Cyprus University of Technology
Faculty of Communication & Media Studies

Doctoral Dissertation

INVESTIGATING IMMERSION IN RELATION TO SCIENCE LEARNING IN LOCATION-BASED AUGMENTED REALITY SETTINGS

Yiannis Georgiou

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CYPRUS UNIVERSITY OF TECHNOLOGY

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APPROVAL FORM

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I would like to dedicate this dissertation to my wife, whose love and support was my shield during this battle… to my son, for being my inner power… and to my parents, who taught me how to fight for conquering my goals and dreams!

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ABSTRACT

Immersion, which can be defined as a multi-level continuum of cognitive and emotional involvement, has been argued to facilitate science learning in technology-rich environments. Nonetheless, empirical evidence is often contradictory; this may be partially attributed to the effects of students' individual differences and cognitive load. To-date, there is scant research investigating the relationship between immersion and science learning, while accounting for the potential effects of cognitive load and students' individual differences. The overarching research goal of this research was to explore the impact of immersion on students' conceptual learning in environmental science in the context of augmented reality (AR) settings.

This goal was addressed through a combination of studies, using mixed methods. The studies culminated with the empirical investigation of a proposed cognitive model of immersion in AR settings with 135 10th graders. The proposed cognitive model of immersion acknowledges the potential effects of domain-specific motivation, cognitive motivation and cognitive load on high school students' immersion. To investigate this model three methodological challenges needed to be first addressed. First, an AR development platform was designed, to allow the development of a location-aware AR app in Greek. Second, the Augmented Reality Immersion (ARI) questionnaire was developed to measure students' immersion in location-based AR settings. Third, the Need for Cognition Scale - Short Form (NfC-SF GR) questionnaire was adapted, thus ensuring a reliable measurement of high school students' cognitive motivation.

Statistical analyses, which included pre- and post-test comparisons, correlations, multiple regressions and cluster analyses, contributed to the model's validation and provided empirical substantiation for two claims: Immersion is positively predicted by domain-specific motivation and cognitive motivation, but negatively predicted by experienced cognitive load. In turn, learning gains are dependent on the level of immersion that students achieve. This work contributes to theory development (through the validation of the cognitive model of immersion); methodology (through the validation of the ARI and NfC-SF GR questionnaires); and design (through the development of the *TraceReaders* AR platform).

Keywords: Immersion, Location-based augmented reality settings, Learning, Domain-specific motivation, Cognitive motivation, Cognitive load, Science Education

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INTRODUCTION

The advent of immersive digital learning environments is argued to provide greater opportunities to engage students in transformative ways of learning science (Barab & Dede, 2007; Dede, 2009). Immersion, which can be defined as a subjective psychological experience of cognitive and emotional involvement, has been claimed to be one of the main driving forces fostering students' science learning in digital learning environments (Cheng, She, & Annetta, 2015). Dede (2009), who defined immersion "as the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (p.66), has stated that immersion can enhance science education in at least three ways by allowing: (a) multiple and complementary insights of complex scientific phenomena, (b) situated learning, and (c) the transfer of skills in real world situations.

Location-based Augmented Reality (AR) apps, as an emergent type of immersive environments, have only recently been introduced to science education (Cheng & Tsai, 2013). While immersive virtual environments seek to replace reality, location-based AR seeks to supplement it, by blending the real world with virtual elements (Klopfer, 2008). This augmentation of reality is achieved as mobile and context-aware technologies respond to students' position in the real world, and augment physical landscapes with digital information (Cheng & Tsai, 2013). Location-based AR settings are, thus, hypothesized to foster science learning, as they contribute to students' immersion in blended spaces of educational interest.

According to Hickey (2009), immersive learning environments hold tremendous potential for science education. Clarke, Dede and Dieterle (2008) have emphasized that there is a need to integrate immersive technologies into instructional design and pedagogical practices, while leveraging their educational affordances for better preparing students for the future. In recent years, learning scientists and instructional designers have employed a variety of immersive interfaces, resulting in different types of immersive learning environments (e.g. virtual reality environments, computer and video games, virtual worlds, augmented reality environments). However, despite the growing number of immersive learning environments for science education, there are only a few empirical studies investigating the impact of immersion on students' science learning; these studies are limited to the context of virtual environments and are still inconclusive.

1. Problem Statement

Previous empirical studies, which have investigated immersion in relation to science learning, are situated in the field of virtual reality (Moreno & Mayer, 2002; Winn, Windschitl, Fruland, & Lee, 2002; Witmer & Singer, 1998), and game-based virtual worlds (Cheng et al., 2015; Cheng, Lin, She, & Kuo, 2016; Hsu & Cheng, 2014; Rowe, Shores, Mott, & Lester, 2011; Schrader & Bastiaens 2012a, b). The results of these studies are, rather, inconclusive, as some of them provide empirical substantiation of the positive effects of immersion on students' conceptual learning (Rowe et al., 2011; Winn et al., 2002), while others report that immersion is not related to learning outcomes in science (Cheng et al., 2015; Hsu & Cheng, 2014).

Cheng et al. (2016) suggested that the relation between immersion and learning in science might be more complicated than initially hypothesized. Some researchers have argued that immersive virtual environments can provoke high levels of cognitive load, which then mediates students' immersion and detracts students' attention from salient educational content (Moreno & Mayer, 2002; Nelson & Erlandson, 2008; Schrader & Bastiaens, 2012a; Wrzesien & Alcañiz Raya, 2010). Another explanation, which may account for such inconclusive findings, is that immersion may be also mediated by individual students' characteristics, such as prior knowledge (Cheng et al., 2016), or immersive tendencies (Schrader & Bastiaens, 2012b). However, to our knowledge, there are no published studies investigating a model specifying relationships between students' individual differences, cognitive load, immersion and conceptual learning in science.

Another factor confounding our understanding of the impact of immersion on student learning in location-based AR settings, is that published studies on students' immersion are drawn from different digital contexts, most of them non-AR. According to the existing literature, achieving high levels of immersion in location-based AR settings for learning science appears to be a very demanding process, given that students must successfully deal with a set of different challenges relating to: (a) the naturalistic context in which location-based AR activities take place (e.g. Squire & Klopfer, 2007; Reid, Hull, Clayton, Melamed, & Stenton, 2011), (b) complex problem-solving processes, around which learning sciences location-based AR activities are often developed (O'Shea, Mitchell, Johnston, & Dede, 2009; Squire, 2010), (c) cognitive load, which is often seen as a major drawback in mobile and location-aware AR app implementations with students (Dunleavy, Dede, & Mitchell, 2009; Dunleavy & Dede, 2013; O'Shea et al., 2009), and (d) the educational content, which differentiates location-aware AR apps for learning science from non-educational immersive apps (Kickmeier-Rust & Albert, 2010).

Under these circumstances, it remains unclear whether and how immersion affects science learning in location-based AR settings (Cheng & Tsai, 2013), and in particular the level of immersion that is required to facilitate students' conceptual learning in such contexts. Furthermore, the subjective nature of immersion raises questions about the contribution of students' individual differences to their learning. The intricate relationship between immersion and science learning is of increasing interest to researchers (Cheng et al, 2016); to achieve a more nuanced understanding of the impact of immersion on students' conceptual understanding more empirical studies are necessary, which can contribute to the development of an evidence-based, explanatory framework of immersion for science learning.

2. Theoretical Framework

This study sought to investigate whether immersion in location-based environmental science AR settings is related to students' conceptual understanding. Aligned with the overarching research purpose of this doctoral study, the theoretical framework of this study is organized in three sections. The first section presents the integration of location-aware AR apps in science education and their immersive affordances, offers a definition of immersion in location-based AR settings, and discusses its potential to facilitate students' conceptual learning in environmental science. The second section presents the existing empirical research investigating immersion in location-based AR settings. Finally, the third section discusses the literature on the influence of the subjective constructs of cognitive load and motivation on students' immersion in location-based AR settings.

2.1 The Integration of Location-aware AR Apps in Science Education

A growing body of research argues that location-aware AR apps create new possibilities for contextualizing science learning and immersing students in blended spaces of educational interest (Cabiria, 2012; De Souza E Silva & Delacruz, 2006; Dede, 2009;

Klopfer & Squire, 2008; Laine et al., 2016). Learning environments incorporating immersive technologies, such as location-aware Augmented Reality (AR) technologies, have only recently been introduced to science education (Cheng & Tsai, 2013). These apps are employed in outdoor spaces and can result in engaging learning environments, which are often built around authentic and complex real-world problems. Due to their immersive affordances location–aware AR apps seem able to address some of the main challenges that science education must deal with.

Research suggests that students' interest in learning science is at a low point, since present-day science education often fails to engage students' interest to learn science (Eurydice network, 2011). Given that the subject of science is often considered abstruse and challenging, many students cannot often engage in science learning activities and fail to obtain a deeper understanding of science (Lee & Anderson, 1993). Traditional science education has also been criticized for presenting science as a decontextualized corpus of scientific knowledge that must be memorized, rather than organizing contextually relevant educational activities about real-world phenomena (Fensham, 2004). At the same time, science instruction practices can often make it difficult to organize contextually relevant educational activities with real-world objects and phenomena (Laine, Nygren, Dirin & Suk, 2016).

Location-based AR settings that combine digital technologies, narrative and games with scientific content (Laine et al., 2016) have the potential to immerse students in the science learning activities. This combination creates new possibilities for immersing students in technology rich learning environments, where they can collaboratively address and investigate meaningful problems, thus scaffolding their conceptual understanding (e.g. Barab & Dede, 2007; Cabiria, 2012; de Souza e Silva and Delacruz, 2006; Dede, 2009; Klopfer & Squire, 2008). In this context, immersion which has been previously defined as a gradated psychological process of cognitive and emotional involvement in technology rich learning environments (Barab & Dede, 2007; Dede, 2009; Cheng et al., 2015; Cheng et al., 2016), such as location-based AR settings, might be of paramount crucial in the field of science education.

2.1.1 Immersion in Location-based AR settings

Immersion is a widely-used construct in literature discussing digital apps, such as computer and video games, avatar-based virtual worlds or virtual reality apps. One of the most widely used definitions of immersion is that immersion is “the participant’s suspension of disbelief that she or he is ‘inside’ a digitally enhanced setting” (Dede, 2009, p.66). As entertainment and learning around such digital experiences are assumed to be dependent on the degree of immersion achieved, namely the degree to which users become cognitively and emotionally engaged with a given digital application (e.g. Brooks, 2003; Cheng et al., 2015), immersion is a construct of high interest in such contexts.

Immersion has been also discussed in the context of location-aware augmented reality (AR) apps. Location-aware AR apps, as a new form of interactive media, have been largely embraced in the fields of gaming and education, as they have been argued to provide users with enriched and immersive experiences, which in turn are asserted to promote enjoyment, engagement in a task and even learning (e.g. Dede, 2009; De Souza E Silva & Delacruz, 2006).

Despite the popularity of the term, Weibel and Wissmath (2011) have commented that immersion in mediated environments has previously been explained through the constructs of “presence” and “flow”, often provoking a definitional confusion. Many researchers have pointed out that instead of employing these terms synonymously, flow and presence should be conceived as two optimum states of engagement, while immersion should be defined as a sub-optimal psychological process of becoming engaged (e.g. Baños et al., 2004; Brown & Cairns, 2004; Jennett et al., 2008). More specifically, flow can be defined as the process of optimal experience, “the state in which individuals are so involved in an activity that nothing else seems to matter” (Csikszentmihalyi, 1991, p.4). On the other hand, the construct of presence has usually been restricted to non-exhaustive and loosely-stated definitions such as “the feeling of being there” (Heeter, 1992) in a digital environment, providing a sense of deep involvement. Comparing presence and immersion, Jennett et al. (2008) argued that while presence and flow are often considered as optimal “states of mind”, immersion can be viewed as a gradated psychological process of engagement that may provoke flow and/or presence.

