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Exploring educational immersive videogames: an empirical study with a 3D multimodal interaction prototype

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ABSTRACT

Gestural interaction devices emerged and originated various studies on multimodal human–computer interaction to improve user experience (UX). However, there is a knowledge gap regarding the use of these devices to enhance learning. We present an exploratory study which analysed the UX with a multimodal immersive videogame prototype, based on a Portuguese historical/cultural episode. Evaluation tests took place in high school environments and public videogaming events. Two users would be present simultaneously in the same virtual reality (VR) environment: one as the helmsman aboard Vasco da Gama's fifteenth-century Portuguese ship and the other as the mythical Adamastor stone giant at the Cape of Good Hope. The helmsman player wore a VR headset to explore the environment, whereas the giant player used body motion to control the giant, and observed results on a screen, with no headset. This allowed a preliminary characterisation of UX, identifying challenges and potential use of these devices in multi-user virtual learning contexts. We also discuss the combined use of such devices, towards future development of similar systems, and its implications on learning improvement through multimodal human–computer interaction.

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Multimodal interaction; user experience; digital game-based learning; virtual reality; gesture interaction; augmented reality

1. Introduction

We are witnessing an outburst of new low-cost gestural interaction devices for the so-called natural user interfaces (NUI). However, there is a knowledge gap about the experience of using these devices. The assumption that their interaction is natural has been challenged, exposing the high levels of artificiality it entails (Malizia and Bellucci 2012). Consequently, there is scarce empirical basis for recommending ways to design, plan, specify, and implement systems that embrace somatic interaction, be it through gestures, large body movements, or a combination of both. Hence, there is also a lack of empirical studies within the scientific field of learning, gathering, and analysing data from the user's perspective: acceptability, interest, and motivation to learn using multimodal environments.

We undertook exploratory case studies using the 'Primeira Armada da Índia' videogame prototype, whose research objective was to increase the understanding of how different forms of interaction relate to learning and how they influence students' engagement and interest with a virtual reality (VR) environment. Among secondary and high school students, teachers and videogame experts, 437 users took part and six testing sessions were conducted, which aimed to characterise the user experience (UX) of two players: Helmsman and Giant. The UX data collection procedure known as co-discovery (Kemp and Gelderen 1996) was adopted: two users discussed and explored the prototype simultaneously, mediated by the researcher (Holzinger 2005; Yogasara et al. 2011b). This method was applied in an unstructured form. Despite mediation and small tips on the use of devices, users could explore freely in an open space, following their instincts and free will, unable to predict interaction outcome between them.

The remainder of this paper is organised as follows: Section 2 presents an overview of UX, multimodal human–computer interaction and digital game-based learning (DGBL); Section 3 addresses related empirical case studies, namely, motion-based devices, VR and augmented reality (AR); Section 4 describes the early stages of the developed prototype and adopted devices; Section 5 details the methodology used to conduct the case study; the results of the study are presented in Section 6; Section 7 discusses the outcomes between this study and related

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published studies; finally, some thoughts, limitations and future work are presented.

2. Background

2.1. User experience

UX comprises all aspects regarding end-user interaction with a product or an interactive system (Law et al. 2009; Nielsen and Norman 2015). It is dynamic and related to users' emotions, beliefs, preferences, behaviours, and more that occurs before, during, and after the use of a product (Hassenzahl 2008; Law et al. 2009; DIS, ISO 2010), and is further related to project features and the context in which the interaction takes place (Hassenzahl and Tractinsky 2006). Therefore, it is important to assess UX systematically during all development stages.

Although the literature provides plenty of UX evaluation methods, few can be adopted to evaluate projects in their early stages, and there is a lack of effective multi-method approaches (Vermeeren et al. 2010). The palette thins further when focusing on multimodal interfaces (Bargas-Avila and Hornbæk 2011; Wechsung 2014). Co-discovery (Zimmerman, Forlizzi, and Evenson 2007; Yogasara et al. 2011b), also known as constructive interaction (O'Malley, Draper, and Riley 1984), is one of the few methods available. It consists of the involvement of two participants (preferably friends), in exploration and simultaneous discussion of a prototype, while the researcher observes and gives necessary inputs (Jordan 2002). Co-experience contributes to a holistic perspective of UX in its social context, through the construction of meaning and emotions between users using a system/product (Forlizzi and Battarbee 2004).

