning is that few investigations have been conducted in real classroom settings (Georgiou, & Ioannou, 2019a). Informed by Prieto et al.'s (2011) orchestration framework, the present study enacted a technology-enhanced embodied learning environment in three school classrooms, trying to overcome the constraints. The constraints included the novel nature of motion-based technologies in relation to usability issues, various technical limitations of Kinect cameras affecting the classroom setup, and the lack of multiplayer affordances in the selected digital games, restricting students' collaboration (only one child at a time was able to play the game). These limitations were augmented by a set of more traditional constraints such as time constraints, classroom management, the different learning pace of each group, and constraints set by the curriculum. Variables concerning the teacher, students, resources, subject, and classroom culture and norms (rules, routines and expectations) had also influenced what and how students learned. The orchestration strategy adopted in this work aimed to present ways to make more effective use of time affording opportunities for students to engage with the curriculum content. We implemented technology-enhanced embodied learning using technological and non technological stations and even though there was an operational autonomy of learning stations, there was also a conceptual connection among them. Students rotated among the learning stations, to make a good use of the time. The designed learning activities took into consideration the curricular goals and the affordances of the technology.

7.5.2 Alignment/Synergy

Our approach used minimal and manageable resources for implementation. The technology used in the present study allows learners to interact with the learning content via gestures/body movement. In stations, an emphasis was given in promoting reflection and awareness of other teammates. We believe that the integration scenario can be applied even by less experienced teachers.

7.5.3 Models/Theories

Drawing on principles of orchestration, from previous empirical studies and our own empirical work (Georgiou, Ioannou, & Ioannou, 2019; Ioannou, 2018; Ioannou, Georgiou, Ioannou, & Johnson-Glenberg, 2019) we have formulated a set of guidelines on classroom orchestration for technology-enhanced embodied learning. These guidelines are subject to further study, refinement, and empirical validation:

- Learning design/co-design with stakeholders. The inclusion of emerging technologies, like the embodied learning technologies, in the classroom ecosystem introduces new layers of complexity that teachers have to deal with. This requires exploring the design space to successfully integrate new technologies with current teaching and collaborative learning tools, within the constraints of an authentic classroom (Martinez-Maldonado, Dimitriadis, Clayphan, Muñoz-Cristóbal, Prieto, Rodríguez-Triana, & Kay, 2013). Co-design between researchers and practitioners as well as professional development are important if we want teachers to work effectively in implementing embodied learning (Georgiou, & Ioannou, 2019a).

- Create learning stations. Traditional classrooms have 16 or more students. Therefore, practitioners should aim at having more than one learning station for different groups working concurrently on the same task. Yet, setting up multiple technology-enhanced embodied learning stations is practically impossible. Due to the large projection size and the space needed for students to move, a maximum of two stations could be placed in the classroom. Alternative low-tech stations can be included. Stations with paper-pencil elements can work successfully as they are already integrated in most teachers' routines (Dimitriadis, Prieto, & Asensio-Pérez, 2013). A learning rotation stations model can be adopted so that all students can engage in the technology-enhanced embodied learning experience.

- *Keep group-size small*. Small-group activity allows the students to take full advantage of the technology-enhanced experience. By having small groups, students can avoid waiting time between turns, which can result in off-task discussions and behaviors (Ioannou, 2018; Ioannou, Georgiou, Ioannou, & Johnson-Glenberg, 2019). Moreover, activities in small groups, when designed effectively, may positively reduce social loafing, and also facilitate the teacher's management of the class so they can provide feedback more effectively (Martinez-Maldonado, Dimitriadis, Clayphan, Munoz-Cristobal, Prieto, Rodríguez-Triana, & Kay, 2013).

- Enable small-group collaboration. While students clearly have fun with the interface, current forms of embodied learning apps or games are not necessarily "collaborative" yet. Participants seem to engage in too many individual tasks which sometimes lead to unproductive collaboration and limited discussion. To support collaboration (rather than cooperation), it is important that learners have a shared focus around which negotiation can occur; that is, they need to be effectively supported in jointly attending to what each other are doing to ground the collaboration (Clark, & Brennan, 1991). In addition, learners need to have a reason to negotiate with each other. To support teamwork, collaboration scripts may be used to define activities and sequences of activities while also matching activities to roles and assigning roles to individual learners (Dimitriadis, 2012; Alvarez, Alarcon, & Nussbaum, 2011). Studies have reported that interdependent, differentiated roles effectively scaffold collaborative problem solving within mobile learning games (Dunleavy, Dede, & Mitchell, 2009; Squire, & Jan, 2007). This collaboration can be used initially and gradually fades as learners develop their collaboration skills internally.

- Have debriefing sessions. In a technology-enhanced classroom, students' interactions naturally become playful (Ioannou, 2018), which although beneficial, can also cause problems in terms of lack of reflection. For example, sometimes the students spend too much time “playing” without communicating their findings or reflecting with their peers. These problems imply that strategies should be applied to reduce these negative effects and let students focus more on reflection and discussion. In a goal-driven learning situation, it may be desirable to encourage students to step back from "play" in order to discuss and reflect on their learning process. The learning activity can be designed to frame these temporal pauses as part of the user experience in ways that trigger reflection. With the station rotation model, breaks to stop and move to another location are a good time for reflection. Teachers should trigger learners to stop and reflect on the effects of their actions (Price et al., 2009). Reflection allows the mental model to cohere. Plenaries (or mini plenaries) in the form of debriefing sessions are acknowledged as a widely employed pedagogical technique, relating to scaffolding, orchestration or student/teacher interaction.

- ***Scaffold learning***. Scaffolding can be done by the teachers themselves, by the students, and/or by the technological system. Technology-enhanced embodied learning must purposely be designed to trigger interactions that produce positive learning outcomes. Scaffolding can take many forms, such as providing guidance, feedback, or prompts. The teacher leads the educational process in the classroom and is in charge of filling the gaps that exist between the students and the game, promoting discussion and reflection on contents (Villalta, Gajardo, Nussbaum, Andreu, Echeverría, & Plass, 2011). In order to encourage students towards an informed problem-solving approach (and away from guessing behaviour) Lee-Cultura, Sharma, Cosentino, Papavlasopoulou, and Giannakos (2021) recommended offering problem solving hints (e.g., via the system or educational facilitator) or taking preventive measures to reduce children guessing. It is also important to recognize the role of social interaction in learning. Learners can benefit from interacting with peers or teachers to discuss ideas, share perspectives, and receive feedback. Therefore, technology-enhanced embodied learning experiences should also include opportunities for social interaction, such as collaborative tasks. In our design, we employed two of the proposed ideas by Dillenbourg and Fischer (2007) which can trigger specific interactions: (a) placing students in a situation in which they need to engage in effortful interactions in order to build a shared understanding and (b) structuring collaboration by means of scripts. Both strategies worked well in the technology-enhanced embodied learning experience of the present implementation.

- ***Provide teachers with professional development and serve the role of the teacher.*** Teachers play a significant role in the technology integration process (Ertmer et al., 2012; Levin & Wadmany, 2008). Ongoing professional development opportunities should be an integral part of the technology-enhanced, embodied learning environment integration initiatives. Professional development opportunities should concentrate on both teacher beliefs regarding the benefits of embodied learning and competencies (Inan, Lowther, Ross, & Strahl, 2010; Zucker, & Hug, 2008). According to Díaz, Nussbaum, Nopo, Maldonado-Carreño, and Corredor, (2015) teacher training is essential for effective access to updates for resources and strategies that integrate digital elements in order to reinforce the teaching process. Moreover, in order for teachers to develop effective integration lessons, professional development must focus on the pedagogical aspects of integrating technology-enhanced embodied learning environments to better ensure that the use of technology-enhanced embodied learning environments results in increased student learning. In our work in DBR Cycle 3, the teacher's role in orchestrating learning remained the most important aspect for the successful learning experience. It entails a process of managing the affordances and constraints of the available tools in the most optimal way to support student learning. The teacher's role is to orchestrate the supporting features – the visual cues, the prompts, the questions, the instructions, the demonstrations, the collaborations, the tools, the information sources available, the framing of the learning environment, the group formation, the role assignment for every activity, the number of children involved in the activity and so forth.

7.6 Conclusion

DBR Cycle 3 highlights the essential need to consider new orchestration strategies for the successful implementation of technology-enhanced embodied learning in authentic classrooms. The essential contribution of this work is the presentation of an experience report about implementing an orchestration strategy for designing embodied learning, guided by the published framework of Prieto, Holenko Dlab, Gutiérrez, Abdulwahed, & Balid, (2011). In sum, DBR Cycle 3, presented evidence for the success of the orchestration strategies adopted. Furthermore, we presented newly generated design principles related to the real-world design setting under investigation and building on the previous framework adopted. Our findings, based on interview data with the teachers, supported the idea that our orchestration strategy can guide the successful implementation of technology-enhanced embodied learning in authentic classrooms. The next DBR cycles could further refine this strategy. It is not a simple process to shift laboratory success to real world learning settings. The study of classroom orchestration strategies is of paramount importance, addressing the way teachers design and manage technology-enhanced embodied learning classrooms and the involved activities and constraints in real-time.

