Technology-enhanced Embodied Learning: Designing and Evaluating a New Classroom Experience

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ABSTRACT: The enactment of embodied learning in the authentic classroom introduces new challenges. The educational system has yet to develop a clear vision or learning design models that would guide the implementation of embodied learning using digital technologies and manipulatives. This study presents an example of a learning design for technology-enhanced embodied learning in an authentic classroom. Three forms of physical embodiment (direct, surrogate and augmented) are enacted using a model consisting of a single educator and rotating across learning stations. The case study takes place in a multidisciplinary lesson around historical information. In this lesson, Year 4 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 evaluates the technology-enhanced embodied learning experience from the perspective of the learners. Data from 34 students demonstrate learning gains, as well as positive perceptions of the learning experience in terms of their relationship with their teammates, their sense of personal development, and the overall classroom orchestration. We conclude with lessons learnt, limitations and suggestions for future work. With this study, we aim to spark a dialogue on how technology-enhanced embodied learning can be successfully enacted in real-world classrooms, highlighting the need for more studies in the intersection of technology, design and pedagogy.

Keywords: Embodied learning, Technology integration, Technology-enhanced learning, Classroom orchestration, Learning design

1. Introduction

Research on learning design is being increasingly influenced by theories of embodied cognition. These indicate that we learn better by engaging our senses through our bodies and that the mind is not an abstract and isolated entity, but rather, it is integrated into the body's sensorimotor systems (Barsalou, 1999; Barsalou, 2008). Advocates of embodied cognition argue that cognition is both perceptuomotor and modal, in the sense that we function in the world through sensation, perception, imagination and motor action, and by engaging with cultural forms, artefacts, language and practices that have evolved to support our survival and development (e.g., Georgiou & Ioannou, 2019; Hostetter & Alibali, 2008; Johnson-Glenberg, 2018). From this perspective, knowledge is grounded on the experience(s) that we collect with our senses, mediated by our body. That is, action experience has a strong influence on the cognitive and neural processes and influences thought (Goldin-Meadow & Beilock, 2010) and memory (Ianì, 2019).

Driven by an embodied view of human cognition, educational technologists and learning scientists are striving to design learning experiences that promote multisensory processing, using technology as well as tangibles and manipulatives. A large spectrum of technologies based on novel interaction modalities—ranging from multi-touch to virtual reality—have been developed to enrich these learning experiences. These technologies aim to promote sensory engagement by offering new opportunities for physically interacting with objects and digital representations, foregrounding the role of the body in interaction and learning. Currently, virtual reality (VR) appears to be the most prominent tool in enabling embodied learning. The increase in commercial VR technologies, which are both affordable and immersive, in combination with a growing availability of virtual content, provides new possibilities to introduce VR into schools and other educational institutions (Johnson-Glenberg, 2018).

This study adopts "Instructional Embodiment Framework" (IEF) proposed by Black, Segal, Vitale, and Fadjo (2012). Based on IEF, instructional embodiment is composed of two main categories -- physical and imagined embodiment. A physical embodiment may be "direct," "surrogate," or "augmented." "Direct embodiment" is achieved when the user moves in a certain way in a physical space, while "surrogate embodiment" applies when the user gives instructions to a programme. Other researchers describe this as a "manipulated form of embodiment", referring to the use of physical objects such as tangibles and manipulatives that allow for the learning of concepts to be directly embedded into the physical material of the object, as well as through the embodied interactions learners have by manipulating these objects (Minocha, Tudor, & Tilling, 2017; Pouw, Van Gog, & Paas, 2014; Price, Sheridan, Pontual Falcao, & Roussos, 2008)."Augmented Embodiment" refers to the use of a representational system, such as an avatar, in conjunction with an augmented feedback system (such as Microsoft's Kinect and display system) to embed the embodied learner within an augmented representational system. In addition to the physical embodiment, an individual also embodies action and perception through imagination. Imagined embodiment is characterized as the mental simulation of physically embodied action (Black et al., 2012).