Within an educational perspective, learning experience is the UX with an e-learning system or a platform (Shi 2014). It goes beyond traditional usability evaluation, concerned with effectiveness, efficiency, and satisfaction of the learner performing a task, and is also related to hedonic aspects of using the technology, such as students' engagement, serendipity, and enjoyability. Despite recent interest towards UX by instructional designers, some questions remain unanswered (Pribeanu 2013): which technological features do students wish? Which attributes better support their engagement? These questions are explored throughout this study, as an attempt to contribute to the field.

2.2. Multimodal human–computer interaction

There is a growing research effort to leverage human communication skills through speech, gestures, facial expressions, and other communication modalities of interactive systems (Turk 2014), since human interaction with the world is inherently multimodal (Quek et al. 2002). Research goals in this field are the development of technologies, interaction methods, and interfaces that employ and combine senses towards more natural interaction by users.

Today, saying 'natural' (in contexts such as NUI) is about highlighting the contrast with classical computer interfaces that employ control devices whose operational gestures do not map directly to intended operations (Malizia and Bellucci 2012). Norman claims that NUI are not natural at all: they do not follow the basic principles of interaction design (Norman 2010). Gesticulating is natural and innate, but gestural interfaces are based upon a set of predefined gestural commands that must be learned just as classical ones. Morgado (2014) proposed that somatic commands leverage users' individual/social cultural backgrounds due to this conflict.

Multimodal human–computer interaction addresses these obstacles by selecting gestures or gestural emblems that have a somewhat widespread meaning across cultures, attempting to minimise critical failures. This has acquired special relevance with the appearance of low-cost somatic interaction devices such as Wii Remote,[1] Leap Motion,[2] Parallax,[3] Myo Gesture,[4] EyeToy,[5] and Microsoft Kinect.[6] Likewise, VR and AR experience a resurgence via low-cost immersive headsets (e.g. Google Cardboard,[7] Vuzix iWear,[8] and Oculus Rift[9]) or AR glasses (e.g. Google Glass,[10] Meta Glasses,[11] and Microsoft HoloLens[12]). The creation and exploration of new multimodal techniques and applications towards more natural interaction are thus an opportunity – its combination in particular, since most systems only integrate two modalities, such as speech alongside touch or visual gestures (Turk 2014).

These concepts have also been applied to education and e-learning, in support of a wider variety of student preferences and interests (Sankey, Birch, and Gardiner 2011), specifically through the development of interactive multimodal learning environments, such as 3D virtual worlds and social media, using verbal and non-verbal modes to represent content knowledge (Moreno and Mayer 2007). The use of these environments has been shown to enhance learning, rendered more flexible, self-oriented, and enjoyable (Birch 2008; Picciano 2009).

2.3. Digital game-based learning

DGBL is defined by Prensky (2001) as the development and use of computer games for educational purposes. Despite convictions about the potential of games and their progress, disappointingly DGBL mostly focuses on knowledge acquisition (Boyle et al. 2015), rather than identified potential for higher-order relationships with knowledge (e.g. Gee 2003). Nevertheless, research has demonstrated their positive learning outcomes (Connolly et al. 2012), for example, students' engagement (Wang and Chang 2010), motivation (Dickey 2011), achievement (Jui-Mei et al. 2011; Hamari et al. 2016), and behaviour change (Greitemeyer 2013), among others.

DGBL involves complex learning environments, where players can easily become weary or disoriented with the amount and multimodality of information. The role of teachers/tutors becomes crucial and demanding. To diminish the cognitive effort, players require appropriate guidance and support through meticulous selection of information (Wouters and van Oostendorp 2013). Players' actions usually result in game environment changes, which can lead to intuitive learning: results achieved without knowing how to explain or integrate them with prior knowledge (Ausubel, Novak, and Hanesian 1968).

Despite the growing understanding of game characteristics related to greater engagement and learning outcomes, there is much to discover (Boyle et al. 2015). It is important to remember that game development for learning is a convoluted process which can imply large costs, requiring more field studies that systematically explore and map characteristics to foster students' engagement and learning.