8 DBR CYCLE 4

This chapter reports on DBR Cycle 4 – Replicating and confirming the orchestration strategy that derived from DBR Cycle 3 while revising learning aspects. This study showed a significant gain in student learning when technology integration and orchestration strategies were made explicit to the educators. Results from DPR Cycle 4 are published in a major EdTech journal [Ioannou, M., & Ioannou, A. (2020). Technology-enhanced Embodied Learning: Designing and Evaluating a New Classroom Experience. *Educational Technology & Society, 23*(3), 81–94.]

8.1 Introduction

In DBR Cycle 4, we tried to replicate and confirm the orchestration strategy that derived from DBR Cycle 3 and to revisit learning aspects in technology-enhanced embodied learning which were unclear in earlier cycles of the work. In this cycle a history lesson plan about archaic kingdoms was co-design between teachers and the researcher. Teachers were already trained in enacting technology-enhanced embodied learning, including the use of multi-sensory technologies, per their participation in previous cycles of the DBR. The Learning Station Rotation Model was adopted again in this cycle as it enables different teams to operate autonomously, and it permits the teacher to rotate across learning stations and assist students where needed.

In DBR Cycle 4, all stations enacted some form of embodied learning experience using devices such as tablets as well as more immersive technologies such as VR headsets. This cycle was driven by the "Instructional Embodiment Framework" (IEF) proposed by Black, Segal, Vitale, and Fadjo (2012), according to which the use of embodiment as an engaging activity for the student may be modeled by the teacher in a sequence or system of movement, imagination, and exploration within a formal instructional setting. The study presents an example of a learning design for technology-enhanced embodied learning in an authentic classroom, using a model consisting of a single educator and learners rotating across learning stations. The aim was to evaluate the technology-enhanced embodied learning experience from the perspective of the learners, addressing two research questions:

(i) Did the students experience learning gains?

(ii) What were their perceptions of the technology-enhanced embodied learning experience?

8.2 Learning design

8.2.1 Context

The study took place in a multidisciplinary lesson based on historical information. In this lesson, primary school students (i) take virtual tours among the ruins of Archaic kingdoms using mobile VR headsets; (ii) use programmable floor robots to learn about the various occupations people had back then; and (iii) create storyboards based on historical information using web-based digital tools. The study employed a variety of activities with technologies (virtual reality, robot programming, tablets), each harnessing the power of embodied learning according to Black et al.'s (2012) IEF framework. The students engaged in a virtual field trip, programmed the Bee-bot, and created storyboards. An important consideration is that we used affordable technologies enriched with content that is aligned with the national educational curriculum. We aimed to combine the physical and digital worlds and to enable a multisensory and embodied learning experience to promote an understanding of historical information in a multidisciplinary lesson.

8.2.2 The Learning Station Rotation Model

DBR Cycle 2 and 3 informed the learning design in this study. We adopted the Learning Station Rotation Model (Ioannou, Ioannou, Georgiou, & Retalis, 2020), which allows students to rotate through learning stations on a fixed schedule. In our own prior research, we presented designs and orchestration strategies for technology-enhanced embodied learning that took into consideration real classroom realities: limited access to technology, a single teacher handling 15 or more students, a curriculum that needed to be covered, as well as the teachers' aim to enact constructivist and student-centered pedagogy.

In this study, the classroom was organised into three stations. The students were split into three groups of six students each (i.e., they rotated into groups of six). They worked individually (for station 1) or in pairs (for stations 2 and 3). At station 1, the students used mobile VR headsets and the Google Expeditions app. At the second station, the students used programmable floor robots (Bee-bots). At the third station, the students used tablets to create storyboards. Each station could operate independently and there was no need for the students to follow a sequential order. For the last 15 minutes of class, the students converged for a plenary discussion of major ideas from the overall experience. See Figure 14 for the Learning Station Rotation Model adapted in this study.

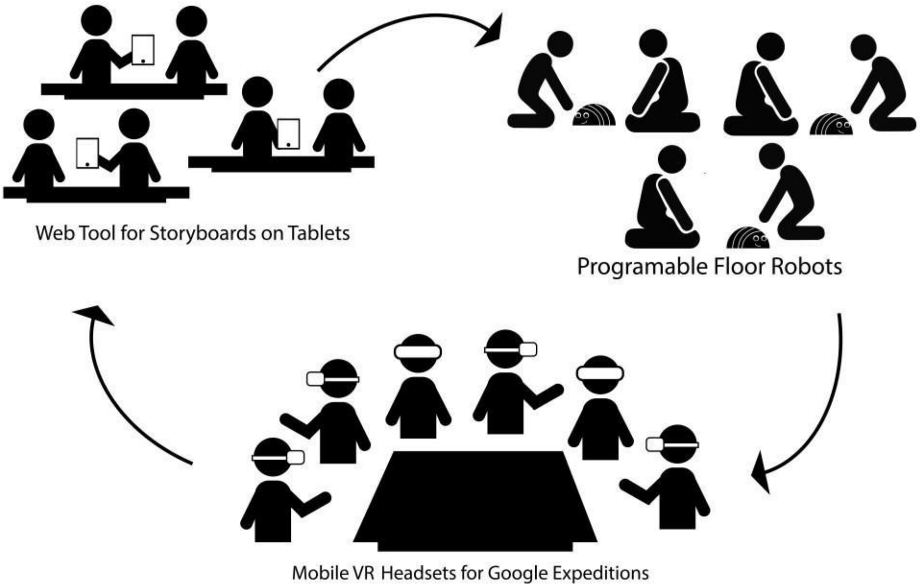


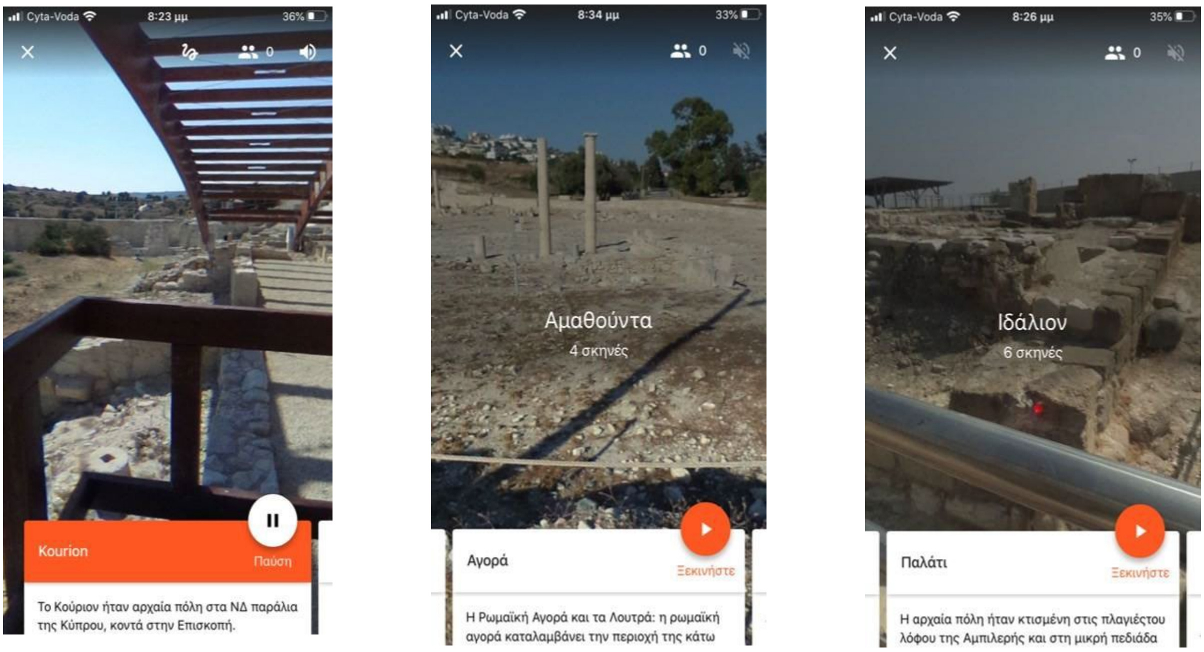
Figure 15: Learning Station Rotation Model

8.2.3 Station 1 – Mobile VR headsets and Google Expeditions

In recent years, affordable, commercial virtual reality technologies have proliferated, along with the availability of virtual content, providing new opportunities to bring VR to schools and other educational institutions (Johnson-Glenberg, 2018). VR technologies offer vivid and immersive audiovisual interfaces for eliciting bodily activity (Lindgren et al., 2016; Lindgren, & Johnson-Glenberg, 2013). With VR, body-based experiences are more perceptually immersive, allowing learners to experience a more authentic and meaningful educational space (Lindgren et al., 2016; Dede, 2009).