Agreeing with the definition of Jennet et al. (2008), we argue that the operationalization of immersion as a continuum towards flow and presence seems to be crucial in the context of AR location-aware apps. While several AR researchers have previously attempted to address AR immersive experiences through the evaluation of flow and presence (e.g. Bressler & Bodzin, 2013; McCall et al., 2011; Regenbrecht & Schubert, 2002; Von Der Pütten et al., 2012), it seems that shifting our focus towards the evaluation of immersion provides a more viable option, given that the concepts of flow and presence have often emerged as too excessive for describing the users' experience in the context of location-aware AR apps. Previous studies in the field have indicated that total immersion, in terms of flow, is a transient state, while a sense of presence could hardly be achieved and maintained in the context of AR location-based settings (e.g. McCall et al., 2011; Reid et al., 2005). Unlike virtual environments taking place in settings where many factors such as temperature, light, props and noise can be controlled, location-aware AR apps provide situated experiences where the environment is often a real public space or a physical site where these parameters remain beyond the designer's control (Reid et al., 2011). Under these circumstances, external elements like cars, insects, animals, outdoor noise and other unexpected events cannot be controlled and could act as external distractions, preventing the users' focused attention and thus disrupting the immersive experience (Dunleavy et al., 2009; McCall et al., 2011; Reid et al., 2005; Reid et al., 2011). Therefore, in order to delineate location-aware AR experiences appropriately, a definition of immersion which considers different degrees of cognitive and affective absorption may seem more appropriate when compared to borrowing the definitions of the constructs of presence or flow.

2.1.2 Immersion in Relation to Science Learning

The uniqueness of location-aware AR apps has often been attributed to their immersive affordances (Dunleavy & Dede, 2013; Wu, Lee, Chang, & Liang, 2013; Yuen, Yaoyuneyong, & Johnson, 2011). AR's most significant advantage might be its "unique ability to create immersive hybrid learning environments that combine digital and physical objects, thereby facilitating the development of processing skills such as critical thinking, problem solving, and communicating through interdependent collaborative exercises." (Dunleavy et al. 2009, p. 20).

Location-based AR learning contexts are assumed to provoke immersion and support learning, due to a set of unique characteristics (Cabiria, 2012; Dede, 2009; Dunleavy et al., 2009). In particular, location-based AR differs from other digital immersive environments, as it: (a) employs mobile and location-aware interfaces, (b) combines physical and digital spaces, thus creating blended spaces, (c) extends the activity outside the limits of traditional digital space (e.g. the screen) into the physical space, and (d) provides students with rich interactive possibilities, especially interactions with the physical world and with virtual elements augmenting it (de Souza e Silva & Delacruz, 2006; Squire & Jan, 2007). Taking into consideration these characteristics, Kim (2013) has noted, that while virtual environments aim to "cut out" the users from the real world resulting in "virtual" immersion, location-based AR environments are linked to specific contexts of the real world, resulting in a form of "contextual" immersion.

High levels of immersion may provoke the optimal states of "flow" –a sense of full absorption in the AR location-based activity– and "presence" – a sense of feeling surrounded by a blended, yet realistic physical/virtual environment (Cheng & Tsai, 2013). In particular, the experience of flow has a critical role in all learning activities, because it can provoke intrinsically motivated behavior (Schiefele, 2001). According to Csikszentmihalyi (1991), the achievement of the state of *flow* means everything but the learning activity itself is ignored and forgotten. In addition, the psychological state of *presence* might help students focus on the learning activity rather than on the interface employed (Hoffman, Prothero, Welss, & Groen, 1998). Students, who have achieved *presence* invest less effort for navigating in the AR location-aware app. This, in turn, may stimulate the students' willingness to invest mental effort in the learning process (Barfield & Weghorst, 1993; Moreno & Mayer, 2002). Overall, when highly immersed, "students quickly enter a state of suspended disbelief, accept the blended real and digital environment, give their attention over to it, and engage in the variety of options available to them to access content related to the topic being addressed" (Cabiria, 2012, p. 240).

Dede (2009) has argued that immersion can enhance science education in at least three ways by allowing multiple perspectives, situated learning, and transfer. First, immersion can enable multiple perspectives of complex scientific phenomena, given that immersive learning environments can often allow the change of students' frames of reference Second, immersion has been argued to foster scientific inquiry given that immersive learning environments can provide richly situated educational experiences. Third, immersion in authentic and simulated learning worlds is also considered of paramount importance for fostering transfer. Nonetheless, despite these claims there is a lack of empirical studies investigating whether immersion is positively related to science learning in the context of location-based AR settings.

2.2 Investigating Immersion for Science Learning in Location-based AR settings

Review studies focusing on the status, affordances and challenges of location-based AR apps in education, have recurrently stated that location-based AR settings can provide students with engaging learning experiences, due to their potential to provoke immersion and subsequent feelings of flow and presence. Wu et al. (2013) have concluded, for instance, that location-based AR settings can enable students' sense of presence, immediacy and immersion. Yuen et al. (2013) have argued that AR environments can facilitate students' immersion indicating that when this occurs, students are "transitioned from existing within a real-world environment, to acting within a virtually-augmented real-world environment" (p. 132). In addition, the recent empirical studies of Bressler and Bodzin (2013, 2016) have provided empirical substantiation for the claim that a well-designed augmented reality app for science learning can promote scientific practices and immersive experiences. However, these studies did not investigate whether these immersive experiences were related to students' science learning.

According to Cheng and Tsai (2013), there is a lack of empirical studies investigating students' immersive experiences in relation to science learning, even though these are expected to be related to students' behaviors in AR-related learning. The following sections provide an overview of (a) the main challenges that may have hindered the investigation of immersion in relation to science learning in location-based AR settings, and (b) related empirical research in the field of virtual reality environments, which may also provide useful insights in the absence of such studies in location-based AR settings.

2.2.1 Challenges Related to the Investigation of Immersion for Science Learning in AR

Research on the relation of location-aware AR apps and immersion to learn in science might be limited because of the nascent phase of the field. Two plausible reasons, which may explain the lack of empirical studies investigating immersion in relation to science learning are (a) the lack of AR development platforms which would allow the scalabity of location-aware AR apps for science learning, and (b) the lack of appropriate instruments for measuring immersion in location-based AR settings. Each of these two is a challenge which needs to be addressed to move the field forward; each one is briefly addressed next.

2.2.1.1 Challenge 1: The Lack of AR Authoring Platforms

Even though studies on AR learning environments are increasing (for a review see Wu et al., 2013), there are still many open areas for investigation as researchers begin to grapple with issues of technological and instructional design to promote learning. At the same time, and due to the early stage of research and technological development in the area of AR for learning, it appears that more empirical evidence on the learning potential of AR is required to be amassed (Wu et al., 2013). This presumes the availability of educationally-oriented AR platforms allowing the development, testing and scalability of pedagogically-driven AR learning environments. However, such AR technologies for learning are still in their infancy; as argued by Dede and Dunleavy (2013), at the moment, "there are relatively few stand-alone AR development platforms that enable educators and instructional designers to create custom AR without programming skills" (p. 743).

Even though some non-profit, educational authoring AR platforms exist, they are proprietary or do not work with languages other than English. For instance, the seminal work *Environmental Detectives* (Klopfer & Squire, 2008) led to an AR authoring platform that only works with English content. Other educationally-minded AR authoring platforms, such as AURASMA, only run when Wi-Fi is present. Such limitations severely constraint access to, and research of, such environments in many contexts, leading to important obstacles to making AR technologies for learning more widely accessible (FitzGerald, Ferguson, Adams, Gaved, Mor, & Thomas, 2013).

2.2.1.2 Challenge 2: Measuring Immersion in Location-based AR setting

It is widely acknowledged that the assessment of immersion is challenging; especially in the context of location-based AR settings. Existing measures of immersion fall into two categories: objective and subjective assessments. (Jennet et al., 2008; McCall, Wetzel, Löschner, & Braun, 2011), both of which are presented below.

Subjective measures of immersion: Individuals, who participate in an engrossing activity, can identify immersion for themselves, providing subjective accounts about the depth and dimensions of their immersive experience (Jennet et al., 2008). This realization led to a corpus of subjective measures, which often take the form of post-intervention surveys that seek to evaluate individual immersive experiences. According to McCall et al. (2011), such measures have various advantages, since they are easy and inexpensive to use and they are designed to measure immersion by understanding how an individual experienced it. However, attempts to develop validated surveys for evaluating immersion have been few and non-systematic, while existing instruments are oriented towards measuring immersion in the context of non-AR digital games (e.g. Cheng et al., 2015; Jennet et al., 2008; Qin, Rau, & Salvendy, 2009). As such, a major limitation of these instruments is that they are designed to assess students' immersion in digital games running on desktop-based computers, and thus are incommensurable for measuring immersion in location-based AR settings.

Objective measures of immersion: This category of measures have also been proposed in the literature (McCall et al., 2011). These measures take place during the immersive experience itself, and use the participants' physiological or behavioral responses (e.g. skin conductance, heart rate, eye gaze, posture, gestures) as data points. For instance, Jennet and her colleagues (2008) evaluated users' immersion in a highly immersive computer game by observing measurable changes in the movements of their eyes. Fixation data revealed that eye movement in the immersive condition significantly increased over time in comparison to eye movement in the low-immersive digital app condition. Other researchers have attempted to quantify the degree of participants' immersion by measuring the amplitude of Event-Related Potentials (ERPs) to task-irrelevant stimuli, using electroencephalography (EEG). For instance, Burns and Fairclough (2015) measured immersion through ERPs, as "graphical representation of the 'average' changes in the EEG signal in response to having perceived or e.g. consciously responded to a physical or mental stimulus" (p. 108). Finally, other researchers have measured immersion through recording the participants' reactions (e.g. recovery time) to digital games' anomalies creating breaks in users' immersion -e.g. latency or pixelizing of the visual display, audio drop-outs, lack of synchronization (Chung & Gardner, 2012).

Evaluating immersion in location-aware AR settings is quite distinct from controlled laboratories studies (McCall et al., 2011). As a result, researchers have suggested that the traditional measures of immersion are not sufficient to approach the experiences that AR blended spaces offer (Benyon, 2012; Wagner et al., 2009). In conclusion, it seems that to move the field of location-based AR forward there is a need for devising valid and reliable measurements of immersion in this context.

2.2.2 Investigating Immersion for Science Learning in Virtual Reality Environments

Given that location-aware AR apps have only recently been introduced to the field science education (Cheng & Tsai, 2013), researchers have been primarily interested in evaluating the affordances and limitations of these apps for learning science, and identifying any improvements that might be needed. Design-based research has been proposed as an appropriate methodology for research in nascent fields of study, as researchers attempt to improve the theoretical and practical design of technology-enhanced learning environments (Wang & Hannafin, 2005).

Most of the existing studies on AR and science learning have employed design-based research or case study designs, adopting qualitative methodologies, such as interviews, observations, or video analysis, for exploring the AR design affordances and limitations (e.g. Dunleavy et al., 2009; Klopfer & Squire, 2008; Nilsson & Svingby, 2009; O'Shea et al., 2009; Rosenbaum, Klopfer, & Perry, 2007; Squire, 2010; Squire & Jan, 2007, Squire & Klopfer, 2007). According to Bressler and Bodzin (2016), this has resulted in studies with small sample sizes, rather than in empirical studies with larger student populations that are focused on the manipulation and testing of multiple variables related to students' immersive experiences.

Despite the lack of extensive empirical investigations of immersion in location-based AR settings, the topic has received some exploration in the context of virtual reality environments. However even in this, more established field, empirical studies of immersion are still scant and inconclusive. In particular, only eight studies were identified in the literature investigating immersion in relation to science learning in virtual reality settings (Cheng et al., 2015; Cheng et al., 2016; Hsu & Cheng, 2014; Moreno & Mayers, 2002; Rowe et al, 2011; Schrader & Bastiaens 2012a, b; Winn et al., 2002). These empirical studies correlated students' immersion or feelings of presence to their performance and/or learning outcomes in the context of immersive virtual reality environments for learning science. A brief overview of the main findings of each study is provided next.

Winn et al. (2002) conducted a study of twenty-six undergraduates, randomly assigned to either an immersive virtual reality environment or an equivalent desktop version which simulated water movement and salinity in the ocean. The students in the immersive virtual environment, reported that they felt "present" within the learning environment to a greater degree than students who used the desktop version. Students, who were more immersed, also presented increased learning gains in some of the aspects of the learning content related to water movement. Based on these findings Winn and colleagues concluded that immersion in a virtual environment supports students in improving their understanding of dynamic three-dimensional processes, but that it did not promote the understanding of processes that can be represented statically in two dimensional simulations.