There is evidence that technology-enhanced embodied learning can have a positive impact on at least one of the three domains of learning: (a) Cognitive domain, (b) Affective domain, and (c) Psychomotor domain. A number of studies reported an increase in students' conceptual knowledge on a variety of topics related to mathematics (e.g., Arroyo, Micciollo, Casano, Ottmar, Hulse, & Rodrigo, 2017; Alibali, & Nathan, 2012), biology (e.g., Andrade, Danish, & Maltese, 2017), chemistry (e.g., Tolentino, Birchfield, Megowan-Romanowicz, Johnson-Glenberg, Kelliher, & Martinez, 2009), physics (e.g., Enyedy, Danish, Delacruz, & Kumar, 2012) or language learning (e.g., Hsiao, & Chen, 2016; Kosmas, Ioannou, & Zaphiris, 2018). Recent research has shown benefits in terms of knowledge retention as delay test indicated (e.g., Kuo, Hsu, Fang, & Chen, 2014; Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014). A number of studies yield students' engagement with the learning process (e.g., Ibánez & Wang, 2015; Ioannou, Georgiou, Ioannou, & Johnson-Glenberg, 2019; Lindgren, Tscholl, Wang, & Johnson, 2016; Tolentino et al., 2009) as well as on students' increase of motivation for participation in the task (e.g., Georgiou, Ioannou, & Ioannou, 2019; Hwang, Shih, Yeh, Chou, Ma, & Sommool, 2014; Yang, Chen, & Jeng, 2012). The richer the perceptual environment using multiple sensory modalities (e.g., using visuals, voiceovers, and movement) during initial learning the better the student learning, understanding and motivation (Han & Black, 2011). Yet, the enactment of embodied learning in a classroom setting nevertheless increases the complexity of the teaching and learning experience. The educational system has yet to develop a clear vision or learning design models that would guide the implementation of embodied learning using digital technologies and manipulatives. As argued by Ioannou, Ioannou, Georgiou, and Retalis (2020) and Johnson-Glenberg (2019), when it comes to the real-word application of emerging technologies and pedagogies, empirical studies at the crossroads of technology, design and pedagogy are lacking.

This is an investigation of a technology-enhanced embodied learning experience in the classroom. The enactment of embodied learning aims to help better build this embodied experience for better understanding of the historical information, for current learning or subsequent learning, which is conventionally based on verbal or textual input. The study is part of a larger design-based research project on technology integration for embodied learning which aims to inform the current educational practice in real-world classrooms. We begin by presenting an example of a learning design for technology-enhanced embodied learning in an authentic classroom. Three forms of physical embodiment (direct, surrogate, and augmented) are enacted in the classroom and an orchestration strategy is applied, informed by previous empirical work (Ioannou, Ioannou, Georgiou, & Retalis, 2020). The study goes on to the evaluation of the technology-enhanced embodied learning experience from the perspective of the learners.

The research questions of the study are:

- Did the students experience learning gains?
- What were their perceptions of the technology-enhanced embodied learning experience?

2. Learning design

2.1. Context

This study takes place in a multidisciplinary lesson around historical information. We employ a variety of activities with technologies (virtual reality, robot programming, tablets) each harnessing the power of embodied learning according to Black et al. (2012) IEF framework. The students engage in a virtual field trip, programme the Bee-bot, and create storyboards. The idea of expanding the curricular space by integrating technology in existing course units, thus allowing the development of problem solving and teamwork skills together with domain knowledge, is not new (Ioannou, Socratous, & Nikolaedou, 2018).

2.2. The Learning Station Rotation Model

Our previous work informed our 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: a 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 in 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 1 for the Learning Station Rotation Model adapted in this study.