This first station aimed to enable students to go on virtual field trips and visit three archaeological sites in their own country. The researchers developed a 360° VR experience using a free tool called Google Expeditions. The VR experience is based on tours synthesized of images taken at 360 degrees (i.e., spherical images) from Kourion, Amathus, and Idalion, respectively, three sites that feature the remains of Archaic kingdoms.

In the VR pre-production phase, we specified the teaching and learning goals and storyboarded the guided tour for each site based on historical information. In the post-production phase, we used a 360 camera to take the spherical images and created our own tour on the Google Expeditions platform. This was done by importing our images and creating a guided tour based on our storyboard. The Tour Creator app was another platform we used; it allowed us to add multiple scenes in the tour using the uploaded 360 images, as well as sounds, points of interest, and descriptions of each scene. Once the VR tour was ready, the students opened the Google Expeditions app on their smartphones and placed their smartphones into the mobile VR headset. The teacher guided the students through the expedition using a tablet or smartphone; s/he selected points of interest and asked questions that encouraged exploration and discovery (rather than yes/no type of questions). See Figure 16 for how Google Expeditions work and Figure 15 for screenshots from the virtual tours.



Το Κούριον ήταν αρχαία πόλη στα ΝΔ παράλια της Κύπρου, κοντά στην Επισκοπή.

Η Ρωμαϊκή Αγορά και τα Λουτρά: η ρωμαϊκή αγορά καταλαμβάνει την περιοχή της κάτω

Η αρχαία πόλη ήταν κτισμένη στις πλαγιέςτου λόφου της Αμπιλερής και στη μικρή πεδιάδα

Figure 16: Google Expeditions – screenshots from virtual tours of Kourion, Amathus and Idalion

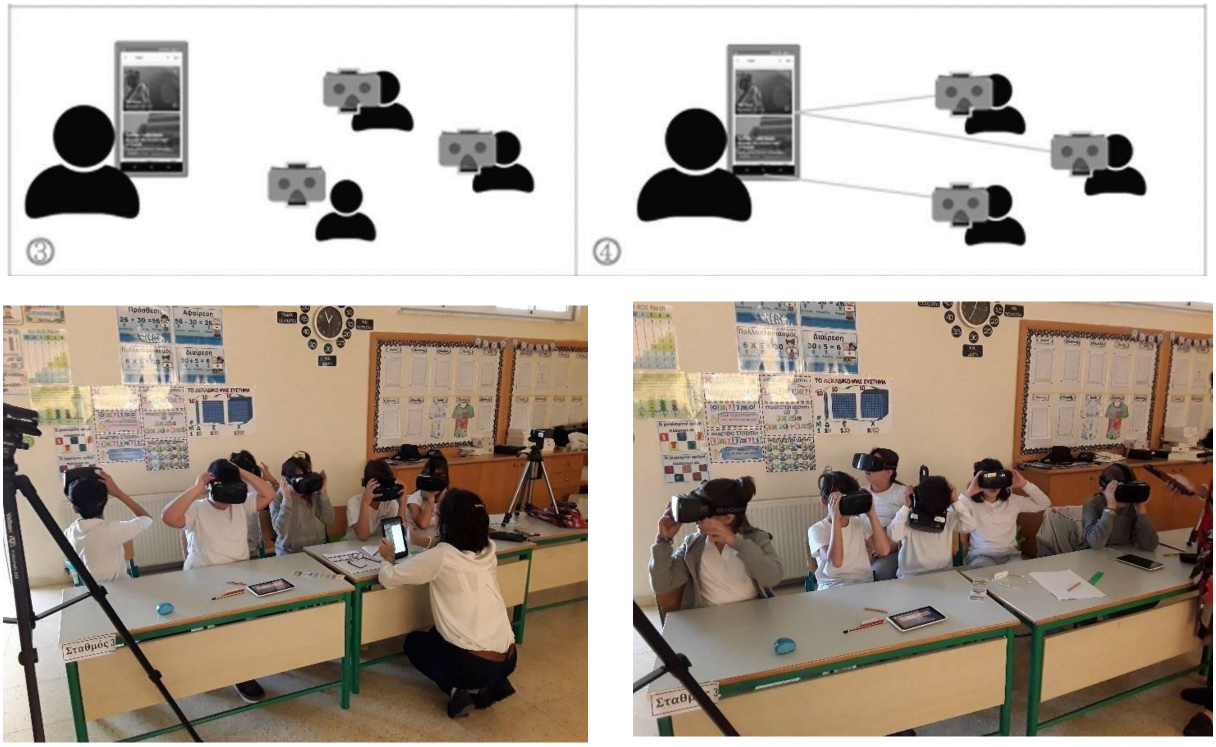


Figure 17: Station 1 – Mobile VR headsets and Google Expeditions tours

The main learning goals of the VR activity were (i) to enable students to describe similarities concerning soil morphology among the archaeological sites and (ii) to help them understand the choices made by Archaic people in order to establish a new settlement. Students used mobile phones along with a compatible mobile VR headset, which allowed them to turn and move as they would in the real world. The digital setting responded to the learner’s movements, the visuals and audio changing naturally to give a sense of reality. Being able to see evidence of the real world, even in the periphery, maintained an illusion of presence, such that learners felt their bodies were inside the virtual environment. The virtual tour was driven by the teacher, who acted as a "guide" for the students in the virtual world, encouraging them to examine points of interest. Some unstructured exploration was useful in the first few minutes for students to get used to the headset and also indulge their sense of curiosity, especially for those having their first experience in a VR environment. Students at Station 1 worked individually (see Figure 16).

8.2.4 Station 2 – Programmable floor robots

Physical tools such as tangibles (e.g., robots) are used in our embodied learning activities, e.g., learning to program (Black et al., 2012; Price et al., 2008). Children engage in a unique process of action and reflection that can lead to abstract thinking (Price et al., 2008). According to Black et al.’s (2012) IEF framework, the embodiment through manipulative falls into the category of "surrogate embodiment", which is a physical embodiment that is controlled by the learner whereby the manipulation of an external "surrogate" represents the individual.

In this second learning activity, students explored the occupations people had in archaic times while also indirectly learning to think computationally. The playful learning activity made use of programmable robots called Bee-bots. Students had to program the toy-like Bee-bot to move on a paper mat with images representing occupations in the Archaic era. The students had to choose a description of an occupation from a set of 16 flashcards, understand the description, and then program the Bee-bot to get to the image of the respective occupation on the paper mat. Students at station 2 worked in pairs (Figure 17). Understanding the occupation was not straightforward and required discussion and agreement between the teammates.

Figure 18: Station 2 – Programmable floor robots

8.2.5 Station 3 – Using tablets to create storyboards

Touching the objects on a screen directly with fingers, rather than having a control device such as a mouse or a stylus, can enhance the haptic channel experience and make the learning experience more relevant to the learning content (Black et al., 2012). Gestural interfaces (also known as natural user interfaces) include touch interfaces and free-form interfaces. Tangible User Interfaces (TUIs) require the user to touch the device directly and are based on a single or multi-touch point. Free-form gestural interfaces do not require the user to touch or handle the device directly (e.g., Microsoft Kinect) (Black et al., 2012). Gestural interfaces suggest new opportunities to include touch and physical movement that can benefit learning, in contrast to the less direct, somewhat passive mode of interaction suggested by using a mouse and keyboard.

The learning goal at station 3 was for the students to learn about myths of the Archaic period through the creation of guided storyboards. A set of how-to sheets helped the students explore the myths of their country's Archaic period. The software utilised included easily customisable templates and a variety of characters and backgrounds ideal for this activity. Students could also create dialogues and narratives for their stories. Students were familiar with the use of the storyboarding tool from previous class activities. Students at station 3 worked in pairs (Figure 18).

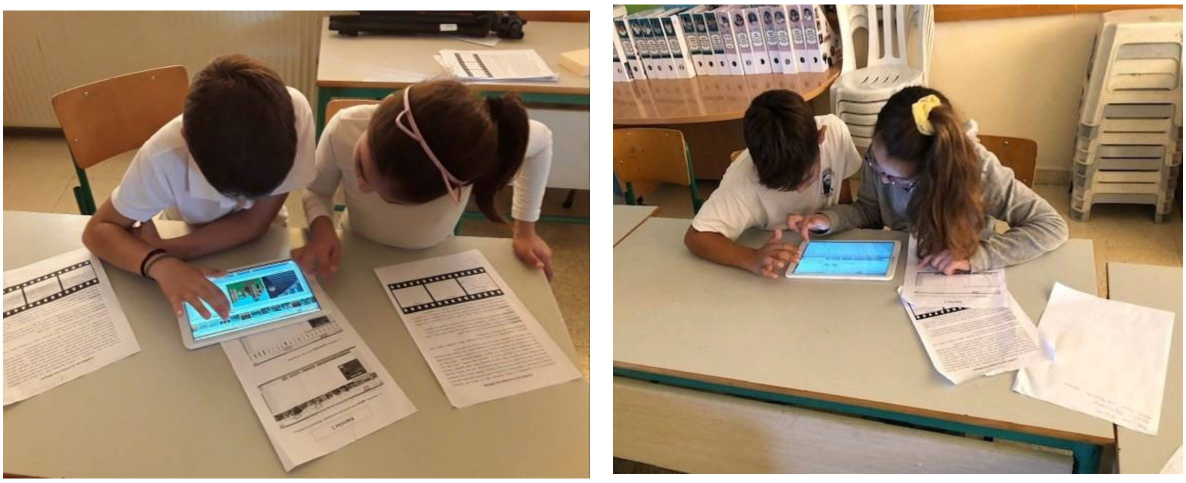


Figure 19: Station 3 – Using tablets to create storyboards

8.3 Methodology

8.3.1 Participants

The participants were Year 4 students (N = 34, 9-10-year-olds) from two classes at a public primary school in the Eastern Mediterranean. 16 participants came from one class (7 girls, 9 boys) and 18 from the other (10 girls, 8 boys). All provided parental consent.