3. Related work

3.1. Motion-based devices

Research suggests that gestural interaction enhances learning: a 2011 report pointed out gesture-based computing as an emergent technology likely to influence education in the near future, supporting new forms of interaction, expression, and activity (Johnson et al. 2011). We provide some of the various studies in this field as examples.

Li et al. (2012) conducted a study with three autistic students for sensory integration training that explored the effects of applying game-based learning to webcam motion sensor games, concluding that the need for abstract thinking was reduced and the level of participation increased. A similar study was carried out with 39 college students by Lee et al. (2012) to explore the effects of using Kinect to improve learning performance, showing that embodied interactions make learners feel more motivated and engaged, and observation of colleagues' performances contributes to adjust everyone else's.

Cassola et al. (2014) presented the Online-Gym system, which captures gymnastics movements of several users concurrently using a Kinect per user, and relays them remotely, allowing users to see everyone within the same virtual world environment, dropping skeletal frames of slower connections for stabilising the quality of service.

Ibánez and Wang (2015) studied 57 elementary school students using a Kinect motion-based educational game for learning about recycling, concluding that the multiplayer game mode positively affected students' learning motivation and engagement.

Perdana (2014) used Leap Motion to develop an alternative method for teaching children music and performance, concluding that there is no ideal motion recognition music-based application, and criticising Leap Motion's low range and lack of accuracy (Potter, Araullo, and Carter 2013).

3.2. Virtual reality

VR in learning/training has a long history (Freina and Ott 2015), especially when physical-world experience is hard or impossible due to limitations such as time, inaccessibility (Detlefsen 2014), danger (Williams-Bell et al. 2015), or ethics (Liu and Curet 2015).

According to Bastiaens, Wood, and Reiners (2014), modern game development engines (e.g. Unity3D and Unreal Engine 4) together with headsets (e.g. Oculus Rift and HTC Vive) can improve authentic learning and high-fidelity virtual environments, and therefore support education. Reiners et al. (2014) also agrees on Oculus' role of authenticity and emotion as a way to aid learning inside immersive virtual environments: applied in the operations and supply chain industry, it can improve safety, security, and sensibility of classroom visitors in more realistic virtually mediated scenarios. After conducting a study with nine intellectually impaired adults and comparing desktop-based VR, where objects are purely seen as images, with immersive environments, Freina and Canessa (2015) concluded that the latter can better train spatial skills since objects are rather perceived as real objects.

Hupont et al. (2015) compared how Oculus impacts gaming quality of experience vs. conventional 2D computer screens. With a sample of 22 users, they report that Oculus increases amazement, astonishment, and excitement, as well as their sense of presence, realism, and naturalness in the exploration and navigation within the 3D environment. Several researchers (Polcar and Horejsi 2013; Llorach, Evans, and Blat 2014; Treleaven et al. 2015) demonstrated the severity of cybersickness symptoms (e.g. nausea and disorientation) when using

Oculus for locomotion tasks within VR. Similarly, Davis, Nesbitt, and Nalivaiko (2014) conclude that such symptoms require more targeted and effective measures to address cybersickness's impact on people's physical condition.

3.3. Augmented reality

AR has been widely adopted for learning and training, especially with mobile applications enabling ubiquitous, collaborative, and situated learning (Wu et al. 2012; Yilmaz 2011). Bringing computation to our personal space may improve the educational activity (Mann and Hrelja 2013). Its benefits are also identified in multiple studies, such as learning content in 3D perspectives (Chen et al. 2011), learning motivation (Di Serio, Ibáñez, and Kloos 2013), spatial ability and engagement (Bujak et al. 2013), and creativity (Yuen, Yaoyuneyong, and Johnson 2011), among others.

Figueiredo (2015) describes several educational activities for teaching mathematics using AR tools that do not require any programming while shaping learning into a more interactive process. He suggests that using AR interactive materials can be motivating and contribute to broaden the class into a VR environment where students can spend more time practising problem-solving. Restivo et al. (2014) also used an AR system to teach direct current circuit fundamentals to students, increasing their motivation by fostering their interest in the use of technologies. Still within Physics education, Barma et al. (2015) developed a serious game based on an interactive mobile AR solution to teach electromagnetism to college students, finding that AR significantly helps visualise the physical phenomenon in 3D, providing a concrete representation of an abstract situation that is not otherwise easily accessible.