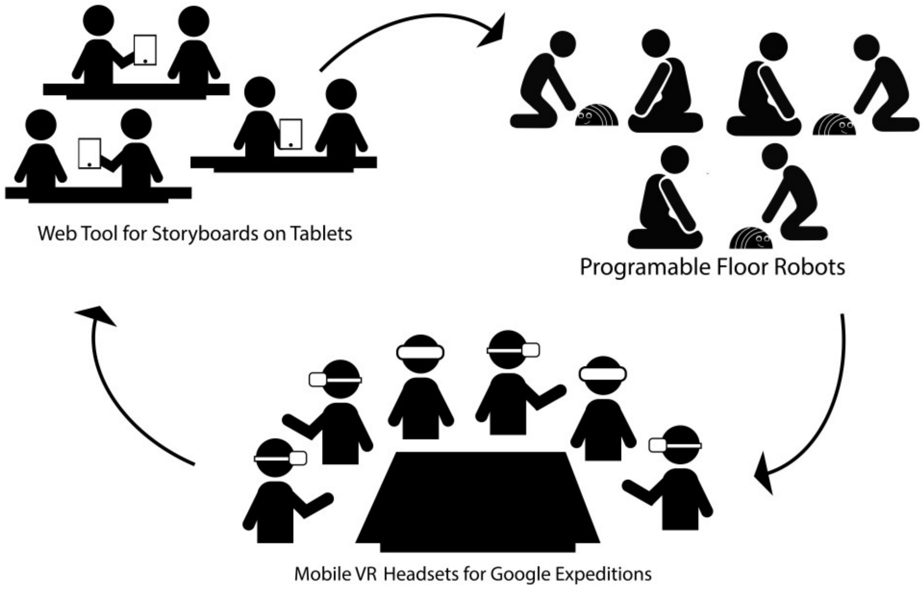

Figure 1. Learning Station Rotation Model

2.2.1. 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 (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 360VR 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 remains of Archaic kingdoms.

In the VR preproduction phase, we specified the teaching and learning goals and storyboarded the guided tour for each site based on historical information. In the postproduction 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 smartphone 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 3 on how Google Expeditions works and Figure 2 for screenshots from the virtual tours.

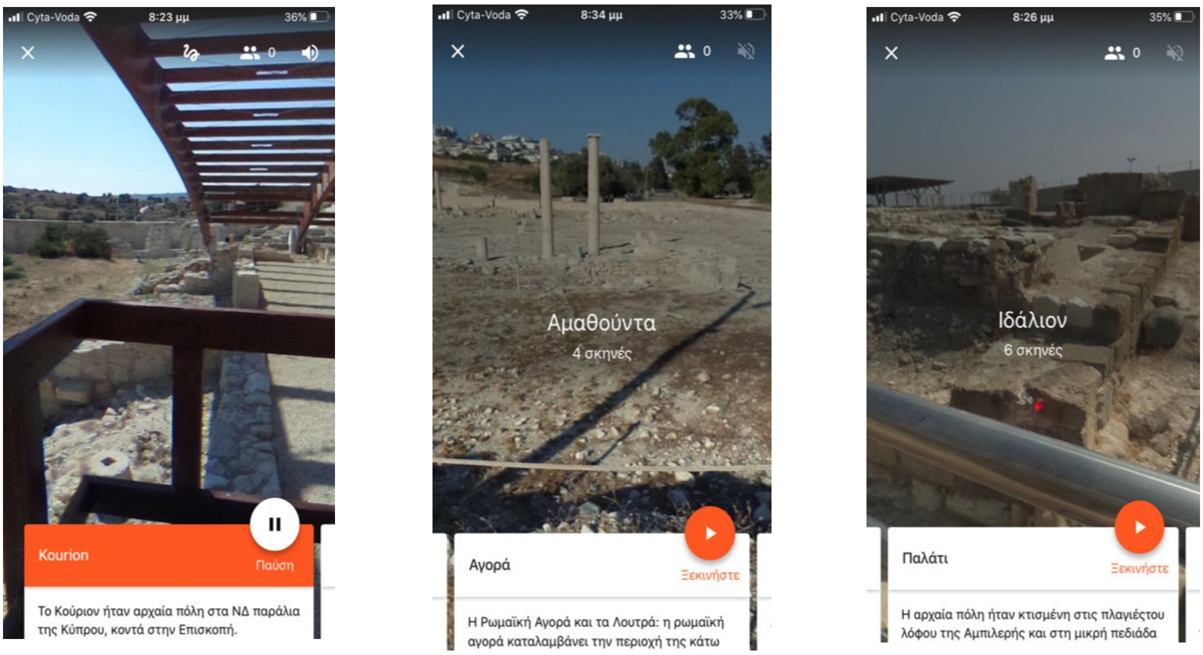

Figure 2. Google Expeditions – screenshots from virtual tours of Kourion, Amathus, and Idalion