The students had not previously used Google Expeditions; it was also their first-time using VR headsets at school. The students were, however, familiar with the technology used at stations 2 and 3 (the Bee-bots and the storyboarding software).

8.3.2 Learning intervention

The learning interventions lasted 80 minutes in each class. Students were divided into three groups of six students each. The students worked alone at station 1 and in mixed-ability pairs at stations 2 and 3. Mixed-ability pairs were formed based on their teachers' knowledge of students' academic background and learning needs, collaboration skills, and social relationships. The intervention started with the teacher briefly presenting the classroom setup and the tasks for each station. Each student group then had 20 minutes to work at each learning station. At station 1, the students went on Google Expeditions tours using their mobile VR headsets. At station 2, the students used programmable floor robots (Bee-bots). At station 3, the students used tablets to create storyboards. See Figures 16-18 for a snapshot of station activities. The students transitioned from station to station at the sound of a bell. The intervention concluded with a 10-minute debriefing of the learning activities, where the teacher asked the students to reflect on their findings and understanding of the activity. Data collection was done immediately prior to and following the intervention.

8.3.3 Data collection and analysis

The study adopted a mixed method design, using quantitative and qualitative data.

8.3.3.1 Understanding of historical information (pre-post-test)

We used a pre-post-test to assess the students' knowledge gains from the experience. The test assessed their understanding of the historical period based on three short-answer knowledge questions (KQs). The three questions were: (KQ1) You rule a kingdom during the Archaic era. You have decided to rebuild your kingdom in a new area. Where would you choose to build it and why? (Possible answers: (i) on a plain, (ii) near the sea for trade, (iii) near the river, (iv) in an area with fertile soil, (v) in an area that is a natural fortress, (vi) near an area with mines); (KQ2) How and by whom do you think the new kingdoms were founded during the Archaic years? (Possible answers: (i) by people moving within Cyprus and looking for a better place to live, (ii) by people who came from neighbouring areas such as Greek settlers, heroes of the Trojan War, Phoenicians or other neighbouring peoples); (KQ3) If you were a resident of an Archaic kingdom, what professional choices do you think you would have? (Students could name up to 10 professions). Multiple answers were possible, and points were awarded for historical accuracy. The total score was awarded out of 100: 5 points for each answer to the first question (maximum of 30 points), 10 points for each answer to the second question (maximum of 20) and 5 points for each answer to the third question with a maximum of 50 points. A paired sample t-test was conducted to assess learning gains from pre to post testing.

8.3.3.2 Perceptions of technology integration (post-test)

A post-interventional questionnaire evaluated the students' perceptions of technology. The questionnaire was slightly modified from previous studies conducted by Ioannou, Ioannou, Georgiou, and Johnson-Glenberg (2019) and other researchers (Wu, Chang, & Guo, 2009; Maor & Fraser, 2005), and presented evidence of reasonable internal consistently in the present study. The questionnaire assessed technology integration on three subscales, using a 5-point Likert agreement: *"Relationship"* (9-items scale's Cronbach's alpha = .705), assessing the extent to which students had opportunities to discuss their ideas and support each other (e.g., I asked other students to explain their ideas; students were willing to help each other). *"Personal development"* (10-items scale's Cronbach's alpha = .615), assessing the extent to which students were motivated to learn and think about their personal learning (e.g., students set up study goals on their own; I got to think deeply about what I was learning). *"System maintenance and change"* (5-items scale's Cronbach's alpha = .755), assessing the extent to which the "system" was easy to work with (e.g., it was easy to learn how to use the stations; the setup was fun). • The data collected were analysed via descriptive statistics.

8.3.3.3 Perceptions of technology integration (focus groups)

When the experience was completed, we conducted two focus groups, each with eight students selected by the class teachers to create a mixed group in terms of gender and ability. Each focus group lasted 25 minutes and aimed to understand the students' overall learning experience. Driven by Moos' (1987) conceptual framework of technology integration, the students were probed to discuss their experience in terms of: (a) their personal development (i.e., what were the main factors that helped you learn while participating in this experience?), (b) their relationships with others (i.e., how did you collaborate with team members at each learning station?), and (c) system maintenance and change (i.e., did you encounter any problems while using the technologies in the learning stations? How did those problems affect you?). The interviews were all transcribed verbatim. A thematic analysis was conducted focusing on the aforementioned three dimensions of our conceptual framework: “Relationship,” “Personal development” and “System maintenance and change.” The analysis was done by two independent coders with nearly 90% agreement; all disagreements were resolved following a discussion between the coders.

8.4 Findings

8.4.1 Understanding of historical information (pre-post-test)

A paired-samples t-test of pre-post total mean scores across the three knowledge questions, indicated significant learning gains from pre (*M*= 0.85, *SD*= 0.56) to post testing (*M* = 1.65, *SD* = 0.56), *t*(34) = -7.05, $p < .001$, with large effect size (*d* = 1.43). Table 10 presents the paired-samples t-test per individual knowledge question, showing statistically significant gains in all three questions. Overall, the embodied and immersive learning experience as enacted in this work, appears to have enabled students’ learning and understanding about the historical information under consideration.

Table 9: Paired-Samples t-test per Knowledge Question

	Mean (post test - pre test)	Std. deviation	*t*	*df*	*Sig.* (2-tailed)
KQ1	.53	.90	-3.45	33	$.002^{**}$
KQ2	.35	.85	-2.43	33	$.021^{*}$
KQ3	2.50	1.24	-11.79	33	$.000^{***}$

Note. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

8.4.2 Perceptions of technology integration (post-test)

Descriptive statistics demonstrated positive attitudes on all three dimensions of the technology integration questionnaire. The mean scores were well above the midpoint of the scale (the median of the scale is 3 and total score is 5), namely: (i) $M = 4.33$ ($SD = 0.47$) for “Relationships”, suggesting that the students discussed their ideas and were supportive to each other; (ii) M=3.60 ($SD = 0.59$) for “Personal development,” suggesting that the students were motivated to learn and thought about their own learning; and (iii) $M = 4.53$ ($SD = 0.50$) for “System maintenance and change,” suggesting that the learning stations, as a system, were easy and fun to use.

8.4.3 Perceptions of technology integration (focus groups)

What follows is an overview of the core ideas discussed by the students, coded and organised within the three dimensions of our conceptual framework.

8.4.3.1 Relationships

Students reported the value of teamwork for their learning, especially with reference to the programmable robot station and the storyboarding station. More specifically, the students spoke about the exchange of views and ideas that took place at these two stations, as well as peer assistance and collaboration.

> *I liked working in pairs because we could play for longer, agree on how to do our assignment, and help each other.* [Boy5 - focus group 1]

> *I liked that my teammate L. was sharing her thoughts with me on how we could improve our storyboard.* [Girl6 - focus group 2]

> *I had some difficulties figuring out how to do the storyboard, but P. showed me how because she could do it easily.* [Girl5 - focus group 2]

> *I worked very well with my teammate. We shared our thoughts and helped each other. For example, I was reading my flashcard and we were both trying to guess the occupation mentioned.* [Girl4 - focus group 2]

However, students reported negatively on VR’s lack of multiplayer functionality.

> *It would have been better to work as a group in VR. In the virtual tour I found myself trying to find where the other members of my team were, I kept asking them, "where are you?" and "what do you see around you?" [*Boy6 - focus group 1]

8.4.3.2 Personal development

Students reported that the activity had a positive impact on their personal learning development in the sense that it motivated them to learn and think about their personal learning.