Moreno and Mayer (2002) used an agent-based multimedia educational game to compare low vs. high immersive environments. They assigned college students to a low immersion VR condition (the game was displayed via desktop computer) or to two variants of high immersion VR conditions (game displayed via a head-mounted display while sitting, and game displayed via a head-mounted display while walking). Students who learned in more immersive virtual reality environments were reported to achieve higher levels of presence. However, the increased sense of presence did not lead to increased learning, as students in the highly immersive condition did not necessarily learn more when compared to their peers who worked with the less immersive version of the game. As a result, Moreno and Mayer (2002) argued that even though immersive learning environments are often expected to promote students' learning in science, more immersive learning environments are likely to distract students, thus deteriorating their learning gains.

Rowe et al. (2011) studied the *Crystal Island* game-based virtual world for science education. They were interested in investigating whether game-based virtual worlds can make learning engaging and whether students' engagement can result in increased learning gains. They conducted a study with 153 middle school students interacting with the *Crystal Island* virtual world, which revealed a strong and positive relationship between students' immersion in the virtual learning environment, in-game problem solving and learning outcomes.

Hsu and Cheng (2014) developed *BioDetective*, an immersive role-playing game, and investigated its impact on a cohort of 7th graders. They examined the relationship between students' gaming performance, science learning and experienced immersion. They concluded that students' science learning was improved through *BioDetective*, and that students of higher immersion had a better problem-solving performance than students of lower immersion. However, the obtained results revealed that there were no significant correlations between immersion and learning outcomes. Hsu and Cheng (2014) assumed that students might have been cognitively overloaded, as they invested most of their mental efforts on the gaming and narrative aspects of these learning environments. This cognitive load, they argued, may result in decreased cognitive resources allocated to the educational content that must be learned.

Likewise, Cheng et al. (2015), who examined the impact of a game-based virtual world on middle school students reported that immersion led to higher gaming performance. However, becoming more immersed in the game did not affect science learning outcomes. In this context, Cheng et al. (2015) discussed their findings and provided plausible explanations for the lack of relationship between immersion and science leaning. First, they suggested students might have only undergone engagement without deeply experiencing higher levels of immersion and because of this the impact of immersion on science outcomes was not traceable. Second, they argued that cognitive overload could have mediated students' immersion, thus preventing a positive effect of immersion on their science learning. Finally, drawing on evidence from the cognitive neuroscience research, the authors suggested that immersion in gaming environments may have a positive impact on episodic memory; however, the understanding of scientific concepts embedded in the game often relates to students' semantic rather than episodic memory.

Schrader and Bastiaens (2012a) investigated whether the design of immersive experiences affects students' feelings of presence or their learning gains. In their study, they assigned 84 middle school students to a low immersion condition (hypertext learning environment) or a high immersion condition (a game-based virtual world). According to their findings, feelings of presence were positively related to learning outcomes; students in the low-immersion environment outperformed their counterparts who were assigned to the high-immersion game. A mediation analysis showed that the relation between presence and students' learning gains was partly mediated through increased cognitive load.

In a subsequent study, Schrader and Bastiaens (2012b) investigated whether the effect of virtual presence is predicted learner characteristics. In particular, they investigated how the variation of the feeling of presence experienced during a game-based virtual world can be explained by students' immersive tendencies. Their study included a cohort of 8^{th} graders, divided in two groups (high vs low immersive tendencies); all students used the same game-based virtual world for science learning. Examining the data using correlation and regression analyses, Schrader and Bastiaens (2012b) found that higher immersive tendencies were related to an increased sense of presence within the game-based virtual world; this, in turn, resulted in students' higher learning gains.

Finally, Cheng et al. (2016) investigated the impact of immersion on 63 seventh graders who employed a game-based virtual world for learning science, as well as the effects of students' prior knowledge on immersion. They found that students with more prior knowledge could easily learn the targeted scientific concepts without being deeply immersed in the game. On the other hand, students with lower prior knowledge required higher levels of immersion to master the game and learn the scientific knowledge embedded within the game.

To summarize, these empirical studies suggest that immersion as a subjective human experience may be mediated by learner characteristics (Witmer & Singer, 1998). In addition, these studies imply that cognitive load may negatively affect students' immersion and subsequent learning in science.

2.3 AR Immersion in Relation to Motivation and Cognitive Load

Drawing from the extant literature on the nature of location-based AR tasks, and relevant empirical studies from the field of immersive virtual environments, we posit that the impact of location-based AR settings on students' immersion may be mediated by cognitive load and students' motivation, in terms of domain-specific motivation and cognitive motivation.

2.3.1 Motivation and Immersion in Location-based AR Settings

Theoretical models of immersion have defined immersion as a process of cognitive and emotional involvement, during which students may voluntarily allocate their attention towards an immersive learning environment; however, for this to occur, students' motivation has been hypothesized as a significant determinant (e.g. Brown & Cairns, 2004; Jennett et al., 2008; Scoresby & Shelton, 2011). Motivation has also been considered as a prerequisite to experience the immersive states of presence or flow (Lombard & Ditton, 1997; Weibel & Wissmath, 2010; Wirth et al., 2007). However, according to Weibel and Wissmath (2010), convincing empirical substantiation for these claims is missing.

Based on the review of the literature it appears that domain-specific motivation and cognitive motivation may positively predict students' immersion in location-based AR settings. Both these types of motivation are discussed in the following sections in relation to students' immersion in location-based AR learning environments.

2.3.1.1 Domain-specific Motivation

A substantial difference between an immersive environment for entertainment versus one for learning purposes is the educational content that must be integrated and learned by the students (Kickmeier-Rust & Albert, 2010). A location-based AR learning activity can be appealing when the student has domain-specific motivation and, thus, is interested in the instructional topic (Scoresby & Shelton, 2011; Wirth et al., 2007). Therefore, domain-specific motivation may positively affect students' immersion.

2.3.1.2 Cognitive Motivation

Cognitive motivation, as a stable personality trait, reflects an individual's tendency to invest cognitive effort in challenging tasks (Cacioppo, Petty, & Kao, 1984; Cacioppo, Petty, Feinstein, & Jarvis, 1996; Petty, Briñol, Loersch, & McCaslin, 2009), such as those in location-based AR learning contexts. As part of location-based AR activities for learning science, students are usually asked to deal with compelling but complex and ill-structured real-world problems; for their solution students are asked to collect and synthesize relevant data as they progress through multiple resources grounded on virtual sources or on the physical environment (Dunleavy et al., 2009; Klopfer & Squire, 2008; O'Shea et al., 2009). In addition, because of their naturalistic settings, location-based AR activities are likely to produce more variation in the level of attention that students devote (Reid et al., 2011). In this context, students of high cognitive motivation, who are accustomed to thinking carefully and engaging in ill-structured problems, may be also inclined to deeply attend a location-based AR activity. In turn, we hypothesize that this may facilitate immersion, which requires students' focused attention (Cheng et al., 2015; Jennett et al., 2008).

2.3.2 Cognitive Load and Immersion in Location-based AR Settings

The most frequently reported limitation of the impact of location-aware AR apps on science learning is students' cognitive load; researchers speak, in particular, about the extraneous and intrinsic types of cognitive load, which can diminish the working memory resources required for processing the learning information (Dede & Dunleavy, 2013; O' Shea et al., 2009; Squire & Jan, 2007). According to cognitive load theory, learning can be facilitated by managing cognitive load that is imposed by the learning materials (intrinsic load) and by the way these materials are presented (extraneous load), to maximize the working memory resources required for processing the new information (productive or germane load) (Paas, Tuovinen, Tabbers, & van Gerven, 2003; Sweller, van Merrienboer, & Paas, 1998). Previous research with mobile learning environments has suggested that the split-attention and redundancy effects could contribute to the inducing of extraneous load, which may overload students' cognitive capacities (Liu, Lin, & Paas, 2013, 2014). In addition, intrinsic cognitive load has also been discussed in association with learning in location-based AR settings. As argued by Dunleavy et al. (2009), location-aware AR apps require students to apply a set of complex skills, such as collaborative-problem solving, inquiry-based skills, geo-spatial navigation skills, and handheld manipulation. The concurrent cognitive activation of all these skills may overburden students, resulting in high levels of intrinsic cognitive load. Depending on their skills, and the design of the location-based AR activity, students can experience different levels of cognitive load, which in turn may affect the cognitive processes involved for achieving immersion.

3. Research Purpose

The purpose of this doctoral dissertation was to conceptualize and empirically investigate immersion in relation to science learning in location-based augmented reality settings. In particular, the goal of this doctoral dissertation was to investigate the relationship between immersion and students' conceptual understanding in the context of environmental science. The overarching research question guiding this doctoral dissertation was: *What is the nature of the relation between immersion and science learning in location-based AR settings, accounting for the effects of cognitive load and motivation?*

4. Overview of the Methodology

Given the stated purpose of this doctoral work, mixed methods were employed. During the initial stage, a design-based approach was employed for the development and validation of a location-aware AR app for science learning. Subsequently, a case study design was employed, grounded in qualitative techniques, for investigating the nature of immersion and the relationship between immersion and science learning in location-based AR settings. Finally, during the last stages of this dissertation, quantitative analysis techniques were employed to investigate the relationship between immersion and students' conceptual understanding in location-based AR settings, as well as the potential effects of cognitive load and students' motivation.

To accomplish its goals, this doctoral study had to address three main methodological challenges, which are presented next.

4.1 Lack of Augmented Reality Authoring Systems for Greek-speaking Students

As Dede and Dunleavy (2013) indicated, "there are relatively few stand-alone AR development platforms that enable educators and instructional designers to create custom AR without programming skills" (p. 743). The review of existing authoring platforms at the outset of the Ph.D. study indicated that there were no available platforms which could (a) support the development of location-aware AR learning apps in Greek, (b) run in outdoors spaces in an offline mode in the absence of Wi-Fi, and (c) allow users to capture and store data to engage in evidence-based inquiry learning.

4.2 Lack of Valid Instruments for Measuring Students' Immersion in Location-based AR Settings

Attempts to develop validated instruments for evaluating immersion so far have been few and non-systematic, while existing instruments are oriented towards measuring immersion in non-AR digital settings. However, location-aware AR apps are a unique media type which significantly differs from other digital learning environments, as they blend physical and virtual contexts (Wagner et al., 2009). These contexts render the instruments to assess immersion in non-AR environments incommensurable to the nature of the experience.

4.3 Lack of Validated Instruments for Measuring Cognitive Motivation with Greek Students

Cognitive motivation is theorized in the literature as a relatively stable trait that relates to the degree to which an individual enjoys tasks involving deep thinking. The 18-item Need for Cognition Scale–Short Form (NfC–SF), developed by Cacioppo and Petty (1984), has often been used to assess individual differences in cognitive motivation. Even though the NfC-SF has become a standard measurement in behavioral sciences and has been adapted in different languages, the NfC-SF has not been validated in Greek. In addition, even though there are many studies focusing on the instruments' adaptation, research regarding its validity with young children and adolescents is still limited (Preckel, 2014).

5. Goals of this PhD Study

The present doctoral study addressed the following goals:

- The development of an AR platform allowing the design of location-aware AR apps for inquiry-based science learning for Greek-speaking students
- The development and validation of an instrument for evaluating immersion in location-based AR settings
- The translation, adaptation and validation of the Need for Cognition (NfC-SF) measurement, for Greek-speaking high-school students
- The investigation of the hypothesized cognitive model of immersion in location-based AR activities supporting students' conceptual understanding in environmental science.

6. Organization of this Dissertation

The dissertation is organized in the following five chapters.

- ***Chapter 1: The design of the TraceReaders AR platform***

  This chapter presents *TraceReaders*, the AR development platform which was used to investigate immersion for science learning. The chapter also describes the development and validation of the "Mystery at the lake" location-based AR app, employed in the context of this doctoral dissertation, to investigate the relationship between immersion and science learning in location-based AR settings.

- ***Chapter 2: A case study for investigating immersion in relation to science learning***

  This chapter presents a small-scale, pilot study which investigated the impact of immersion on students' learning process, while employing "Mystery at the lake". In particular, this study examines the learning processes of two dyads of students, who reported diametrically opposing views about their immersive experience while employing the "Mystery at the lake" location-aware AR app.