Morgado (2015) analyses Google's Ingress alternative reality game and extracts suggestions for the educational application of its dynamics using multi-user participation, location-aware mechanics, and reinterpretation of the physical reality around the users, should an Ingress game development application programming interface become available. Leue, Jung, and Dieck (2015) assessed how Google Glass enhanced visitors' learning outcomes within an art gallery environment. With a sample of 22 participants, they revealed that this device helped visitors see connections and enhanced their knowledge and understanding of paintings. Google Glass has been used experimentally, with some high-profile cases in medical education and surgery intervention (Aungst and Lewis 2015). However, its high power consumption, low battery capacity, and heating are disadvantages, especially if deploying in healthcare, where issues such as hygiene, data protection, and privacy need to be addressed and are currently limiting chances for professional use (Albrecht et al. 2013).

4. The 'Primeira Armada da Índia' prototype

'Primeira Armada da Índia' (or 'First Fleet of India') is a videogame prototype, described in a previous paper (Morgado, Cristóvão, et al. 2015). It was inspired by the recent celebration of the 800 years of the Portuguese language and thus named after the fleet of Vasco da Gama, a renowned Portuguese navigator from the fifteenth century. The presented prototype depicts an episode later described in the sixteenth century by Luís Vaz de Camões in his epic poem 'Os Lusíadas' ('The Lusiads'), where a Portuguese ship from the Age of Discovery is approaching the Cape of Good Hope and faces the mythical stone giant Adamastor, who tries to prevent the ship from crossing from the Atlantic Ocean to the Indian Ocean (Camões 1997). The prototype, developed using Unity3D, consists of the Helmsman (Player 1) of Vasco da Gama's ship and the Adamastor giant (Player 2), facing each other in a VR world (cf. Figure 1). In its early stages, in the version used in the first two case studies, Player 1 used Oculus Rift DK2 to immerse in the ship rear deck and freely observe the richness of the scenery in 360°: the ship, the sea, and the Adamastor

Figure 1. 3D conceptual model and in-game environment.

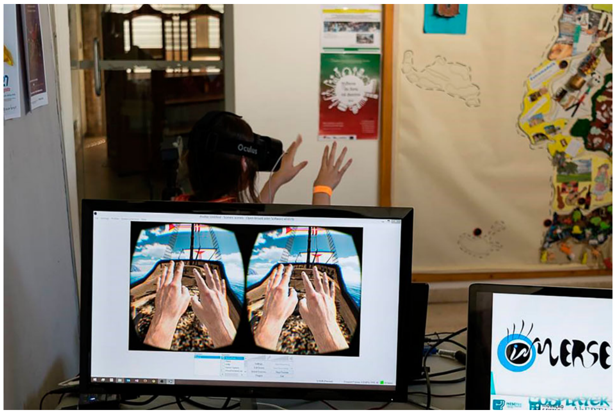

Figure 2. Public demonstration of the prototype.

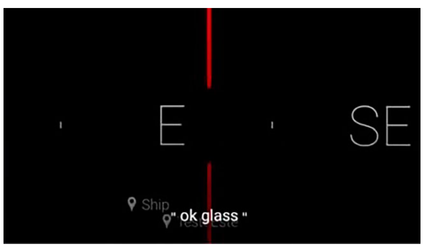

Figure 3. Player 2's point of view.

giant. The latter was able to move his torso and arms according to Player 2's body movements captured by Microsoft Kinect 2, using a Unity package developed by Filkov (2014).

In an attempt to improve the overall experience, the current prototype has a more realistic ocean (Bruneton, Neyret, and Holzschuch 2010) and integrates more devices, increasing interaction possibilities. Player 1 can now listen to the 3D sound of seagulls and waves, and uses Oculus with a Leap Motion attached, to immerse in the VR deck. The addition of Leap Motion enabled users to see a representation of their hands (cf. Figure 2), increasing their sense of presence in the virtual world.