> *VR was a great way to learn about where the archaic kingdoms were built. At the other two stations, I was motivated to learn about people's occupations and about the myths of the Archaic era.* [Girl1- focus group 1]
>
> *I liked using VR because I was seeing everything right there... and I liked the feeling of being there and watching it like it was real. It was fun to learn this way.* [Girl2 - focus group 1]
>
> *I liked the Bee-bot station because I had to think about how to program the Bee-bot robot to move in a certain way. We had to read the flashcard first and correctly guess each occupation. I liked the other stations too... It was a creative exercise, doing our own storyboard and writing our own dialogue based on myths we learned in our history lessons.* [Girl4 - focus group 2]
>
> *The arrows showed where I had to look while walking around. The teacher's asking questions helped me think about the soil morphology and take better notice of the points of interest.* [Girl3 - focus group 1]

The students also commented on how the experience was fun and engaging; they preferred it to a typical learning experience.

> *It was also fun and easy to learn.* [Girl4 - focus group 1]
>
> *I liked the creation of a storyboard because I could use my creativity.* [Girl3 - focus group 2]
>
> *Using VR, I felt like I was on a school trip to an archaeological site. It was so much more fun than a typical lesson or even going on a field trip.* [Girl2 - focus group 1]

Students did, however, report two disengaging factors that inhibited their personal development: time pressure and a lack of feedback at stations 2 and 3.

> *We need more time at the stations. For example, at station 3 with the storyboard, we only had five minutes to write down the dialogue, and it was difficult to finish on time.* [Boy1 - focus group 2]
>
> *Sometimes we wanted to ask our teacher a question, but she was busy at the VR station, and we had to wait until we got her attention, or we had to ask our teammates to help us. We were wasting time waiting for help.* [Boy8 - focus group 2]

8.4.3.3 System maintenance and change

The students were positive about the "system": they reported it was easy and fun to work with. They further commented that VR allowed for a feeling of presence, and that this had a positive impact on their learning. Participants reported that they were surprised by how immersed they felt in the VR sites.

> *It was a fun and easy way to learn history. It was like a typical lesson but enriched with technology and games, which made it fun to learn about historical content.* [Boy2 - focus group 2]
>
> *The virtual reality activity was amazing because we could see the places and feel like they were real, and you were really there at the archaeological site.* [Boy5 - focus group 1]

Students reported negatively on two aspects of the exercise: the discomfort caused by the size of the VR headset and also the inconvenience of having to sit on the floor while working with the programmable floor robots.

> *I liked the virtual tour, but it felt annoying here (pointing to his face) because the headset was loose, and I had to hold it to my face when I was looking down. The teacher tried to adjust the size, but it was still loose.* [Boy7 - focus group 1]
>
> *I liked that I could work with my teammate in our own space, but it was difficult to work on the floor with the Bee-bot. It would have been better if we had some cushions to sit on or had sat at our desks.* [Boy8 - focus group 2]

8.5 Discussion and implications

In DBR Cycle 4, we tried to replicate and confirm the orchestration strategy that derived from DBR Cycle 3 and to revisit learning aspects in technology-enhanced embodied learning which were unclear in earlier cycles of the work. The study presented an example of a learning design enacting three forms of physical embodiment (direct, surrogate, and augmented) in a multidisciplinary lesson around historical information, using a model of rotating across learning stations, orchestrated by a single educator in the classroom. Results from 34 learners demonstrated learning gains as well as positive perceptions of the learning experiences in terms of "Relationship," "Personal development," and "System maintenance and change." Below, we reflect further on our findings.

With respect to RQ1 (*Did the students experience learning gains*?), responses to the knowledge test, as well as reporting in the focus groups, revealed that the technology-enhanced embodied learning approach managed to transform the experience of discovering new places, understanding spatial relations, and learning historical facts, making it both enjoyable and effective. In the focus groups, the students said the virtual field trips were an effective and intriguing way of learning. They appreciated the teacher's guidance through the VR experience, which, they said, helped them learn more effectively. This finding is consistent with other authors writing about VR in education, who have argued that embodied learning can enhance involvement in learning processes (e.g., Chittaro, & Buttussi, 2015; Georgiou, Tsivitanidou, Eckhardt, & Ioannou, 2020; Jha, Price, & Motion, 2020; Skulmowski, & Rey, 2018). It appears that the design of the learning stations allowed students to engage with a variety of information and gain knowledge in a fun way.

With respect to RQ2 (*What were their perceptions of the technology-enhanced embodied learning experience?*), the students seem to have had an overwhelmingly positive learning experience in terms of "Relationship," "Personal development," and "System maintenance and change," as evident in both the quantitative and qualitative data. The Learning Station Rotation Model seems to have a significant impact on students' engagement. They were active, managed themselves, and solved problems in the context of each learning station. The students elaborated that the technology-and manipulatives-enhanced stations were preferable to conventional ways of classroom learning and that they constituted an attractive and fun learning environment that fuelled their interest and curiosity. This finding is in line with Minocha et al., (2017) who argued that, because the students are in control of where they look and for how long, they can follow their interests and curiosity, hence giving them a sense of empowerment over their own exploration. Johnson-Glenberg (2018) also found that whenever users felt they had control over the environment, they experienced agency, which is in line with the reporting of the students in the present study.

Overall, the effectiveness of the VR field trips was related to the concept of presence and immersion. Presence refers to users' subjective belief that they are in a certain place, even if they know that the experience is mediated by the computer (Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001). In VR heritage scenarios, "cultural presence" plays a key role; it's not just a feeling of "being there" but of being-not only physically, but also socially and culturally-"there and then" (Champion, 2010). Although the low-cost development in this work did not offer the students a highly interactive experience with virtual objects - which would have been possible with advanced VR tools like Oculus Rift or HTC Vive - the experience was perceived as immersive in terms of presence and thus highly enjoyable. The enactment of embodied learning aims to help better build this embodied experience for a better understanding of the historical information for current learning or subsequent learning, which is conventionally based on verbal or textual input. Indeed, compared to a conventional learning design, learners in an embodied experience can get immersed in the virtual context and engage with the learning content, getting realistic information on abstract and complicated concepts or artifacts. The VR field trip was designed to offer a virtual but authentic learning context in which learners could imagine what a real field trip to a site would be like. This immersive and interactive experience from the comfort of the classroom gave them meaningful learning moments without the expense of a long journey. Today's affordable motion-sensing input devices, together with freely available apps, can support learning design for embodied interaction and could provide solutions when mobility is costly and not always possible. With this study, we aim to encourage more educators to take advantage of these affordable tools.

An important consideration is that in our work, we used affordable learning technologies enriched with content that is aligned with the national educational curriculum. We aimed to combine the physical and digital worlds and to enable a multisensory and embodied learning experience to promote an understanding of historical information in a multidisciplinary lesson. Our focus was on low-cost technologies as schools often lack the financial resources, technological infrastructure, and professional development for teachers. Therefore, we recommend the deployment of low-cost and easily built VR environments (Kalpakis, Palaigeorgiou, & Kasvikis, 2018; Palaigeorgiou, Karakostas, & Skenteridou, 2018), as well as apps that can be integrated with existing educational curricula or are flexible enough for teachers to edit the content based on students' needs and learning goals (Kharrufa et al.,2013a;2013b; Ioannou, 2018). With this study, we aim to encourage more educators and learning designers to develop content and share their experiences.

The students had a negative response to the VR's single-player mode: they expressed a desire to meet up in the virtual space, suggesting that the experience was indeed immersive and that they wanted to be at the same place at the same time. This could confirm the previously reported human need for social exploration of heritage sites using a mobile phone guide (Suh, Shin, & Woo, 2009). Learning in the classroom, especially for this age range of students, is a fundamentally social activity, but most VR technologies, like the one used in this study, do not currently offer a group mode for collaborative learning. Therefore, VR embodied learning experiences should ideally unfold within a well-structured group learning context or follow a scenario with embedded teamwork. This may include individual work and teamwork, along with class-wide activities or plenary discussions.

Moreover, the lack of feedback from the teacher at stations 2 and 3 was commented on by the students as a negative factor in terms of their personal development. During the design of the experience, the thinking was that thanks to the tangible interface of the technologies used at stations 2 and 3, the teacher would easily be able to monitor the progress of each group while remaining at the first station. However, it turned out to be difficult for the teacher to manage the VR station guided tour while also keeping track of the progress of the groups at the other two stations. While guiding the virtual tour, the teacher could only keep a visual track of whether the students in that group were progressing with the activities. The station rotation model (Ioannou, Ioannou, Georgiou, & Retalis, 2020) would have worked better if the virtual field trip was self-guided rather than guided by a teacher, or if some form of collaboration between teammates was in place (e.g., one student guiding another student based on how-to sheets). This scenario warrants future investigation and might also address the negative comments students had about the VR single-player mode.

Some more negative comments concerned the headsets and the classroom setup. The physical features of VR headsets play a role in the overall user experience. In this study, the subjects were pre-teen children, and the mobile VR headset was too big for some (even after fastening the strap as tightly as possible). This caused discomfort for some students as they had to hold the headset up to their faces. The students also reported that it was tiresome to work on the floor at station 2; they would have preferred to have a cushion or work at their desks. Future studies would do well to address these issues for young learners.