- ***Chapter 3: The development and validation of the ARI questionnaire***

  This chapter presents the development and validation of the ARI [Augmented Reality Immersion] questionnaire: an instrument for measuring immersion in AR location-aware settings. To achieve this goal, a multi-step process was employed to develop and validate a novel instrument; analyses included exploratory factor analysis with 202 high school students, followed by a confirmatory factor analysis with 162 high school students. The development of this instrument was subsequently employed for the investigation of the overarching research question guiding this doctoral work about the nature of the relation between immersion and science learning in location-based AR settings, accounting for the effects of cognitive load and motivation.

- ***Chapter 4: Translation, adaptation, and validation of the Need for Cognition Scale (NCS-SF-GR)***

  This chapter presents the adaptation and validation of the "Need for Cognition Scale–Short Form" questionnaire (NfC-SF) in the Greek language (NfC-SF-GR). To achieve this goal, a multi-step process was followed, which included: (a) the translation and adaptation of the questionnaire in the Greek language, (b) a reliability analysis of the instrument's items in combination with an exploratory factor analysis with 177 secondary school students, and (c) a confirmatory factor analysis to define the underlying structure of the scale, using a sample of 532 secondary school students.

- ***Chapter 5: A cognitive model of immersion in relation to science learning***

  This chapter investigated the relationship between immersion and students' conceptual understanding in location-based AR settings, while accounting for the potential effects of students' motivation and cognitive load. This chapter resulted in a cognitive model of immersion for science learning in location-based AR settings, which was empirically investigated and validated with 135 10th graders.

The dissertation concludes with a discussion of the main conclusions and suggests future pathways for research.

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CHAPTER 1: THE DESIGN OF THE *TRACEREADERS* AUGMENTED REALITY PLATFORM

Abstract

Location-aware Augmented Reality (AR) technologies that enable the digital augmentation of the real world can provide enriched learning experiences, through situating the learning content in authentic contexts and promoting inquiry-based learning. However, there is a lack of free-access, stand-alone platforms that can allow teachers and instructional designers to develop location-aware AR apps without programming skills. In addition, existing AR platforms cannot support the development of location-aware AR apps in Greek that can run in outdoors spaces in an offline mode, while also allowing users to capture and store data, aligned. The research aims of the present doctoral study could not be addressed without such an AR platform which would allow the design of location-aware AR apps in Greek. This chapter describes the *TraceReaders* platform for supporting Greek-speaking students' inquiry-based learning.

1.1 Introduction

Despite early calls by visionaries in education to transcend the boundaries of the classroom (Dewey, 1938), a holistic view of learning, which conceptualizes learning as occurring everywhere and anywhere, and emphasizes learning through experience, has only recently started being acknowledged as important. Ongoing technological developments, such as Augmented Reality (AR) technologies on mobile devices, are offering exciting opportunities for realizing the potential of such experiential learning. This chapter is focused specifically on location-aware AR technologies running on mobile devices, which are defined as those mobile technologies that take advantage of modern technological developments, such as geospatial reference and global positioning systems, to enable the dynamic amplification of the here and now with digital information that allows students to learn by interacting with the environment around them. It has been argued that such experiences can motivate students, and respond to just-in-time learning needs (Santos et al., 2016).

Even though studies on AR learning environments are increasing (for a review see Wu et al., 2013), there are still many open areas for investigation as researchers begin to grapple with issues of technological and instructional design to promote learning. At the same time, and due to the early stage of research and technological development in the area of AR for learning, it appears that more empirical evidence on the learning potential of AR is required to be amassed (Wu et al., 2013). This presumes the availability of educationally-oriented AR platforms allowing the development, testing and scalability of pedagogically-driven AR learning environments. However, such AR technologies for learning are still in their infancy; as argued by Dede and Dunleavy (2013), "there are relatively few stand-alone AR development platforms that enable educators and instructional designers to create custom AR without programming skills" (p. 743). Even though some AR platforms exist, they are, in many cases, inaccessible and unavailable in non-English languages; similarly, there is lack of studies discussing how these "augmented reality for learning technologies" are informed by learning sciences theories.

This chapter will focus on the design of the *TraceReaders* (Georgiou & Kyza, 2013), a bilingual AR technology for supporting reflective inquiry in situ, and is divided in four sections. The first section describes the theoretical commitments guiding the design of the AR learning platform. The second section briefly presents the affordances of the tool, outlining the design rationale for supporting students' authentic inquiry-based learning in the field, while overcoming challenges reported in the literature. The third section digs deeper into the complexities of the *TraceReaders* location-aware AR apps, outlining the affordances of these apps to support authentic and scaffolded inquiry-based learning activities. Finally, the fourth section describes the "Mystery at the lake" location-aware AR app which was designed and employed for the purposes of the present doctoral study.

1.2 Theoretical Framework

The design of the *TraceReaders* AR platform was informed by the theory of experiential learning, as proposed by Dewey (1938), and, as an extension of this theory, by the conceptualization of learning in situ, as happening in both formal and informal settings.

1.2.1 Experiential Learning

The theory of experiential learning is based on two principles. The first principle, the *experiential continuum*, highlights the importance of a holistic perspective to learning; that is, each learning experience, regardless of where it takes place, builds on all previous ones. According to Dewey, "every experience is a moving force" (p. 38). Nonetheless, the quality of the experience is of import to the development of learning. The second principle is *interaction*, which Dewey describes as consisting of external and internal conditions, which together, make up experience. Simply put, the external conditions may be viewed as environmental stimuli, such as a learning activity, while the internal conditions refer to the reflection and abstraction that needs to accompany the doing to enable learning. It is the internal conditions that, in turn, decide the quality of experience, but without the coupling of both conditions, learning cannot take place.

1.2.2 Learning in Situ

Informal learning happens everywhere; this work is focused on informal learning afforded by visits to outdoor spaces, such as environmental science centers and archaeological sites. This design-based work begins with the premise that such visits can motivate young people to learn, and can have positive impact on cognitive and affective outcomes (Dewitt & Storksdieck, 2008). This premise has been supported by theoretical arguments in the literature; empirical work in support of this potential exists more in science education, and less in history education. Location-aware AR technologies provide an ideal venue towards this direction, since these technologies combine the physical with the virtual, and can help achieve just-in-time learning in situ.

1.3 The *TraceReaders* AR Platform

AR technologies for learning are still in their infancy; even though some non-profit, educational platforms exist, they are proprietary or do not work with non-English languages. For instance, the seminal work on Environmental Detectives (Klopfer & Squire, 2008) led to an AR authoring platform that only works with English content. Other educationally-minded AR authoring platforms, such as AURASMA, only run when Wi-Fi is present. Such limitations severely constraint access to, and research of, such environments in many contexts, leading to important obstacles to making AR technologies for learning more widely accessible (FitzGerald, Ferguson, Adams, Gaved, Mor, & Thomas, 2013).

In a review of the state-of-the-art in mobile AR technologies for learning, Dede and Dunleavy (2013) discussed the affordances and limitations of six popular development platforms [ARIS, BuildAR, FreshAir, Hoppola Augmentation, TaleBlazer, 7Scenes]. These platforms included a browser-based editor that enables the design of AR environments, allowed the embedding of multimedia sources, virtual objects and characters, and were characterized by location-based functions that triggered virtual content according to users' position in the real world. Beyond these features, most of the apps were equipped with additional functionality allowing: (a) dynamic triggering of content depending upon students' input and/or movement, (b) assignment of different roles among participants for collaborative learning, and (c) integration of assessments (e.g., alphanumeric keypads for fill in the blanks, multiple choice) within the AR experience. However, very few of these were equipped with data collection tools allowing users to capture and store data during the AR experience. In addition, none of these apps was reported to be equipped with scaffolding tools supporting students' reflection or tools that related to annotating, interpreting or organizing data.

The design of *TraceReaders* (Georgiou & Kyza, 2013) addresses some of the aforementioned limitations. The *TraceReaders* platform is a bilingual, location-based AR platform that works with both Greek and English content. The platform consists of an authoring tool, that allows the development of custom AR learning environments for problem-based inquiry learning, and a location-aware AR app which allows the students to access the information in situ, using the GPS coordinates set by the designer of the AR learning environment; each set of coordinates can be considered a hotspot; when students, using a mobile device, such as a tablet, approach the hotspot, the app triggers the augmentation with pre-selected information that is relevant to that specific location. Each *TraceReaders* learning environment uses multimedia content (text, videos, images or graphs) to display information to the user. This functionality allows designers to augment a real-world location by creating a dynamic layer on top of the physical space. In addition, each *TraceReaders* learning environment can be used online or offline; in the latter case, no internet connection is required to run the learning environment.
The app is equipped with a set of tools designed to support students' learning experience (Figure 1.1). These tools include:

a) An interactive map, indicating the hotspots' position in the physical world as well as the ever-changing position of the learner in the physical space;
b) A capturing tool, allowing students to capture either screenshots from the data sources presented on tablets when a hotspot is activated, or pictures from the real world;
c) A data folder in which the pictures students have captured are stored;
d) A notepad, allowing students to take notes during their investigation;
e) A conceptual map creator, allowing students to create a concept map by connecting the data they collect during their investigation;
f) A chat tool, allowing synchronous communication between the different pairs of students employing the learning environment, and
g) A mission button, allowing students to re-access on their mission during the learning activity.

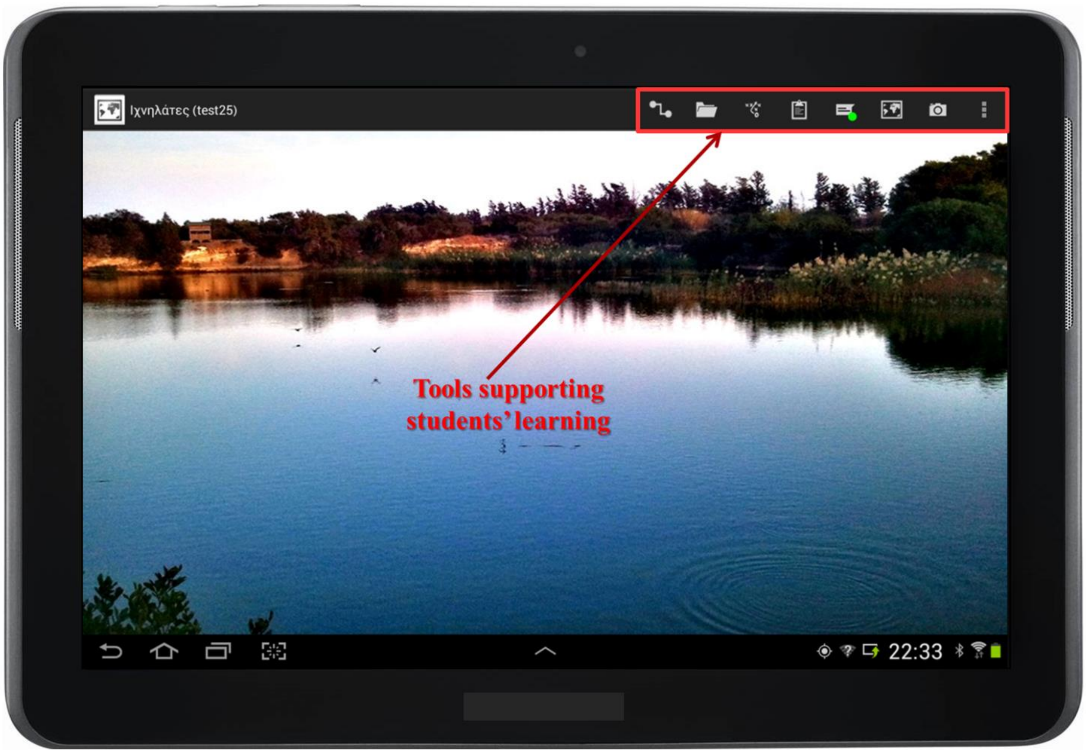

Figure 1.1: The *TraceReaders* augmented reality app

TraceReaders also supports the collection of research data during the students' learning activity. More specifically, when activating the app on the tablet, a voice recorder is also activated capturing students' discourse. In addition, a log file is automatically saved on each tablet, capturing all students' actions in the learning environment, along with time stamps.