Player 2, on the other hand, does not use a headset in spite of Adamastor being stranded on the Cape of Good Hope within the VR world. Player 2, while controlling Adamastor's torso and arms through body movements detected by Kinect, uses Google Glass to access contextual information such as the current position of the ship in the virtual world and to consequently be able to throw rocks in the desired direction by doing a throw gesture in front of the Kinect (cf. Figure 3).

5. Methodology

Six exploratory case studies were conducted to evaluate UX in the 'Primeira Armada da Índia' prototype and its potential in education. Altogether, 437 users participated in these studies, ages ranging between 14 and 60 years old. During each of the sessions, two or three researchers mediated users' interaction. The studies (cf. Table 1) took place in educational events in schools and in videogames/VR meetings in Portugal.

We adopted the co-discovery UX assessment method as mentioned earlier (Kemp and Gelderen 1996), where two students play together and their interaction is mediated by researchers (Holzinger 2005; Yogasara et al. 2011a). Data were collected through participant observation (Nardi 1997; Delamont 2004; Arnould, Price, and Moisio 2006) and questionnaires. Researchers' mediation was in the interest of guiding, observing, describing, and analysing the interactions between the users while playing 'Primeira Armada da Índia'. The

Table 1. Exploratory case studies summary.

Study ID	Local/event	Users	Profile	Total duration (hours)	Duration per user (minutes)	Ages interval	Prototype version	Data collection
S1	Sicó vocational training school – science and entrepreneurship week	72	Students	6	10	14–17	Alpha	Participatory observation
S2	S. Pedro High School – information session on college-level science and technology programmes	36	Students and teachers	3	7	14–55	Alpha	Observation grid
S3	Manga & Comic Event 2015	137	Teenagers and adults	16	7	13–52	Beta	Participatory observation and questionnaire
S4	Microsoft Game Dev Camp 2015	113	Students, videogame experts and academics	12	6	18–60	Beta	Participatory observation and questionnaire
S5	Portugal Virtual Reality Meetup 2015	18	VR experts	3	10	20–40	Beta	Participatory observation and questionnaire
S6	UTAD – science and technology week	61	Students and teachers	6	6	14–50	Beta	Participatory observation and questionnaire

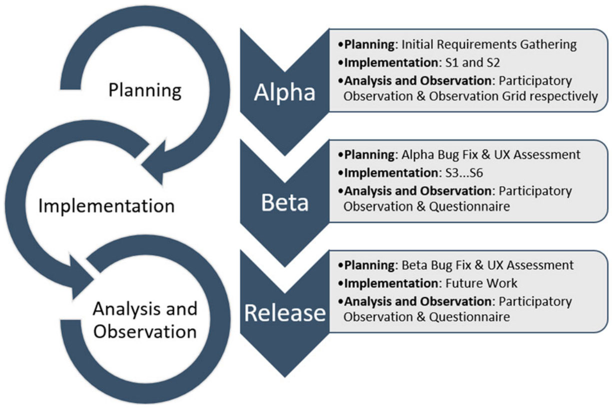

Figure 4. Research model adopted throughout the studies.

questionnaire was based on the analysis of the first study (Fernandes et al. 2015) and adopted from the second study onwards to quantify the participants' opinions and beliefs as well as the incidence of some identified physical sensations. Answers to the questionnaires were also confronted with the descriptions made by the researchers from their observations. Throughout the case studies, a three-phase cycle research model was followed: planning, implementation, analysis, and observation. The alpha prototype, used in studies S1 and S2, served as support for the Beta and subsequent studies (cf. Figure 4).

All UX assessments were carried out in a mobile laboratory due to the fact that the studies took place in different contexts. Laboratory studies are widely used to assess the UX in the early stages of the development of a product or in exploratory studies (Roto, Obrist, and Väänänen-Vainio-Mattila 2009). Our laboratory was set up with the following devices: a laptop, an Oculus DK2, a Leap Motion, a Kinect 2, a Google Glass, and a WiFi Access Point. The videogame ran on the laptop where the Oculus Rift and its attached Leap Motion were connected for Player 1. Kinect 2 was also connected to the laptop, but physically distant from it. Its location was chosen considering that it had to face one of the main cardinal points (to match Glass' cues) and capture Player 2's movements. Player 2 also wore Google Glass, connected to the laptop wirelessly via the WiFi Access Point.