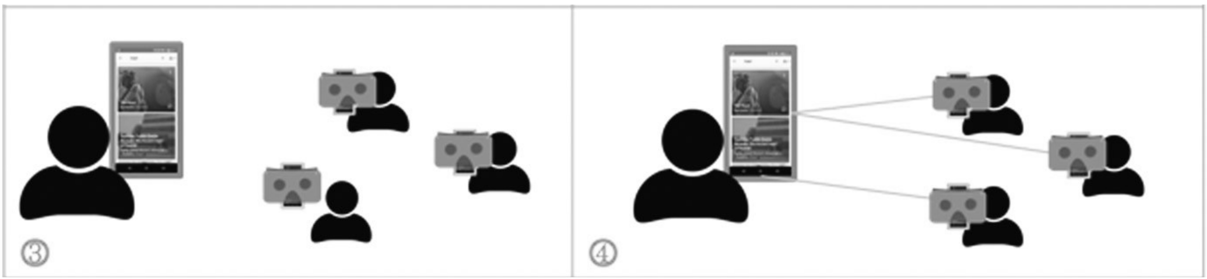

Figure 3. Google Expeditions – How it works with students as explorers and the teacher as a guide

Figure 4. 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 Figures 3 and 4).

2.2.2. Station 2 – Programmable floor robots

Physical tools such as tangibles (e.g., robots) are used in our embodied learning activities e.g., learning to programme (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. (2012) IEF framework the embodiment through manipulative falls into the category of "surrogate embodiment" which is 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 programme 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 flash cards, understand the description, then programme the Bee-bot to get to the image of the respective occupation on the paper mat. Students at station 2 worked in pairs (Figure 5). Understanding the occupation was not straightforward and required discussion and agreement between the teammates.

Figure 5. Station 2- Programmable floor robots

2.2.3. 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. Touch use 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 6).