1.4 *TraceReaders* and Inquiry-based Learning

The design of the *TraceReaders* was also theoretically informed by literature on inquiry learning. In line with Dewey's reference to the internal conditions of learning, and based on prior work with inquiry learning on desktop computers, this work focused on two main learning challenges: (a) how to support students in engaging in authentic inquiry, and (b) how to scaffold the learning activity to support student autonomy and learning. The following sections discuss both challenges, highlighting the *TraceReaders* features, which were designed to address them.

1.4.1 Engaging Students in Authentic Inquiry

Existing research has indicated that engaging students in authentic inquiry is a major challenge. Previous studies with AR have indicated that students are often observed to frame the inquiry process as a "scavenger hunt" activity, due to naïve scientific skills and simplistic beliefs regarding the scientific process (e.g. Dunleavy et al., 2009; Klopfer & Squire, 2008). Under these circumstances, it was deemed necessary to design AR learning environments that support students' engagement with more authentic learning practices, such as data collection, analysis and interpretation, while in the field. In particular, each *TraceReaders* learning environment revolves around a problem-based scenario. This scenario is introduced with a video and is accompanied by a driving question which guides students on what they should be striving for. In addition, students are asked to collect the data that are relevant to the case, using the capture tool that is available on the app. This tool allows students to capture screenshots from the physical or virtual space when a hotspot is activated. These data are automatically stored in a data folder, which students can then use as evidence.

1.4.2 Scaffolding the Learning Activity

Much evidence in the literature about inquiry learning indicates that students need to be scaffolded in order to learn. This need becomes more urgent in the case of location-based AR implementations, given that location-aware AR apps require students to apply a set of complex skills, such as inquiry skills and geo-spatial navigation skills; this in turn, may overwhelm and distract the students from the salient educational content (Dunleavy et al., 2009; Dunleavy & Dede, 2013). In this context, the design of *TraceReaders* was based on the following key design principles: (a) the AR experience should be activity-based. The problem-based approach contributes to the coherence of the activity and helps students focus. (b) Reflective inquiry is connected to the types of activities the students are asked to engage in; if such activities are not designed for, reflection will not necessarily take place. (c) Reflection-on-action in situ should be encouraged through activities that are motivating to students and are short in duration and fun at the same time. For instance, asking students to film a video on site to respond to the problem they were trying to solve proved to be more motivating and doable than asking students to type a response on tablets. (d) Learning in informal spaces can lead to cognitive load. Therefore, students should be scaffolded in obtaining and recording data as evidence to support the development of evidence-based explanations. These design principles are exemplified in the design of the *TraceReaders* AR app, and in particular, in the data capture tool, the notepad and the concept map tools (Figure 1.2).

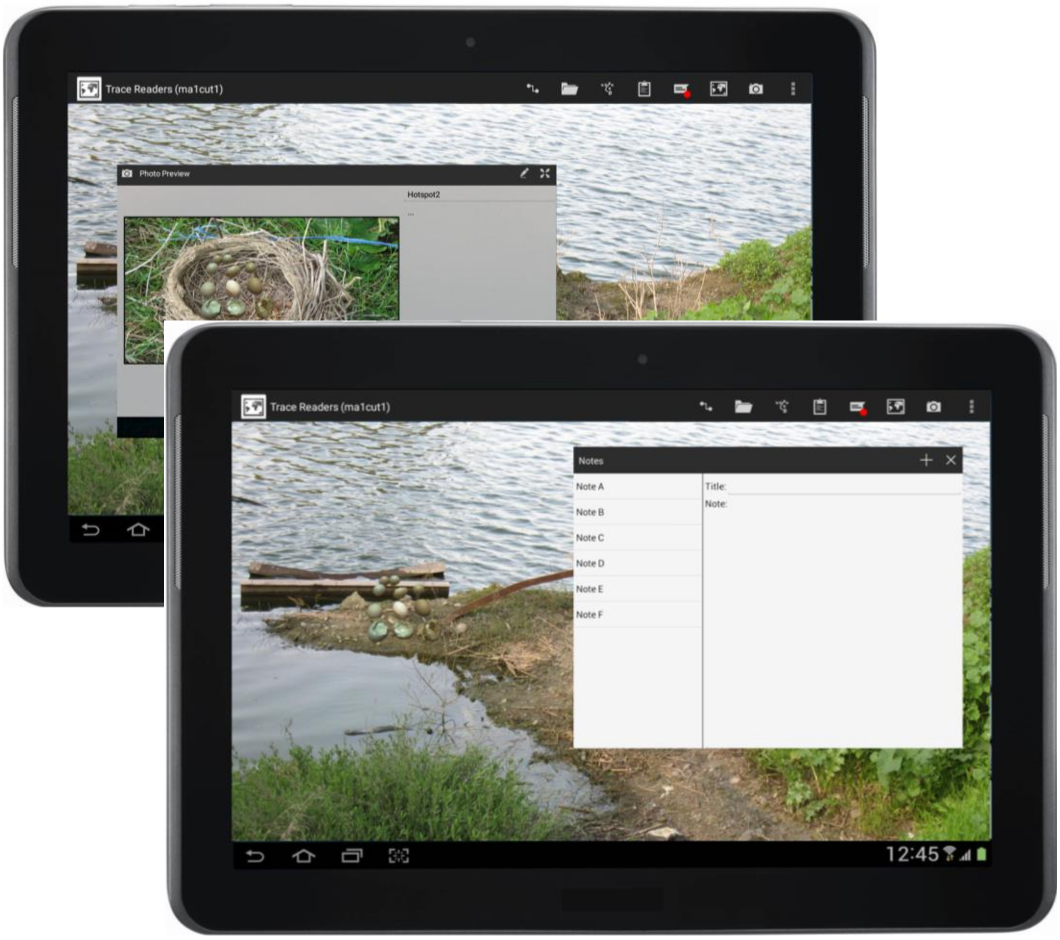

Figure 2.2: The *TraceReaders*' capturing tool and notepad

1.5 *TraceReaders*: "Mystery at the Lake"

To exemplify the affordances of *TraceReaders*, this section will describe the "Mystery at the lake" location-aware AR app, which was developed on the *TraceReaders* AR platform, for the purposes of the present doctoral study.

"Mystery at the lake" was developed and hosted on the *TraceReaders* platform. This location-based AR learning environment was designed to engage middle and high school students in inquiry-based science and takes the form of a narrative-driven investigation. In particular, the goal of this location-aware AR app is to engage students in an explanation-building process about a problem-based environmental case for expanding students' understanding of scientific concepts related to an aquatic ecosystem, such as eutrophication and bioaccumulation. In addition, the app aims to support students' inquiry-based skills, such as data gathering behaviors, organization and synthesis of data, data interpretation and evidence-based reasoning. The learning activity was grounded on the instructional approach of problem-based learning. In line with the approach of problem-based learning, the instructional design of the learning activity was based on key design principles, which aimed to support students' case-based reasoning and reflection-in-action. The following sections provide more details on these three aspects: (a) problem-based learning, (b) case-based reasoning, and (c) reflective inquiry.

1.5.1 Problem-based Learning

Problem-based learning is an instructional method in which students can learn science through investigating an open-ended or an ill-structured problem (Hmelo-Silver, 2004). In particular, problem-based learning is structured around an experiential learning process which is organized around the investigation, explanation and resolution of meaningful problems for the students (Barrows, 2000; Torp & Sage, 2002). As part of the problem-based learning process, students are initially provided with a problem-based scenario; they analyze the problem presented by identifying the relevant facts and they formulate their initial hypotheses and guiding questions; these guiding questions lead to students' investigation. For the completion of each problem students apply their knowledge and reflect on the abstract knowledge obtained (Hmelo-Silver, 2004; Hmelo-Silver & Barrows, 2006; Pepper, 2009). Overall, the problem-based approach helps focus the scientific inquiry. Furthermore, students are asked to work collaboratively, as collaboration is a key feature of problem-based learning.

Similarly to other *TraceReaders* location-aware AR apps, the "Mystery at the lake" was developed around a problem-based scenario. According to this scenario, students work in pairs to solve an environmental problem relating to a lake near a local environmental center. The learning scenario is introduced through a video, in which a researcher presents an environmental science problem regarding the decline of the mallard duck population at a lake and asks students to work in pairs to investigate the problem. According to the scenario, there is a significant decrease in the number of mallard ducklings when compared to previous years, which in turn may be related to a bigger ecological problem at the lake.

One of the key features of problem-based learning is the use of a well-structured scenario relating to real life for enabling a fruitful learning process (Boud & Feletti 1991). The environmental problem selected for the AR learning activity integrated a number of characteristics for promoting problem-based learning as it was complex and ill-structured, while at the same time it was realistic, motivating for students' need to know and learn, and was facilitating argumentation and explanation building (Barrows & Kelson, 1995; Gallagher Gallagher, Stepien, & Rosenthal , 1992; Kolodner, Hmelo-Silver & Narayanan, 1996).

1.5.2 Case-based Reasoning

Case-based reasoning suggests a specific approach of problem-based learning in which students learn by engaging in problem solving and other activities that motivate the need to learn, as well as that give them the opportunity to apply what is being learned in a way that affords real feedback (Kolodner, 1997; Kolodner et al., 1996; Schank & Cleary, 1994). In particular, according to Kolodner et al. (2003), case-based reasoning means "extending one's knowledge by interpreting new experiences and incorporating them into memory, by reinterpreting and re-indexing old experiences to make them more usable and accessible, and by abstracting out generalizations over a set of experiences" (p. 502).

"Mystery at the lake" was designed to support case-based reasoning. The first version of "Mystery at the lake" included ten hotspots (Figure 1.3), three of which presented students with three relevant environmental cases; each of these experiences could be re-interpreted and used to support the students' investigation of the environmental science problem related to the decline of the mallard duck population.

Figure 3.3: The first version of "Mystery at the lake"

In particular, each of these hotspots provided information about an environmental case related to the decline of a different bird species.

- Environmental case 1: The decline of flamingos due to lead bioaccumulation caused by the intense shooting activity at a shooting center nearby a local lake
- Environmental case 2: The decline of falcons due to bioaccumulation caused by the intense use of pesticides at a farming area, for protecting the crops
- Environmental case 3: The decline of herons, due to eutrophication caused by the intense use of fertilizers at a farming area, nearby the lake

The remaining hotspots (n=7) provided data relating to the mallard duck inhabiting the lake (Figure 1.4) or data related to a set of measurements about the lake ecosystem (e.g. nitrates, phosphates).

Figure 4.4: An example of a hotspot providing information about the mallard duck reproduction

Overall, students were expected to employ the three previous cases (decline of flamingos, falcons, herons), as valuable experiences for solving the problem-based case about the decline of the mallard ducks. In other words, according to Kolodner et al. (2003) this means that for solving this new environmental problem related to the decline of the mallard ducks, students were expected to adapt an old solution, or merging pieces of several old solutions, for interpreting this new environmental case in light of similar environmental cases, or projecting the effects of a new environmental case by examining the effects of a similar old environmental case.

1.5.3 Reflective Inquiry

Reflecting on the relationship between problem solving and learning is a crucial component of problem-based learning and can support the development of students' scientific knowledge (Salomon & Perkins, 1989). According to Hmelo-Silver (2004) reflection supports students in (a) relating their new knowledge to their prior understanding, (b) mindfully abstracting knowledge, and (c) understanding how their learning and problem-solving strategies might be reapplied.

In this context, a crucial aspect during the design of the AR learning activity "Mystery at the lake" was to support and promote students' reflection, as they were attempting to investigate this complex problem for providing an evidence-based explanation. In this context, special emphasis was placed on reflective inquiry scaffolding, which according to Kyza, Constantinou and Spanoudis (2011) refers to those "structures that can support the coupling of students' inquiry activities and reflection during students' explanation-building process" (p. 2492). In particular, these scaffolding structures were realized through the integration of the notepad and data capture tool, which students were instructed to employ for capturing and reflecting on the available data related to their problem-based investigation. Both of these tools supported students' science inquiry though the mechanisms of articulation and reflection, as presented by Kyza & Edelson (2005).