6. Findings

All case studies followed similar design principles and method, so we combined their data into a single dataset. We then classified the results into two main categories of analysis based on each player role: Helmsman and Adamastor. In each category, we present the data related to the users' preferences, and physical and psychological responses.

6.1. Helmsman player (Oculus Rift + Leap Motion)

In general, the majority of the users involved in the case studies gave very positive feedback and stated their interest in the prototype, particularly in the Beta version, where new elements were introduced, such as 3D sound, a more realistic ocean, and Leap Motion for hands' detection.

Although in the first two case studies (S1 and S2), with the early version of the prototype, some students reported symptoms related to cybersickness, their proportion tends to decrease substantially as the sample size increases.

These symptoms were felt occasionally – only 3.9% users reported them (17 out of 437) – and had minimal impact on the subsequent experience of the players, which proceeded with the exploration of the virtual environment regardless. In an attempt to overcome such symptoms, some players would squeeze the headset, adjusting it to their head.

A minority complained about the low environment resolution in Oculus Rift (15.1% – 66 out of 437), but from S3 onwards many users reported the lack of precision of the Leap Motion (31.3% – 103 out of 329). Nevertheless, a considerable amount of users delved into the environment, looking at every detail of the ship, ocean, sky, rocks, and Adamastor giant. So extensive was this that most would attempt to touch the ship and other virtual objects (70.5% – 232 out of 329), even trying to touch the floor of the physical space. Some other inquisitive situations include stretching the arms to reach Adamastor, even though he was visually far from the ship within the virtual environment; some colleagues of the helmsman's players would wiggle their hands to produce air flow, making the player assume that wind was coming from the virtual environment; some users sensed the crashing waves and revealed their craving to row after the 3D sound inclusion (also from S3 onwards); and a user reported some bad smell within the ship.

The sense of presence and immersion in the environment was felt gradually, eventually growing after enabling hands visualisation through Leap Motion and consequently arousing greater curiosity and expectations towards new interaction possibilities and control of the character. Prospects were now higher and, as a side effect, some users mentioned disappointment with not being able to stretch their necks to appreciate the outside of the ship, move freely, or even fire a cannon. As a negative aspect, some users – mainly females – complained about the big, hairy hands morphology, pointing out their lack of adaptability while mentioning its masculinity, as well as their inadequate size. Others would get distracted with the hands instead of searching for Adamastor, which hints at the need for guidance.

Emotions also played a meaningful role in the experiments. The majority of users were enthusiastic during the sessions (81.2% – 355 out of 437), laughing, shouting, and threatening Adamastor when he gesticulated, mainly because they were aware that a colleague was controlling its avatar from the physical space – some still asked to make sure.

Lastly, regarding the interaction with Adamastor, some students asked the giant to throw rocks at the ship, and a few became bewildered, losing their reference and not managing to locate him alone – some colleagues guided them, based on a monitor streaming Oculus' point of view (POV). Adamastor also revealed some issues, such as his arms behaving unnaturally and the low amplitude of his head movements.

6.2. Adamastor player (Kinect 2 + Google Glass)

Contrary to the Helmsman's player experience, a high number of users expressed less enthusiasm and acceptance towards the role of Adamastor, struggling over doing it. Notwithstanding, resistance decreased with the Beta version, where new components were combined, namely, a real-time compass application in Google Glass and being able to grab and throw rocks. Despite some interaction constraints and issues such as arms behaving unnaturally and the low amplitude of head movements, most users enjoyed their play experience, praising its potential and suggesting improvements and other scenarios.

Positioning the player's body accurately is imperative for this character, due to Kinect's image acquisition and subsequent interactions. Several users did not grasp how to do it (33.2% – 145 out of 437) and some (17% – 62 out of 365) started to gesticulate before the capture was active (not quantified in S1). Hesitancy of when or how to interact with the Helmsman player also occurred, thus the need to inquire if the behaviour was being displayed in the virtual world. Some would often turn to the other player rather than face Kinect, ceasing to control Adamastor. Such cases appear to leverage UX negatively, leading to disinterest and confusion during the experiments – especially in S1 where an extremely large dropout rate (94.4% – 68 out of 72) was verified. In this sense, factors such as users' and devices' physical placement, and mediator's role proved to be vital. This was validated through some modifications and interventions by our team of researchers in the subsequent studies (starting at S2). When S1 took place, the Helmsman players had their back turned on Adamastor players, and mediators purely provided minor technical instructions regarding devices' use. From that study onwards (until S6), mediators arranged the space in a way that players would face each other slightly diagonally, portrayed the scenario, and heartened players interaction. The aforementioned adjustments also led to a greater acceptance – no more dropouts – by Adamastor participants.