In closing, we conclude that the students' performance and input revealed positive learning gains and attitudes and underlined that the learning station model, the use of technologies and manipulatives, and the design of the learning activities were successful in providing an engaging embodied learning experience. With this study, we presented a successful enactment of technology-enhanced embodied learning in the classroom, replicating and confirming the orchestration strategy that derived from DBR Cycle 3 and documenting learning aspects that were unclear in earlier cycles of the work. The study highlighted how technology-enhanced embodied learning can offer learning opportunities for students and therefore deserves major consideration as mainstream education practice. The study demonstrated significant gains in student learning when technology integration and orchestrations strategies were made explicit to the educators.

9 DISCUSSION OF KEY FINDINGS

The overarching goal of this work was to address technology enhanced embodied learning in authentic classroom contexts and present orchestration strategies and guidelines that will enable wider application. The purpose of this chapter is to present the most important results that derive from the four stages of this DBR work. Each cycle of work operates with one another to inform theory, strengthen the design of learning experience and present practical examples and guidelines that will help maximize the value and benefit while minimizing the barriers to the adoption of technology-enhanced embodied learning in authentic classrooms. In this chapter, we summarize key findings from the research cycles and distinct research questions; yet, the findings are discussed holistically, drawing on knowledge drawn from across cycles of work, demonstrating our progression of understanding in regard to the specific research objectives of the work. The chapter concludes with a discussion of contributions to current knowledge, limitations of the overall DBR work, and suggestions for future research.

9.1 Key findings from across DBR cycles

9.1.1 Understanding the main challenges of introducing technology-enhanced embodied learning in a classroom context (RQ 1.1, RQ 1.2)

Across the four cycles of the DBR research, the transformation of the classroom in an embodied learning environment introduced challenges that concerned: (1) a single teacher in a dynamic environment, (2) practicalities in serving a large group of students, (3) local contexts and adoption preferences, linked to conditions inherent in real classroom that are not captured by laboratory studies (Cai et al., 2014), and (4) professional development for teachers who are less familiar with, or convinced of, the embodied pedagogy (Abrahamson, Nathan, Williams-Pierce, Walkington, Ottmar, Soto, & Alibali, 2020).

9.1.1.1 A single teacher in a dynamic environment

The technology-enhanced embodied learning experiences in this DBR research were enacted in authentic classrooms and coordinated by a single teacher. Through cycles of research, we have developed and enacted a learning experience design according to which students work in learning stations with rotation. Having one technological station with high-embodied technology for each group proved to be an exhausting task for the teacher and an intrusive experience for the learners (DRB Cycle 2; Ioannou et al., 2019). In follow up cycles of research the “Learning Station Rotation” model was implemented where some stations used high-embodied technology while other stations used more conventional interfaces or materials (DBR Cycles 3-4). This set-up allowed students to work independently in smaller groups and allowed the teacher to focus on supporting others as needed (Ayob, Halim, Zulkifli, Zaid, & Mokhtar, 2020). Moreover, the “Learning Station Rotation” model allowed teachers to make effective use of the limited physical space of a school classroom, effective management of class time, including the time required for setting up the equipment, and to effectively apply inquiry learning as a pedagogical approach to facilitate learning in smaller groups of students of varied abilities. Like Aydogmus and Senturk (2019) previously argued, in working stations students have rich learning experiences, do different activities, use different materials to learn, and experience reinforcement of what they have learned.

9.1.1.2 Practicality in serving a large group of students

Our first two cycles of work (DBR Cycles 1-2) revealed that there are aspects of embodied learning technologies that are not as easily scalable for schools. Embodied learning technologies, especially those that support motion tracking, need significant space for student activity. For instance, Microsoft’s Kinect add-on for the Xbox 360 console demands that users stand between 6 and 8 feet from the sensor and that there is enough space for one or more players to move side to side. For example, to set up the interactive floor technology (DBR Cycle 1), we needed the whole classroom space. Then, having students walk or jump during the game caused undesirable noise and interference from one group to another. Similarly, Kinect cameras are extremely sensitive to the environment (DBR Cycle 2); the sunlight and long distances between students and cameras have a significant impact on depth estimation and accuracy. Overall, physical space limitations or the distraction that can occur during gameplay for those attempting other tasks proved to be an issue that we had to overcome. In DBR Cycles 3-4, to avoid intrusions from one group to another, all students were kept busy and engaged in their station, allowing enough space for students in the embodied station to move during gameplay. In fact, findings demonstrated that the use of conventional materials such as paper, cards, etc., or devices that students and teachers were already familiar with was evaluated positively. This setup allowed the teacher to focus on a group of students at a time. For those students using the embodied learning station, teaching support was important to help them deep into the learning aspect of the game.

9.1.1.3 Local context and adoption preferences

A variety of local contexts and conditions inherent in real classrooms can inhibit adoption. These barriers are not captured by laboratory studies (Cai et al., 2014) and must be addressed in real classroom settings. In sum, all cycles of work involved practicalities and logistics of integrating technology and enacting embodied learning, mostly evident from the perspective of a teacher. Teachers had to set up from scratch on their own, within a limited time, and then completely pack everything away again. Technology such as the Kinect camera has a simpler setup process and is easier to operate, and therefore was preferred by the teachers. Kinect technology was portable and allowed flexibility in terms of where and how it could be set up and used. This finding is in accordance with similar findings from Stanton et al. (2001), who argue that a physically modular and foldable design is required by teachers in schools. Our findings also confirm previous research by Kreitmayer, Rogers, Laney, and Peake (2013) reporting that embodied technology for the classroom had to be (a) easy to learn, (b) easy to set up and take down within a few minutes during a school break, (c) technically robust and unobtrusive, so that teachers can focus on the students' needs in the moment, and (d) scalable and maintainable by using only hardware that can be obtained and replaced at low cost. Findings from this work suggest that for maintaining a favorable embodied learning environment, aspects such as the usage of time, space, and classroom resources are fundamental necessities.

9.1.1.4 Professional development

Support for teachers emerged as a necessity in our DBR Cycles and was successfully achieved in DBR Cycles 3-4, consistent with previous work addressing teachers who are less familiar with (or convinced of) the embodied pedagogy (Abrahamson et al., 2020). Teacher professional development helped the teachers embrace technology-enhanced embodied learning and face the challenges of orchestrating the classroom around a range of activities. Even though in all four cycles of work, the teachers had the support of researchers in designing appropriate tasks and enacting the experience, without adequate professional development in DBR Cycles 1-2, teachers struggled to implement technology-enhanced embodied learning. By providing teachers with the necessary training and support, it became possible to improve the effectiveness of the experience and enhance student learning outcomes in DBR Cycles 3-4. It also became evident that educators need practical examples and learning design models that would guide their implementation of embodied learning, consistent with previous work by Georgiou and Ioannou (2019a) who addressed teachers' concerns through professional development for the successful adoption of technology-enhanced embodied learning in the classroom. DBR Cycle 4 showed a significant gain in student learning when technology integration and orchestration strategies were made explicit to the educators.

9.1.2 Perceptions of the learning experience/High-embodied vs a Low-embodied Experience (RQ 2.1, RQ 2.2)

Across the four cycles of work, findings shed light on the factors affecting learner's perceived experience in technology-enhanced embodied learning, in terms of the classroom setup and the support strategies. Namely, a series of factors associated with technology were mentioned by students as having affected their perceived experience in a negative way, especially DBR Cycles 1-2. Logically, technical issues can negatively impact the experience, whilst locomotion and classroom noise can be destructive. On the other hand, positive perceptions are linked to the gaming nature of experience, teamwork and inquiry learning.

9.1.2.1 Technical issues will negatively impact on the experience

It is not uncommon for students to encounter technical issues or challenges when engaging in technology-enhanced (embodied) learning. In our studies these challenges arose from factors like hardware, software, or connectivity issues for example, some synchronization issues in DBR Cycle 1 (floor technology) and some movement tracking issues in DBR Cycle 2 (provoked by students' proximity to the Kinect). These types of technical issues had a significant impact on students' perceived experience and engagement with embodied learning; they disrupted the flow of the game, detracted students from the learning objectives of the lesson, and created frustration and or disengagement. Such technicalities were addressed in DBR Cycles 3-4, for example via setting up the embodied technology away from windows, as direct sunlight could cause system errors (Ioannou et al., 2019) and leaving enough space for kids to be away from the Kinect sensors. Moreover, teachers proactively provided students with clear instructions for using the technology and monitored technical problems as they arose.