1.5.4 Overview of the "Mystery at the Lake"

During the activity, students assume the role of environmental investigators (*TraceReaders*); this requires them to collect and interpret data provided by a number of virtual characters, in order to develop an evidence-based stance regarding the environmental problem presented. While in the field, each pair shares a tablet, equipped with Global Positioning System (GPS), and activates the AR app that includes documents, images, videos and data related to the environmental investigation; the data are triggered as students approach different "hot spots" around the lake. In particular, as students move around in their physical location, a map in the augmented reality app displays the location of the hotspots in the real world.

More specifically, as students approach a hotspot, a virtual character appears and augments the real landscape, by providing information related to a different aspect of the problem. Each character has a different role (e.g. resident, farmer, chemist, ecologist, birdwatcher, etc.) and all these characters provided new evidence to the students, thus contributing to the emergence of a narrative plot, framing the environmental problem. In its essence, this narrative is structured around the three main plausible explanations related to the previous problem-based cases presented: lead bioaccumulation, pesticides bioaccumulation, and eutrophication that could justify the decline of the duck population. Hence, during the learning process students are asked to weigh all the evidence they gather, and use it to achieve an evidence-based explanation. By the end of the activity, students are asked to report their final evidence-based decision about the problem-based environmental case, while rejecting other alternate explanations, by preparing a 3-minute video.

1.5.4.1 The Augmented Reality Hotspots

The learning activity included 10 augmented reality hotspots. These hotspots were: Hotspot 1: Bishop's lake; Hotspot 2: Poaching; Hotspot 3: Farming activity; Hotspot 4: Mallard duck reproduction; Hotspot 5: Herons, Hotspot 6: Water quality, Hotspot 7: Falcons, Hotspot 8: Mallard ducks, Hotpot 9: Mosquitoes and Hotspot 10: Flamingos. Each hotspot was triggered once the students were within a radius of 20 meters; once triggered, the app automatically displayed a variety of information about the hotspot on the students' tablets. Clicking on the available options enabled the students to view multimedia content and find out more about the hotspot. Information was presented as a video, text or image; videos were accompanied by a transcript of the narration, which could be shown or hidden on request. This context-aware presentation of information which is coupled with the specific location has the capacity to help students organize the information more efficiently (Chiang et al., 2014) and can contribute to reducing cognitive load (Mayer & Moreno, 2003).

1.5.4.2 An Example of a Hotspot

This section provides an overview of Hotspot 6, as an example of a hotspot which provided students with a set of multimedia data related to the water quality of the lake. As students arrive at "Hotspot 6: Water quality" a virtual character image appears on the tablets' screen. When students select the image a cartoonish character appears on the screen and introduces students at the hotpot.

> ***George Papanikolaou - Biologist (Department of environmental management)***
>
> *"Good morning… As I've seen you to approach I thought you're really very lucky! You came right on time, as I have just completed a series of measurements and tests related to the investigation of the quality of the lake's water. These analyses attempted to identify the aquatic invertebrates present in the lake water. You see, the presence of aquatic invertebrates in the lake water is a significant indicator for the condition and sustainability of the lake's ecosystem. In addition, my analyses focused on the identification of nitrates and phosphates in the lake's water, as these can result in the decrease of dissolved oxygen in the water. Given that the mallard duck nests, reproduces and finds food in the Bishop's lake, information related to the status of the lake ecosystem might help us solve the mystery."*

As shown in Figure 1.5, student's introductory screen also includes a menu with four additional options: (a) Aquatic invertebrates, (b) Measurement of aquatic invertebrates, (b) Nitrates and phosphates, and (d) Measurement of nitrates and phosphates.

Figure 5.5: The introductory screen of "Hotspot 6: Water quality"

When students select the "Aquatic invertebrates" option, the app displays a diagram with the aquatic invertebrates identified at the lake and their tolerance to water pollution, along with the following text.

> *Freshwater aquatic invertebrates include organisms such as grubs and insect larvae, crustaceans, snails or worms, which, as their name indicate, have no spine. In the diagram you can see the six aquatic invertebrates which one can encounter in the water of the Bishop's Lake.*
>
> *In addition to the name and photos of each identified species, you can see the tolerance of each species to organic pollution 1-10. In accordance to the international scale for pollution tolerance, aquatic invertebrates which are highly resistant to organic pollution are assessed with 1 degree. Conversely, the aquatic invertebrates, which are less resistant to organic pollution, are assessed with 10 degrees. Additionally, the diagram will provide you with the needs of aquatic invertebrates in dissolved oxygen which recruit from water. In addition, you can identify the needs of each organism in dissolved oxygen.*

When students select the "Measurement of aquatic invertebrates" option, the app displays a graph indicating the numbers of the aquatic invertebrates measured, along with the following text.

In the graph you can find the measurements of the aquatic invertebrates which were identified at the Bishop's Lake in 2009, as well as the measurements of the aquatic invertebrates that I have conducted today.

In particular, based on the ACFOR scale, the aquatic invertebrate population was classified in five categories, depending on the population's presence in the lake, as follows:

- *Abundant (identified in greater than or equal to 30% of the water sample)*
- *Common (identified in 20 to 29% of the sample)*
- *Often (identified at 10 to 19% of the sample)*
- *Occasionally (identified in 5-9% of the sample)*
- *Rarely (found in 1-4% of the sample)*

When students select the "Nitrates and Phosphates" option, the app displays an image of phosphates and nitrates, along with the following text.

The lakes, depending on the amount of nutrients they contain (nitrates and phosphates), are classified as (a) oligotrophic, (b) mesotrophic, (c) eutrophic and (d) Hypereutrophic, as follows:

- *Oligotrophic lake: Nitrates (<0.3 mg / L) / Phosphates (<0.01 mg / L)*
- *Mesotrophic lake: Nitrates (0.3-0.5 mg / L) / Phosphates (0.01-0.03 mg / L)*
- *Eutrophic lake: Nitrates (0.5-1.5 mg / L) / Phosphates (0.03-0.1mg / L)*
- *Hyper eutrophic lake: Nitrates (> 1.5 mg / L) / Phosphates (> 0.1 mg / L)*

Finally, when students select the "Measurement of nitrates and phosphates" option, the app displays a graph indicating the number of the aquatic invertebrates measured, along with the following text.

The greater the amount of nitrates and phosphates in a lake, the greater the number of algae that grows and covers the surface of a lake, preventing aquatic plants employ light to photosynthesize and produce oxygen. Therefore, the oxygen is in the lake water is gradually reduced and the aquatic organisms suffocate.

Specifically, with regard to the amounts of dissolved oxygen in the lakes:

- *Dissolved Oxygen > 6 mg / L - Survival of more aquatic organisms*
- *4-6 mg / L dissolved oxygen - Most aquatic organisms are negatively affected, however they survive*
- *Dissolved oxygen 2-4 mg / L - Most aquatic organisms begin to suffocate*
- *Dissolved oxygen is 1-2 mg / L - Most aquatic organisms die*
- *Dissolved oxygen 0-1 mg / L - Death to all aquatic life in the lake*

In the next graph you can see the results of the chemical analysis of the for the lake water in comparison with the chemical analysis findings of the previous years.

An overview of "Hotspot 6: Water quality" is presented in Figure 1.6

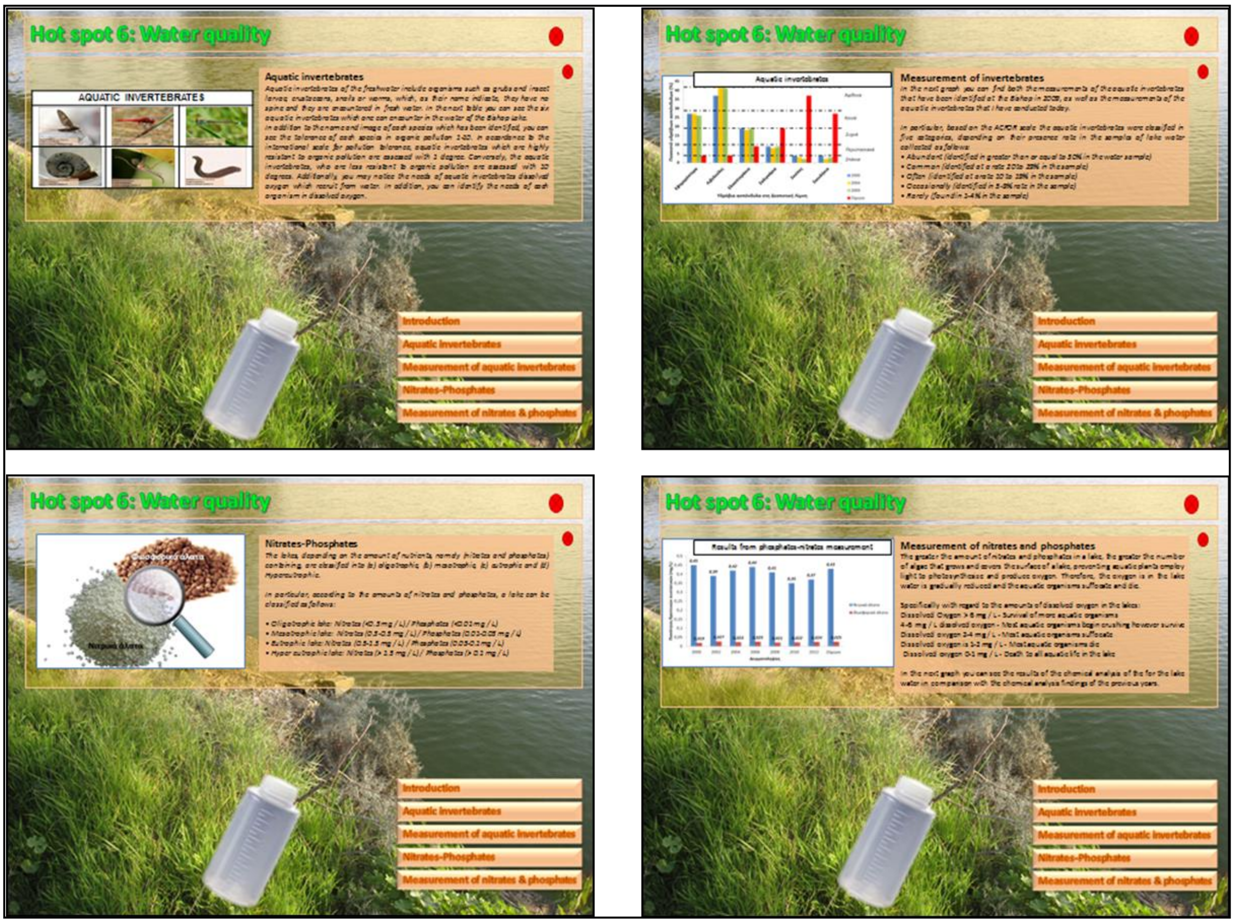

Figure 6.6: Hotspot 6 "Water quality"

1.5.5 The Development of the Location-aware AR App

The learning environment was iteratively developed and empirically validated using a design-based approach (Barab & Squire, 2004; Brown, 1992; The Design-Based Research Collective, 2003). In particular, the first version of the content of the location-aware AR app was initially reviewed by two biological education experts. Both biology experts specialized in environmental science and were the coordinators of the Environmental Education Centre, which hosted the AR learning activity. Both biology experts were asked to review the scientific content embedded in each of the hotspots, and report on the accuracy of the content and its comprehensibility to middle and high-school students. Based on their comments, minor changes were implemented in the educational content for better defining and clarifying the ecological phenomena presented or simplifying any complex scientific phrases.

At a second stage, the location-aware AR app was tested with two different environmental educators, which took the role of students (Figure 1.7). After this process, both environmental educators were asked to provide feedback about the overall difficulty and complexity of the learning process.

Figure 7.7: The environmental educators test the location-aware AR app

Based on their comments, minor changes were implemented in how the three environmental cases reported (e.g. decline of flamingos, falcons, herons), such as removing any unnecessary information and highlighting the evidence that would support students' explanation-building during the problem-based investigation; this also contributed to the simplification of the learning content. Finally, the development of the location-aware AR app was tested in a pilot study with 18 high-school students, who reported on the immersiveness of the learning environment. This pilot study is presented in the next section.