Bringing AR into the scene, with Google Glass (since S3), empowered more interaction: from locating the ship and rocks, as in a map (further visual feedback), to actually grabbing and throwing them through Kinect-detected gestures. However, new issues arose. On the one hand, the small font size of the compass (cf. Figure 3) and its constant need of calibration, along with its dearth of feedback due to the background noise, were a reason of complaint. On the other hand, a considerable number of users were incapable of using Google Glass due to hardware limitations (only 45.9% tried Google Glass – 151 out of 329), particularly its low battery life, rapid overheating, and timeouts. Moreover, the current game prototype forces users to execute movements and gestures in front of Kinect, while turning their head to locate the ship, resulting in a lack of coordination (38.4% – 58 out of 151).

In general, users tried to embody Adamastor and interpret the depicted episode by moving their arms and making peculiar sounds as an attempt to frighten their colleagues. These behaviours and forms of interaction provided amusing moments in the physical space, such as laughing from bystanders, which stimulated their cooperative participation through the suggestion of unique movements and gestures.

7. Discussion

Throughout this section, we discuss and confront the outcomes gathered in our study with other published studies in the field, as an attempt to further enhance the current knowledge regarding UX when employing multimodal educational videogames.

According to other research efforts using Oculus Rift (Polcar and Horejsi 2013; Treleaven et al. 2015), symptoms related to cybersickness episodes, such as nausea and headaches, were witnessed. This is a concern worth some consideration when developing further studies with the prototype. Possible explanations might include the duration of the exposure, the field of view size, and the interpupillary distance (IPD) (Llorach, Evans, and Blat 2014). Even though our average IPD is about 63 mm, its range may vary between 52 and 78 mm. While Oculus Rift's IPD is 63.5 mm, allowing adjustments exclusively within the virtual environment, users with an IPD far from the average will not see as much improvement as they would, should physical adjustments be made in the headset.

The prototype's level of immersion seems to relate to the interaction between the users and their surroundings, becoming a key issue to fully understand their experience (Blascovich and Bailenson 2006). Across studies, immersion was strengthened by multimodal characteristics, such as rolling of the ship (impression of sailing), 3D sound (impression of crashing waves and craving to row), and hand detection (impression of control and sense of presence). Together, they increase environment authenticity and users' enthusiasm and motivation, leading to immersion in the virtual world. However, such features can likewise negatively influence the learning process, resulting in users getting distracted and losing focus (Lim, Nonis, and Hedberg 2006). By the same token, and in accordance with our results, if users are accompanied by colleagues, immersion is lessened due to the perception of what is happening in the physical world surroundings. Despite some technical constraints, we concur with other researchers (Bastiaens, Wood, and Reiners 2014) that even though this kind of VR environments can strongly leverage authentic learning experiences, their development requires a multidisciplinary team with specific skill sets.

Being based on social interaction between players, this multiplayer videogame triggers emotions that further contribute to their interest and motivation: joy, satisfaction, delight, and enthusiasm. They echo the challenging (e.g. role-playing characters and performing predetermined tasks) and the puzzling (e.g. unknown cause-effect) within the videogame and its mechanics. Also, as in other studies (Ibánez and Wang 2015), we witnessed potential cases of situated learning: students collaboratively guided and helped participants to a solution when they were facing an obstacle (e.g. helping Adamastor position properly within the VR environment).

The mediator's role is indispensable to successfully use this kind of prototypes, especially in an educational context (Wouters and van Oostendorp 2013). The role is preponderant not only when designing a prototype, delineating and arranging the environment's information, and learning task proposals, but also in its implementation. In the latter phase, and going towards our study, using a computer screen to stream the users' POV proves to be convenient for managing the learning process, allowing the mediator to constantly be aware of players' sight and actions. In accordance to Freina and Canessa (2015), this allows the player's activity to be controlled (e.g. help focus on the learning tasks, guide them when stuck, or even stop the experience when revealing exhaustion or stress) and the motivation to be incited (e.g. encourage interaction when interest fades).