9.1.2.2 Locomotion and classroom environment can be destructive

While locomotion can be a valuable aspect of embodied learning by allowing students to physically engage with digital environments and objects, it can also present challenges and limitations that may impact the overall learning experience. In the DBR Cycles 1-2, locomotion required students to multitask, such as navigating in the virtual space while also answering questions. This proved to have distracted students from the learning experience. As students reported, in some cases they would be more focused on coordinating their body movements than on the learning content. Also, this factor created increased waiting time between turns, which also resulted in off-task discussions and behaviors amongst the members of the group (DBR Cycles 1-2). To mitigate the negative impact of locomotion, orchestration strategies such as the learning station rotation model were applied in subsequent DBR Cycles 3-4. In this case, the students worked coherently in the learning stations making effective use of the time. Moverover, in DBR Cycles 1-2, students reported how the classroom noise and other groups' interventions while working were two main factors negatively affecting their personal development. A noisy classroom environment may detract from, rather than enhance student learning, which is not a surprising result (e.g., Darling-Aduana & Heinrich, 2018). Students also negatively elaborated on how a set of activity-related factors, such as working in large groups in technology-enhanced embodied learning affected their relationships negatively. In particular, the students reported that it was more difficult to agree on a common strategy and plan their next steps, while there were also many disagreements, with children often fighting over turn-taking and roles in the group. Orchestration strategies along with scripted collaboration around inquiry-based pedagogy were applied in subsequent DBR Cycles 3-4 to address these issues.

9.1.2.3 Positive perceptions of the gaming nature of the experience

Students evaluated positive factors such as the educational nature of the games, the gaming features (e.g., stages, points, rewards), the narrative plot on which the games were structured, as well as the integrated scaffolding (e.g., hints and prompts), which had a positive contribution to their personal learning development (all DBR cycles). In all cycles of work, the large projection of the Kinect games (bigger screen providing more heightened sensory stimuli), the interface (with the use of novel technologies), and in general the gaming affordances of the platform for promoting bodily movement (via the gesture-based interactions), contributed to their experience of immersion, and this had a positive impact on their perceptions of technology use. In all cycles of work, the students reported that game play in technology-enhanced embodied learning activities was preferable to conventional ways of classroom learning and constituted an attractive and fun learning environment. Though play behavior may be criticized as a distraction from learning (e.g., steering children away from learning and problem-solving), the literature generally recognizes play as an essential means for learning, also supporting students' social and emotional skills (Lee-Cultura, Sharma, Cosentino, Papavlasopoulou, & Giannakos, 2021).

9.1.2.4 Positive perceptions of teamwork and inquiry learning

In DBR Cycles 3-4, the students reported how a set of activity-related factors, such as the team-based mode in which the activity was enacted, the collaborative writing task that was assigned (one worksheet to be completed by each group), and the peer feedback strategies that were followed, had a positive impact on their collaboration, enabling the exchange of views and ideas, peer scaffolding, and assistance. Also, in DBR Cycles 3-4, the students evaluated positively the Station Rotation model, perceived to enable teamwork, effective use of time, and engagement with the curriculum content. Indeed, the model allowed us to implement highly embodied learning technology along with more conventional materials and tools, via an inquiry learning approach. The operational autonomy among stations, along with the conceptual connection among them, allowed a successful learning experience overall.

9.1.3 Documenting classroom orchestration strategies for successful embodied learning in the classroom (RQ 3.1)

Building on the orchestration framework of Prieto et al. (2011), strategies of classroom orchestration for technology-enhanced embodied learning become concrete in DBR Cycle 3 and include aspects of learning design, regulation and management of the classroom (i.e., applying a learning stations rotation model), teacher strategy (i.e., moving from group discussions to quick debriefing at plenary), teacher adaptability and flexibility in the dynamic environment, awareness and assessment (i.e., realizing misconceptions via formative assessment all the way). Below we elaborate on some of these strategies, which a detailed discussion is found in DBR Cycle 3.

9.1.3.1 Learning design

Results from DBR Cycles 3-4 suggest that learning experience design with embodied learning technologies can be structured by first giving a short whole-class introduction to the experience (set up of stations, learning goals), followed by an extended period of student independent work in small groups with the embodied learning technology and with more conventional technologies and materials, structured around collaboration activities. This later phase allows for exploration, with students working independently at their stations to test ideas while the teacher circulates around the classroom assessing students' engagement with the task and determining any difficulties they encounter during tasks (Gulay Bozkurt & Kenneth Ruthven, 2018). Finally, a summary of the whole class plenary session to review and elaborate on the lesson is also instrumental for the learning experience (DBR Cycles 3-4). Co-design between researchers and practitioners as well as professional development were found to be important in this DBR, enabling the teachers to design for embodied learning experiences, consistent with previous reports by Georgiou and Ioannou (2019a). Additionally, an inquiry-based approach was proven a key aspect. Findings from DBR Cycles 3-4 revealed that an inquiry-based approach to lesson design, in which students are guided to problem-solve in teams, then interact with the embodied learning technology, and continue the cycle, encourage collaboration and cognitive engagement. These ideas are coherent with those put forward by Minocha, Tudor, & Tilling (2017) in which inquiry-based assignments around virtual field trips with Google Expeditions were designed in such a way that students were only able to solve them while working together. In such, the orchestration of the technology-enhanced embodied learning in DBR Cycles 3-4 was in line with inquiry-based pedagogy by setting out challenging tasks that should be solved collaboratively, in order for the team to pursue follow up activities.

9.1.3.2 Regulation and management of the classroom

Applying the Learning Station Rotation Model in DBR Cycles 3-4, which allows students to rotate through learning stations on a fixed schedule, resulted in an improved experience for students. It appears that the design of the learning stations allowed students to engage with a variety of information and gain knowledge in a fun way. The Learning Station Rotation Model was also implemented in the study by Georgiou and Ioannou (2020). Their findings are in line with our research demonstrating that this classroom orchestration model supported the effective integration of technology-enhanced embodied learning in primary math classrooms and promoted students' engagement and conceptual learning.

9.1.3.3 Teacher strategy/Teacher adaptability and flexibility

The teacher's role in orchestrating learning remains the most important aspect of a successful learning experience. The teachers' role between stations was of a facilitator and a coordinator, visiting one group at a time. The teacher's role was to orchestrate the supporting features—the visual cues, the prompts, the questions, the instructions, the demonstrations, the collaborations, the tools, the information sources available, the framing of the learning environment, the group formation, the role assignment for every activity, the number of children involved in the activity, and so forth. In DBR Cycles 3-4, the teacher was able to switch fluidly between small groups and whole classroom activities without any technological overhead to deal with. The teacher could decide whether to spend more time with small groups vs addressing the plenary. The teacher's role entails a process of managing the affordances and constraints of the available tools in the most optimal way to support student learning and was a key aspect of our orchestration strategy in DBR Cycles 3-4.

9.1.4 Replicating and confirming the orchestration strategy and revisiting learning aspects (RQ4.1, RQ4.2)

Findings from this the overall work, and DBR Cycle in particular, support the idea that technology-enhanced embodied learning can be enhanced significantly when evidence-based orchestration strategies are applied. The guidelines, initially addressed in DBR Cycle 3, were applied, and reinforced in DBR Cycle 4. Learning gains were also addressed in DBR Cycles 4, eliminating the fuzziness of the findings of the previous cycles on the matter of learning gains.

9.1.4.1 Confirming orchestration strategies and guidelines

Orchestration strategies of DBR Cycle 3, were interpreted into a set of practical guidelines on classroom orchestration for technology-enhanced embodied learning, reinforced in DBR Cycle 4. The research was framed by the three characterizing components of how orchestration should be done, per orchestration model of Prieto et al. (2011): *Pragmatism/Practice*. The work was performed in real classroom settings and therefore the techniques present a robust set of guidelines for orchestrating the process of embodied learning activities. *Alignment/Synergy*. Our approach used minimal and manageable resources for implementation; we used known technology that allowed learners to interact with the learning content via gestures/body movement. *Models/Theories*. We formulated a set of practical guidelines on classroom orchestration for technology-enhanced embodied learning that are detailed in DBR Cycle 3: co-design with stakeholders (i.e, researchers and practitioners designing the learning experience together), create learning stations (both high-tech and low-tech stations can be included), keep group-size small (i.e., support teamwork via collaboration scripts), have debriefing sessions (i.e., encourage reflection between stations), scaffold learning (i.e., provide guidance, feedback, and prompts).

9.1.4.2 Learning gains

Our results indicated that in the first two cycles of work (DBR Cycles 1-2), learning gains were limited, as opposed to outcomes of previous research that relates physical activity with increased engagement and learning (Bianchi-Berthouze et al., 2007; Kosmas, Ioannou, & Retalis, 2017; Price & Rogers, 2004). After careful consideration of classroom orchestration strategies and learning design, DBR Cycles 3-4 of our research demonstrated gains in student learning. In fact, DBR Cycle 4 showed significant gains in student learning when technology integration and orchestration strategies were made explicit to the educators. Responses to a knowledge test, as well as student feedback during focus groups, revealed that the technology-enhanced embodied learning experience was both enjoyable and effective for learning. These findings enhance the appraisal of orchestration previously made by other researchers as being a key component of technology provision programs in educational settings. For example, previously studies have reported that when teachers have an orchestration strategy to integrate digital and non-digital resources, student learning is enhanced in relation to the curricular objectives

(Díaz, Nussbaum & Varela, 2015; Díaz, Nussbaum, Ñopo, Maldonado-Carreño, & Corredor, 2015). Also, a study by Dillenbourg et al. (2014) found that the use of orchestration in a physics technology-enhanced learning environment led to higher levels of engagement and better learning outcomes compared to a non-orchestrated condition. Similarly, a study by Martin et al. (2015) found that orchestration in a science technology-enhanced learning environment led to improved collaborative problem-solving skills among students. Overall, our work and findings emphasize the importance of orchestration research, which effectively sets out models and guidelines for the logistical and instructional requirements in a classroom when integrating technology and other learning resources.