1.6 Pilot Study

The pilot study was conducted during the summer of 2013. The study employed a design-based approach (Barab & Squire, 2004; Brown, 1992; The Design-Based Research Collective, 2003) and a naturalistic case study methodology (Stake, 1995; Yin,

1994) collecting data from nine pairs of 11th graders. The pilot study qualitatively investigated the factors which affected high school students' immersion during the implementation, aiming to revise the app as needed, to improve its usability and its immersive affordances.

1.6.1 Methodology

Eighteen 11th graders, working in nine pairs employed the "Mystery at the lake" AR activity (Figure 1.8); the activity lasted approximately 2 hours. At the end of the AR activity, students participated in two group interviews, which lasted 90 minutes each.

Figure 1.8: Students employing the location-aware AR app during the pilot study

The nominal group technique (McPhail, 2001) was used for analyzing the post-activity interviews. According to this technique, students were initially asked to individually write down and justify their viewpoints regarding the immersive nature of the location-based AR activity. The written prompts asked students about issues of immersion, such as, for example, whether they felt engaged with the location-based AR activity during the activity. As a second step, students were asked to share their ideas with the group; the interviews concluded with a debriefing discussion. In this way, the individual input from all group members and their collective reflections were accessed, leading to a richer dataset.

The data were qualitatively analyzed, using the Attride-Stirling's (2001) thematic network analysis to identify students' perceived factors of immersion. As part of the analysis, students' negative or positive evaluation of each aspect of immersion was also identified to investigate the subjective nature of the different factors. If there was consensus regarding the positive or the negative evaluation of a factor among the students, this factor could be considered as a more objective factor affecting students' immersion. In contrast, if there was lack of consensus and a mixed evaluation for a factor, the factor was considered as more subjective.

1.6.2 Findings

The qualitative analysis of the two group interviews led to the identification of 21 factors, which were hypothesized to influence the process of immersion in the location-based AR activity. These factors fell in the following categories: (a) user interface, (b) narrative employed, (c) locality and (d) Unforeseen distractions (see Table 1.1).

Table 1.1: Categorization and evaluation of factors affecting immersion

Theme	Basic themes	Positive Evaluation (Number of students)	Negative Evaluation (Number of students)	Overall Evaluation
Interface	Augmentation of the reality	6	0	+
	Realism, animation, interactivity of graphics	0	9	-
	Realism and fidelity of the virtual characters	0	10	-
	Text-based information	0	8	-
	User-friendliness of interface	6	5	+/-
Narrative	Problem-based investigation	15	0	+
	Agency and first-person perspective	0	3	-
	Topic of investigation	5	9	+/-
	Diversity and usefulness of the data	4	9	+/-
	Competitive nature	2	6	+/-
	Level of challenge	4	4	+/-
	Narrative plot	3	8	+/-
Locality	Nature-based location	15	0	+
	Mobility and location aware nature of the app	8	0	+
	Balance between the physical and virtual world	0	11	-
	Hotspot arrangement	0	6	-
Unforeseen obstacles	Weather	0	17	-
	Technical bugs	0	9	-
	External noises	0	6	-
	Environmental distractions	0	8	-
	Screen glaring	0	6	-

1.6.2.1 *Interface*

The factors relating to the interface seemed to be evaluated more univocally by the students. Students positively evaluated the affordances of the interface to augment their reality and promote immersion. As they explained, the combination of the real and digital worlds was one of the strongest points of the app and contributed to their immersion. However, students negatively evaluated the cartoonish graphics and characters employed, asking for more interactive and animated graphics in combination with more realistic virtual characters. They also negatively evaluated the text-based information provided, suggesting that the text-based nature of the data sources made the experience less enjoyable for them. Finally, as shown in Table 1.1, despite students' consensus in the evaluation of the aforementioned factors, the user-friendliness of the interface received mixed evaluation. More specifically, while most of the students reported that the ease of use of the interface facilitated their immersive experience, others reported that they found the interface complicated. Students, who stated that they had difficulties when employing the AR app, reported that during the learning activity they were anxious and stressed about working with the app.

1.6.2.2 *Narrative*

The factors relating to narrative was assessed as more subjective, as there was a lack of consensus in most of the students' evaluations. As students indicated, the problem-based investigation contributed to their immersion, as they had to investigate a situation which, unlike traditional learning activities, activated their interest. However, students also reported a lack of agency which hindered their immersion since, as they explained, they would prefer to be more actively involved with the activity, by taking, for instance, scientific measurements in the field rather than just receiving secondary information by the virtual characters.

On the other hand, and despite this consensus, students provided mixed evaluations regarding most of the narrative-based factors. More specifically, while many of the students expressed their lack of interest towards the topic of the investigation, others stated that the topic was well-aligned with their interests. In addition, while several students reported that they felt unsatisfied with the level of the challenges, or that the narrative plot lacked surprises, others indicated that the learning activity was challenging or found the narrative plot quite interesting; the latter students seemed to be more immersed in the learning activity. Students' views differed in terms of their evaluation of the diversity and usefulness of the information provided by the different data sources; while some students stated that the diversity of data contributed to their immersion, since they had to connect several pieces of data in order to solve the mystery, others reported that they had to focus on many data, which on many occasions were not useful for the solution of the problem-based investigation. Finally, while some students mentioned that they felt a sense of competition, which made the activity more challenging for them, others reported that what prevailed was the collaboration, within and across the pairs.

1.6.2.3 Locality

Factors relating to the locality were evaluated univocally by the students. Students reported that the nature-based location by the lake was an appropriate locale for the activity, which contributed to their sense of immersion. Nonetheless, students also emphasized the need for a greater coupling between the physical and the virtual world, through the combination of both digital and real artifacts, for the creation of a more immersive augmented reality space. In addition, students disliked the hotspots' circular arrangement by the lake, explaining that they would like to follow a more challenging yet meaningful path of inquiry, during which the hotspots would be more intertwined with the physical space.

1.6.2.4 Unforeseen Obstacles

In addition to the factors reported by the high school students, as affecting their immersion during the activity, most of the students reported also on a number of unforeseen distractions, negatively affecting the whole immersive experience. The most reported distraction was heat, which, according to their reports, affected students' concentration during the activity; the glare of the screen due to the intense sunlight was also an important obstruction. Finally, students also highlighted how environmental distractions (e.g. mosquitoes), external noise and technical problems (e.g. GPS stability, technical issues) were distracting them during the learning activity.

1.6.3 Revisions to the "Mystery at the Lake" Location-based AR App

The findings of the pilot study led to several revisions in the location-based AR app by July 2014. These changes were related to the (a) user interface, (b) narrative employed, (c) locality and (d) unforeseen distractions identified. The changes are briefly presented next.

1.6.3.1 Interface

Following students' comments about the factors relating to interface and which negatively affected the students' immersive experience, the following revisions were implemented. First, the textual information was reduced in all hotspots. Second, when feasible, the text was replaced with videos or images. Third, the cartoonish characters were replaced with realistic, virtual characters. Finally, existing videos and images were replaced with more realistic and multimedia material, such as realistic virtual characters and virtual objects of higher fidelity.

1.6.3.2 Narrative

A key goal of the redesign effort was to reduce the complexity and inherent difficulty of the location-based AR activity. Towards this direction, the narrative plot was simplified by decreasing the number of the environmental cases, about the mallard ducks, employed in the environment.

In particular, in the revised version only two relevant environmental cases remained: (a) The decline of falcons due to bioaccumulation caused by the intense use of pesticides at a farming area for protecting the crops, and (b) The decline of herons, due to eutrophication caused by the intense use of fertilizers at a farming area near the lake. This change also resulted to the decrease of hotspots from ten to eight, and reduced the duration of the activity to 1.5 hours. In addition, more primary data resources were added to the narrative plot (e.g. students were asked to collect data through real props embedded in the natural environment), instead of information from textual secondary resources (Figure 1.9). This change aimed at increasing students' agency and first-person perspective.

Figure 1.9: Students collecting data from the physical world

1.6.3.3 Locality

A key goal of the redesign effort was to integrate the physical and virtual layers as best as possible, by taking advantage of landmarks on site and by inviting students to engage with the physical and the virtual world, not simply being informed about them. In this context, in the revised version of the location-based AR activity students learn about the lake's ecosystem not by navigating through the hotspots, but were also invited to test the quality of the lake water to examine whether variables relating to water contamination or pollution may be contributing to the problem they are trying to solve (Figure 1.10). In addition, the hotspots were placed in a more complex yet meaningful path. Finally, whenever possible, artifacts and real props, related to the virtual information presented on students' tablets, were placed in the real world to enhance the connections between and balance of virtual-real world.

Figure 1.10: Students measuring water quality

1.6.3.4 *Unforeseen Obstacles*

Unforeseen distractions that seemed to affect the learning experience, during the pilot study, were also addressed when possible. For instance, to avoid hot temperatures it was decided that the location-based AR activity would be implemented only during spring instead of summer. In addition, for reducing the reflection of the screen, all tablets were equipped with anti-glare screen protectors. Finally, technical bugs related to GPS accuracy were also addressed and resolved.

1.6.4 Conclusions

This chapter described the rationale behind the development of the *TraceReaders* AR platform. It also described the "Mystery at the lake" learning environment as a location-aware AR app especially designed for the purposes of this doctoral study. A pilot study investigated the factors which high school students reported as promoting or hindering their immersion in "Mystery at the lake", as a location-based AR activity for inquiry-based science education. Several factors relating to the user interface, the narrative, the locality or unforeseen distractions have emerged as affecting students' immersion. These factors were addressed in the revised version of the location-aware AR app for enhancing students' immersive experience. Overall, the present chapter addresses the first methodological challenge identified, which was related to the lack of AR platforms allowing the development of location-aware AR apps for Greek-speaking students. In addition, the pilot study provided useful insights about the factors affecting immersion in location-based AR settings.

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CHAPTER 2: A CASE STUDY OF IMMERSION IN RELATION TO STUDENTS' SCIENCE LEARNING

Abstract

Immersion has been argued to affect students' learning in settings such as virtual worlds and digital games. However, a review of the literature indicates a lack of empirical studies investigating immersion in relation to the learning process. The chapter presents a case study, which characterizes students' immersive experiences during a location-based augmented reality science activity. Two pairs of students were purposefully selected from a cohort of eighteen 11th graders, due to their diametrically opposing views about their immersive experience. The analysis of students' discourse during the activity, and of post-session interviews, yielded a coherent indicator of immersion. To investigate whether each pair's immersion affected the learning process, we analyzed activity logs, discourse and learning outcome of the two pairs during the collaborative learning process. Findings show that immersion was related to the learning process, dramatically affecting students' learning behaviors, such as collecting and interpreting the available data, as well as problem-solving patterns.

2.1 Introduction

Immersion is a widely-used construct in the literature on digital learning technologies, such as computer and video games, avatar-based virtual worlds or location-aware AR apps. According to Dede (2009), immersion is "the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (p.66). Conceptualizing immersion as a gradated process of cognitive and emotional involvement, researchers have argued that heightened levels of immersion can be a powerful contributor to learning (Cheng et al., 2015). Based on the review of the extant literature there is a lack of empirical studies investigating immersion in relation to the learning process or the construct of immersion when students collaborate; this is an oxymoron given that immersion represents a psychological experience unfolding during the learning process (Jennett et al., 2008).

Empirical studies on the topic, mostly using quantitative methodologies, have previously investigated immersion in relation to students' learning gains in the context of game-based virtual worlds and have often resulted in contradictory findings. Although some of these studies have provided empirical support for the positive effect of immersive digital games on students' learning (e.g. Hickey et al., 2009; Ketelhut et al., 2010), other studies have found weak or no relation between immersion and learning outcomes (e.g. Cheng et al., 2015; Hsu & Cheng, 2014). However, even though the latter studies have not identified a positive relation between learning outcomes and immersion, they have indicated that immersion is highly related to students' game scores, suggesting that immersion has a significant impact on students' performance during the learning process. On a similar note, Hsu and Cheng (2014) found no relation between higher levels of immersion and 7^{th} graders' conceptual understanding, but identified relations between high levels of immersion and students' problem-solving skills. These findings led them to assume that higher levels of immersion may affect students' problem-based patterns during the learning process, which may not be identified by simply looking at the learning outcomes.