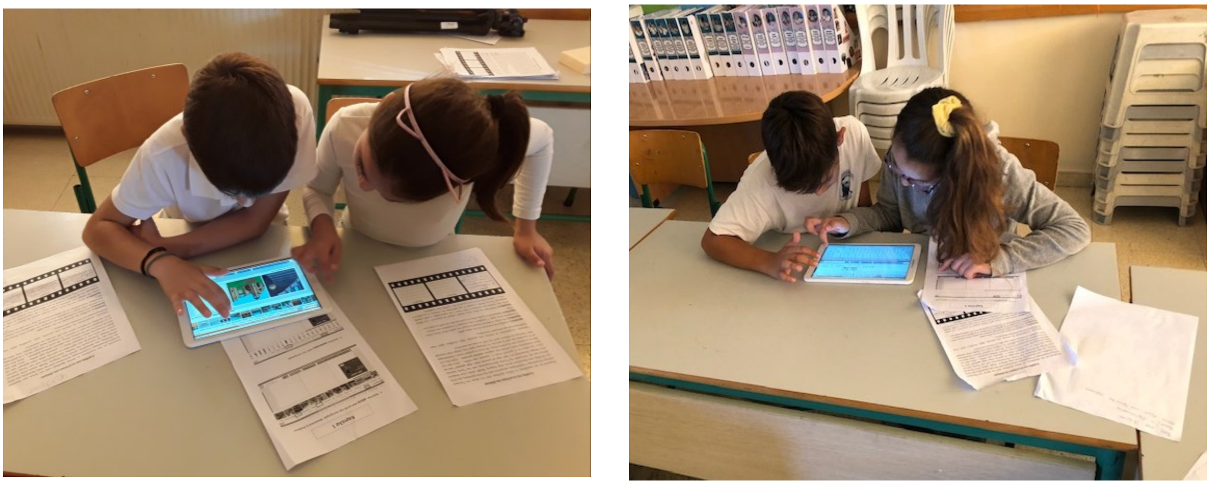

Figure 6. Station 3- Using tablets to create storyboards

3. Methodology

3.1. Research design

This study is part of a broader design-based project investigating the design of technology-enhanced learning settings grounded on embodied cognition theories, which involve orchestration of learning activities in a real classroom setting. The case study uses a mixed method approach to data collection and analysis. According to Creswell and Plano Clark (2011), collecting, analysing and mixing both quantitative and qualitative data in a single study can provide a better understanding of the research question under investigation.

3.2. Participants

The participants were Year 4 students (N = 34, 8-9-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).

3.3. The 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 relationship. The intervention started with the teacher briefly presenting the classroom setup and the task 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 the programmable floor robots (Bee-bots). At station 3, the students used tablets to create storyboards. See Figures 4-6 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 and following the intervention.

4. Date collection and analysis

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

4.1. 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.

4.2. 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.

4.3. 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.

5. Findings

5.1. 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 a large effect size ($d = 1.43$). Table 1 present 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 1. 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. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

5.2. 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.

5.3. 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.

5.3.1. Relationships

Students reported on 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 flash card 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]

5.3.2. 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 Archaic kingdoms where 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 the learn this way. [Girl2 - focus group 1]

> I liked the Bee-bot station because I had to think about how to programme the Bee-bot robot to move in a certain way. We had to read the flash card 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 dialogues 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 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 learning. [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 taking a school trip to an archaeological site. It was so much more fun than a typical lesson or even actually 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]

5.3.3. 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 this had a positive impact on their learning. Participants reported that they were surprised by how immersed they felt within 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]

6. Discussion and implications

This study aimed to investigate a technology-enhanced embodied learning experience in multidisciplinary lesson around historical information. We presented an example of a learning design enacting three forms of physical embodiment (direct, surrogate, and augmented) in the classroom, using a model of rotating across learning stations, orchestrated by a single educator. 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." As part of a larger design-based research project, this study aimed to inform the current educational practice on technology-enhanced embodied learning in real-world classrooms. 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 fueled 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 interest 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; Slater, 1999). 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, 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 aimed to help better build this embodied experience for 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 artefacts. 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 long journey. Today's affordable motion-sensing input devices, together with freely available apps such as Google Expeditions, 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.

In this study we used affordable learning technologies enriched with content that is aligned with the national educational curriculum. We aimed to combine the physical and the 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 (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 for station 2; they would have preferred to have 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. The negative feedback from the focus groups concerning the VR's single-player mode will guide the next stage of this design-based research. First, in future work we aim to capitalise on the design for collaboration around embodied learning technologies that do not naturally encourage collaboration (e.g., VR single-user mode). Collaborative embodiment in technology-enhanced interventions has not been discussed in the literature; relevant work will help to address the development of pedagogical strategies that involve groups of students in technology-enhanced embodied learning. Finally, in the next study, we would aim to investigate the long-term retention of knowledge from this experience, ideally in comparison to some control group receiving traditional teaching on the same lesson. Closing, this study mostly relied on self- reported and retrospective measures. Future study could use in situ measurements (e.g., observation protocols, field notes and log files) for investigating how the learning process unfolds in a technology-enhanced embodied learning intervention such as the one presented here.

7. Conclusion

This study aimed to investigate a technology-enhanced embodied learning experience in a multidisciplinary lesson around historical information. We presented an example of a learning design for technology-enhanced embodied learning in an authentic classroom. Data from 34 students demonstrated learning gains as well as positive perceptions of the learning experiences in terms of "Relationship," "Personal development" and "System maintenance and change." With this study, we aim to spark a dialogue on the successful enactment of technology-enhanced embodied learning in the classroom, highlighting the need to consider more studies at the intersection of technology, design and pedagogy. Technologies enabling embodied interactions continue to offer an enormous range of opportunities and thus deserve major consideration and investigation on how they can be applied in the context of mainstream classrooms.

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