9.2 Contribution to current knowledge

Technological advancements are rapidly creating opportunities for education. Each new technology necessitates research into how it can be best applied. Teaching and learning approaches should not remain constant but should be "rediscovered" as a result of using new technologies and pedagogies in schools, such as technology-enhanced embodied learning. To date, there has been very little empirical research on the intersection of pedagogy and practice of embodied learning in authentic settings. The work contributed to an underdeveloped area of research, addressing technology-enhanced embodied learning and classroom orchestration in authentic classrooms. We integrated and orchestrated several embodied learning technologies, and we tested learning experience designs that produced and presented a set of guidelines. Our orchestration strategies and guidelines point out effective ways of enacting technology-enhanced embodied learning in real classroom settings.

At a time when embodied interaction becomes more commonplace via a range of devices, this work offers practical examples of technology-enhanced embodied learning in the classroom. Namely, consideration of context and implementation and research-driven orchestration strategies make the researcher capable of reproducing the desired beneficial effects in actual use in the classroom as previously reported in laboratory contexts. The detailed examples of technology integration, learning design, and orchestration as shown in this work could lift the veil off the teachers regarding implementation processes in actual classrooms. This work can also pave the way for further design-based research for researchers. The findings of our research contribute to the growing body of research on the orchestration of technology-enhanced embodied learning through empirical research in classroom contexts. There are no concrete studies in the literature that investigate technology-enhanced embodied learning in classrooms from an orchestration viewpoint. Our guidelines stress the importance of pedagogy, content, and technology and the interactions of those three components in order to deliver effective instruction (Harris, Mishra, & Koehler, 2009). Educators wishing to enact technology-enhanced embodied learning in their classrooms will have evidence-based guidelines to follow, as developed by this research.

This study also contributes to the overall educational technology research community by providing knowledge regarding the pedagogical use of embodied learning in the school context. While embodied learning technologies are increasingly being adopted in classrooms, there is little research on how they may be optimally used for learning. Dillenbourg et al. (2011) argued that research has neglected the metaphor of orchestration in the typical classroom. There is indeed little practical guidance to support the integration and orchestration that explicitly aims to leverage movements and embodied interaction in support of cognition and learning in classroom settings. In our research integrating and orchestrating embodied learning technologies that effectively create conditions for learning is addressed. This study offers several concretes, evidence-based, design guidelines to assist this nascent field of integrating and orchestrating technology-enhanced embodied learning in authentic classroom settings so that educators and practitioners as well as researchers can leverage that foundational knowledge to further research.

9.3 Limitations and future directions

Per definition of design-based research, this work took place in authentic classrooms, which brings high ecological validity to this study. Yet, some limitations are inherent to the methodology itself as well as the implementation in the four cycles of this work.

First, most of the students who participated in the cycles of work were exposed to technology-enhanced embodied learning for the first time. Also, each classroom implementation presents a short intervention (i.e., 2 class periods, 80 minutes). That said, some of our finding concerning engagement, positive attitudes, and learning might be associated with a novelty effect, making the true affordances of technology-enhanced embodied learning environments ambivalent. Future studies should therefore target longer-duration implementations comprised of 4-5 sessions in each classroom to explore the participating students' engagement and learning throughout time, from session to session. Long-term studies will assist in better understanding the impact of the learning environments under investigation. On the other hand, it should be noted that this novelty of the experience may have also impeded learning for some of the participating students, given such learning environments were used and tested for the first time, causing difficulties and unexpected events, as reported in all cycles of work. Longer studies with such learning environments would be necessary to eliminate inefficiencies and increase familiarity in their use. Overall, investigating our technology-enhanced embodied learning environments and orchestration strategies in longer-duration studies would be an important future direction of this work.

Furthermore, it would be interesting to examine our technology-enhanced embodied learning environments and orchestration strategies with different age groups. Our technology-enhanced embodied learning experiences were conceived for late-elementary school students. Learning design, including orchestrating the embodied learning experience, for this age group would be quite different from one age group to another. Although factors such as physical classroom constraints might be similar, the use of technology, teamwork, role of the teacher and other factors may differ, as older students (or younger students) have different learning needs, relationship with technology, teamwork capacity among others and that needs to be investigated further. Moreover, in order to generalize findings, a larger representative sample from various educational levels must be targeted. Investigating our technology-enhanced embodied learning environments and orchestration strategies with different age groups would be an interesting future direction in this work.

Last but not least, many of the reflections presented in this design-based research remain the subjective conjectures of the researchers or contextualized findings. Moreover, the researcher's dual role as both the teacher and the observer in the interventions can be seen as a limitation, as it may cause subjectivity in the observation judgments and lead to credibility issues. Although generalization of finding is not the goal of design-based research, future research could recruit more participants from various age groups and school contexts to confirm that our technology-enhanced embodied learning environments and orchestration strategies are replicable in similar interventions. Concerns on subjectivity and reliability that often surround qualitative methods in general, can be addressed with replication of work and evidence of transfer of the results in similar circumstances and context.

Closing, embodied learning environments make it possible for players to interact physically with technologies in revolutionary ways. As Evans et al. (2014) indicated "over time, hardware will become more capable, available, and affordable, software development environments will mature, and understanding of how to design applications for these technologies will grow" (p.689). We foresee that those technologies will soon become affordable everyday technology found in mainstream schools. Consequently, studies of technology interaction and classroom orchestration are timely and relevant; researchers and teachers must have the knowledge to make educated decisions to maximize learning and improving practice.

Much is yet to be learned about how the affordances of these technologies can support embodied learning, and how our conception of learning itself might change considering these new ways of interacting with the world. It is not appropriate to think simplistically about what makes technology-enhanced embodied learning environments effective. The enactment of the learning experience, from the technological setup to learning design, implementation and orchestration is complex and the goal should be to capture the special ingredients in every step and deploy those in serving pedagogical purposes. Research on technology-enhanced embodied learning environments and orchestration is about giving teachers the tools to structure their classes and empower them during the implementation. A focus on orchestration strategies help to guide the teacher through the work to be performed in the classroom, allowing a shift from an instructor-centered arrangement to one where students actively participate with the teacher acting as a mediator (Nussbaum & Diaz, 2013). The guidelines produced in this work for the successful enactment of technology-enhanced embodied learning, building on an existing framework for classroom orchestration, are subject to further study, refinement, and empirical validation with more learners of different age groups and classroom contexts. A logical next step would be to enact similar interventions of technology-enhanced embodied learning with secondary school students to check the consistency of the reported findings in terms of students' learning, perceptions, and engagement. Future studies could further replicate this research focusing on different embodied learning technologies and implementations, towards confirmability and replicability of proposed orchestration strategies.

CONCLUSIONS

This dissertation presented four cycles of design-based research on the implementation and evaluation of technology-enhanced embodied learning in authentic classrooms. Given the popularity of embodied learning technologies in recent days, this research helped to identify issues of technology-enhanced embodied learning via concrete examples of enactment and evaluation. The work focused on extracting guidelines for orchestrating learning experiences in real-world classrooms.

There is limited research available in the rapidly developing field of technology-enhanced embodied learning. Orchestration research, meaning the understanding of specific problems and phenomena that arise in the implementation of such (and any) innovations in authentic settings is considered one of the foremost challenges in the field of technology-enhanced learning (Fischer, Wild, Sutherland, & Zim, 2014; Roschelle, Dimitriadis, & Hoppe, 2013). Addressing the question of how to design and orchestrate effective technology-enhanced embodied experiences in authentic classrooms was worthy of investigation. As the field of technology-enhanced embodied learning continues to evolve, it is necessary to conduct more investigations addressing research in the intersection of embodied learning, technology integration, learning design, and classroom orchestration. This is an important area of educational research, as it addresses learning that takes place in a real classroom, out of a controlled setting and takes context into account.

Overall, the work addressed technology-enhanced embodied learning and classroom orchestration. Orchestration strategies and guidelines were presented, documenting the process that teachers must go through to integrate technology, design lessons, and facilitate implementation. This study showed a significant gain in student learning when technology integration and orchestration strategies were made explicit to the educators. The guidelines that derived from this research can promote wider classroom application of technology-enhanced embodied learning, whilst they can be further refined taking into consideration various school contexts and initial conditions. This work also contributes to the broader educational technology research community by providing knowledge regarding the pedagogical use of embodied learning environments in the school context.

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