Finally, we consider that the choice and subsequent integration of a technology in this type of prototypes are something to bear in mind. It is critical to pre-assess its performance, as well as the aftermath of the UX. The experience should be flexible and self-oriented (Birch 2008; Picciano 2009), taking into account the preferences, characteristics, and specific needs of each user. In this sense, an architecture such as the one developed in the present prototype (Morgado, Cardoso, et al. 2015) seeks to adopt this principle, granting the user the choice of devices and interactions. Such prospects could also solve or lessen existing obstacles, particularly the dearth of coordination of the Adamastor player when using Google Glass and Kinect simultaneously, by replacing the current Kinect grab and throw gestures detection with Myo Gesture bracelets.

8. Final thoughts, limitations, and further work

In this work, we presented an empirical exploratory research with a high number of participants, employing a multimodal educational videogame prototype, where two users experienced and shared synchronously the same 3D virtual environment using distinct devices, something we find original in the field. Our goal was to assess the UX when using these technologies, while taking into account its feasible application and implications in education.

As final considerations, we can assert our conviction that the prototype exposes learning potential, facilitating entertaining, authentic, situated, and self-oriented experiences. We believe that it is mainly due to immersiveness, high fidelity, interaction, and flexibility offered by the prototype, ingredients for motivation and engagement from the users. Nevertheless, the relatively high cost associated with the aforementioned technologies and their limitations, particularly the need for a multidisciplinary development team, suggests that the massive adoption of such prototypes is not yet feasible or sustainable. Therefore, we consider that making technology available is not enough to enable these disruptive technologies to challenge the teaching and learning methods currently practised in our classrooms. It is imperative that the teams developing these scenarios yield the necessary support to both teachers and students so that they make the most out of their potential.

Due to its embryonic and exploratory phase, the presented study and observations make evidence of limitations of technological and methodological nature. Thus, it would be possible to gather a richer data analysis if these observations were made with a more explicit focus and instruments.

As future work, the development of the prototype will continue with the implementation of the remaining game mechanics (e.g. ship and a cannon control) and integration of technologies (e.g. Myo Gesture) that improve users' interaction. Moreover, new studies will be carried out to assess users' experience with every educational actor, to better understand the relationships between their profile and the interest shown in adopting these scenarios as facilitators of the learning process. Additionally, we would like to indicate what we consider to be a research agenda in the field: studies to identify quality standards for the widespread adoption of these VR environments by educational institutions; to assess the potential of these VR environments for collaborative learning; to evaluate the impact of these VR environments in students' motivation and engagement for learning; to develop new tools and guidelines for teachers in the design and delivery of VR learning scenarios; and to integrate these devices in a facilitated and transparent manner. Finally, and based on our findings and their implications, we list some recommendations for further research development and application of these VR environments in education:

- Creation of a multidisciplinary team to develop learning scenarios (e.g. 3D modeller, developer, instructional designer, and teaching staff);
- Adequacy of the interaction devices to the instructional design process, taking into account different learning objectives, activities, and desired outcomes;
- Selection of a flexible and adaptable development method to different application scenarios taking into account the integration of new devices, UX improvements, and interoperability (e.g. Learning Management Systems – LMS); and
- Adequacy of the research method to different application scenarios (e.g. layout of the physical environment, mediator's role, device configuration, and data collection tools).

Notes

1. http://www.nintendo.com/wiiu/accessories.
2. https://leapmotion.com/.
3. https://parallax.com/product/28046.
4. https://thalmic.com/myo/.
5. http://us.playstation.com/ps2/accessories/eyetoy-usb-camera-ps2.html.
6. https://microsoft.com/en-us/kinectforwindows/.
7. https://google.com/cardboard/.
8. http://vuzix.com/UKSITE/consumer/products_vr920.html.
9. https://www.oculus.com/en-us/.
10. https://developers.google.com/glass/.
11. https://www.metavision.com/.
12. https://www.microsoft.com/microsoft-hololens/en-us.

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