The present study investigates the claim that immersion relates to the learning process in the context of a collaborative location-based AR activity. Similarly to other studies of immersion, augmented reality is a context where immersion is assumed to support learning but this claim has not been empirically investigated (Cheng and Tsai,2013; Dunleavy, Dede & Mitchel, 2009). Since there is scant research on investigating immersion and its relation to learning in location-based augmented reality settings, the first goal of this study was to characterize immersive experiences as experienced by the students in the field and as reported at the end of the activity. A second goal of this study was to investigate the relationship between students' immersive experiences, their learning process and outcomes. Understanding immersion in location-based augmented reality settings, and its relation to learning, can help us build more engaging learning environments and support learning in informal and outdoors settings.

2.2 Theoretical Framework

Location-based augmented reality (AR) settings for science education are assumed to increase students' immersion and contribute to learning outcomes, due to set of unique characteristics (Dunleavy et al., 2009). In particular, location-based AR settings differ from other digital immersive environments, as they: (a) employ mobile and location-aware interfaces, (b) combine physical and digital spaces, thus creating blended spaces,

(c) extend the activity outside the limits of traditional space (e.g. the screen) into the physical space, and (d) provide students with rich interaction possibilities with the physical world, as well as with the virtual elements augmenting reality (De Souza E Silva & Delacruz, 2006). However, learning in location-based AR settings is often considered as a highly challenging task. Based on existing literature, location-based AR settings for learning science should be structured around authentic but complex real-world problems; for their solution students are often asked to work collaboratively for collecting and synthesizing relevant data, as they progress through multiple, virtual- or real-based data sources (Dunleavy et al., 2009; O'Shea, Mitchell, Johnston, & Dede, 2009). In addition, collaborating students in location-based AR settings are required to apply a set of complex skills, such as collaborative problem-solving, inquiry-based skills, geo-spatial navigation skills and handheld manipulation (Dunleavy et al., 2009).

Immersion, as a multi-level process of cognitive and emotional involvement, can be crucial in terms of defining students' performance, given the complex nature of collaborative location-based AR activities. Being highly immersed in location-based AR settings, reflects students' perception of feeling surrounded by a blended, yet realistic augmented environment, as being in a unified and single world (Cheng & Tsai, 2013). When this occurs, "students quickly enter a state of suspended disbelief, accept the blended real and digital environment, give their attention over to it, and engage in the variety of options available to them to access content related to the topic being addressed" (Cabiria, 2011, p. 240). Despite these assertions, Cheng and Tsai (2013) have argued that even though immersion is expected to relate to students' behaviors in AR-related learning, there is still lack for empirical studies investigating how the learning process unfolds under the light of experienced immersion.

The present case study focused on two pairs of high school students, who reported diametrically opposite views about their immersive experience during a collaborative AR location-based activity, investigating: (a) How can we characterize immersion in location-based AR investigations, and (b) What is the relation of immersion and learning?

2.3 Methodology

2.3.1 Participants

Eighteen 11th grade students, working in pairs, participated in the augmented reality activity using mobile devices; their AR experience lasted for approximately 2 hours. Students were randomly assigned to pairs. This case study purposefully focuses on two pairs: Janet and David (Pair 1) and Susan and Jack (Pair 2); pseudonyms were employed. These two pairs were selected due to their diametrically opposing views regarding their immersive experience, as expressed by them in interviews, which took place after the activity. This focus provides the opportunity to explore whether and how immersion is related to the learning process during the location-based AR activity.

2.3.2 Learning Intervention

The collaborative location-based AR activity took place at a lake near an environmental science center. During the activity, which took the form of a narrative-driven, inquiry-based investigation, students worked in pairs to investigate the mysterious decline of mallard ducks inhabiting the lake; each pair was provided with a tablet equipped with the AR app. The goal of the activity was to engage students in an evidence-based, explanation-building process, and to expand students' understanding of scientific concepts related to a lake ecosystem. As students moved around in the physical world, a map in the AR app displayed information corresponding to different hotspots. The hotspots were triggered once the students were within a radius of 20 meters; once triggered, the app displayed a variety of multi-modal information (e.g. videos, texts, photographs, and audio) which was relevant to the inquiry-based investigation.

2.3.3 Data Collection

To characterize immersion and investigate its relation to learning, data were collected during and after the pairs' AR activity.

2.3.3.1 Data Collected During the Augmented Reality Activity

The following data were collected during the students' investigation: a) Log files: Students' actions during the intervention were captured in a log file documenting the history of the students' actions, such as time spent on each activity in the app. b) Audio-taped discussions: Each pair's discussions were audio-recorded through a seamlessly integrated recorder within the AR location-aware app employed. c) Pairs' final videos: The overall performance of each pair was evaluated based on whether they had reached an evidence-based conclusion at the end of their investigation. For this purpose, each pair was asked to prepare a 3-minute video at the end of their investigation, in which they presented their final conclusions and arguments.

2.3.3.2 Data Collected After the Augmented Reality Activity

Students participated in two interview groups which took place after the learning activity and lasted for 90 minutes each. The nominal group technique (McPhail, 2001) was used for the post-session interviews. According to this technique, students were initially asked to write down and justify their viewpoints regarding the immersive nature of the location-based AR activity individually. As a second step, students were asked to share their ideas with the group; the interviews were completed with a debriefing discussion. In this way, we received both the individual input from all group members and had access to richer discussion resulting from group interaction on the topic.

2.3.4 Data Analysis

The data were analyzed using mixed methods to answer the questions about the process of immersion during the AR activity and the relation of immersion to student learning.

2.3.4.1 Characterizing Students' Immersion

The views of the four students expressed during the post-session interview were qualitatively analyzed in order to develop an Immersion Indicator, reflecting students' immersion for each pair. For this purpose, we used a coding scheme by Scoresby and Shelton (2011), which defined immersion as a linear process according to which interest for the activity *content*, and *emotion* evoke *motivation*, which in turn results in *engagement* (Table 2.1). Thus, the statements of each pair were categorized per student and according to these four immersive states (content, emotion, motivation, and engagement). Statements per state were also classified as negative or positive, thus providing a more nuanced indication of the ways students experienced each different state. Furthermore, students' statements about each state were grouped using a thematic analysis approach (Attride-Stirling, 2001). The immersion indicators, derived from coding the views of the students in each pair, were supplemented with the analysis of the pairs' discourse during the learning process, which was also coded as positive or negative using the Scoresby and Shelton (2011) coding categories. This process provided a systematic way to characterize students' immersion, addressing both the cognitive and emotional involvement with the location-based AR activity. The inter-rater agreement between two independent researchers, who coded 25% of the data corpus, was estimated using Cohen's kappa and was satisfactory, at κ=.816, p<.001 for the pairs' statements and κ=.741, p< .001 for students' discourse.

Table 2.1: Coding scheme for characterizing students' immersion

Immersive state*	**Definition**	**Examples of positive statements (+)**	**Examples of negative statements (-)**
Content	Students indicate their interest about the activity in terms of expressing their likes and their dislikes about the different aspects of the activity e.g. the actions performed, media design, level of difficulty.	*Jack: To begin with, the topic of our investigation was aligned with my interests, since I like to deal with biological issues, such as eutrophication which was one of the main ideas of the activity.*	*David: I would really prefer it, if our investigation was not about the decline of the duck population. I wish it was about something more exciting.*
Emotion	Students indicate their feelings about the activity, expressing an emotional connection or disconnect with the activity.	*N/A*	*N/A*
Motivation	Students indicate their motivation expressing whether they were looking forward or not to discovering what happens next and accomplishing the learning mission.	*Susan: Oftentimes we experienced the whole activity as something real…We were looking forward to obtain the new clues, in order to confirm the ideas that we had in our minds.*	*David: I really felt that there was no action at all out there.*
Engagement	Students indicate their engagement, or lack of, with the learning process and activities.	*Jack: There was no missing information. During the activity we had the feeling that all the information we needed was there. So what you were doing was to investigate all of this information in order to decide what data we should keep.*	*David: It was all about completing some actions because you have to. And in many cases, since you were in nature, your attention was diverted to other things.*

*Based on Scoresby and Shelton, 2011

2.3.4.2 Analyzing Students' Process of Immersion

In order to relate students' immersion with each pair's learning process, we analyzed data from: (a) log files, (b) audio-taped discussions and (c) each pair's final videos. Quantitative data derived from the log files of the two selected pairs were analyzed descriptively, in order to outline each pair's learning process. The two pairs were contrasted in terms of (a) the number of hotspots visited, (b) the time allocated at the different hotspots for examining the data sources, and (c) the time allocated for examining the data sources, which included inscriptions such as tables, graphs and diagrams. Students' audio-taped discussions were analyzed according to a slightly modified coding scheme by Nilsson and Svingby (2009), in order to classify students' discourse according to learning actions during the collaborative location-based AR activity (see Table 2.2). As part of the audio-taped discussion analysis, an interrater process was employed during which two independent researchers coded the 25% of the data corpus. Cohen's κ was run to determine the agreement between the raters, with satisfactory agreement ($\kappa = .802$, $p < .001$). Finally, each pair's final video was qualitatively analyzed to determine if each pair had reached an evidence-based conclusion by the end of the learning intervention.

Table 2.2: Coding scheme for students' discourse during the learning process

Category*	**Description**	**Example**
Obtaining information	Identifying information from the learning environment through reading sources (text, tables, diagrams) or watching videos	*David: Descriptive information… Below you can find some descriptive information about the lake. Area - 1 hectare (10,000 square meters) Depth - 10 meters Enriched with sweet water from the dam*
Capturing data	Taking photos from the field and keeping notes about them as data	*Janet: Ok. Just a moment to capture a photo. And the title is: "6th hotspot, nitrates and phosphates"*
Problem solving	Discussing the content and how to solve the problem	*Jack: Results of measuring the thickness of the eggshells… Susan: Let me take a look! Jack: Look… The highest the quantity of the lindane is…*

Category*	Description	Example
		Susan: Yes? *Jack: The greatest the eggshell thinning is!* *Susan: I think that this is similar with the frog eggs that we had found earlier…* *Jack: That's right… It's like the previous case…* *Susan: So, the highest the quantity of the lindane is…* *Jack: …The chances for the eggs to survive decrease dramatically!*
Navigating	Discussing navigation issues related to the augmented reality app or to the hotspots augmenting the physical space	*David: Wait. Let's take a look at the map. Should we go towards the 2nd or towards the 9th hotspot?* *Janet: Towards what direction?* *David: Towards this direction is hotspot 2. And there is hotspot 9...* *Janet: And do they have the same distance?* *David: Hotspot 9 is much closer...*
Interacting with other pairs	Discussing application-related issues with other pairs	*Another student: Do you know where hotspot 5 is?* *Jack: You to go back… In the area you were before…* *Another student: But we were there before and couldn't find it!* *Jack: It is towards this direction… And you have to turn your tablet also towards this direction…*
Interacting with teachers	Receiving feedback from teachers during the learning process	*Teacher: How is it going?* *Jack: Great! Great! We are almost there… We are very close to solving the case! It's all about the pesticide, the lindane.* *Teacher: So, is it about the pesticide after all?* Jack: Yes! *Teacher: Do you have evidence for this?*
Off-task discussions	Discussing issues irrelevant to the learning scenario	*David: By the way, I should have come with my shorts today, instead of with these jeans…*

*Based on Nilsson and Svingby, 2009

2.4 Findings

This section reports on findings relating to characterizing immersion in location-based, augmented reality settings and the relation between immersion and conceptual learning.

2.4.1 How is Immersion Experienced in Location-based AR Investigations?

The examination of students' Immersion Indicators showed that Pair 1 (Jack and Susan) achieved high levels of immersion (see Table 2.3). As Jack reported, the activity captured his interest due to the user-friendly app, its topic, diversity of data provided, its nature-based location and its location-aware qualities. Even though he did not provide any indications regarding any emotional connection with the activity, Jack also expressed his motivation by explaining how he felt challenged to analyze and reflect on the data collected. He also mentioned how he and Susan were engaged with the learning process, explaining how they were actively involved with collecting and reflecting on their data. Not all Jack's statements were positive. Jack negatively evaluated the realism of the virtual characters, the lack of competition and agency during the activity as well as the balance between the natural and the virtual world. Susan provided fewer statements about her immersive experience, but also highlighted user-friendliness, and commented that the topic of the investigation and the location-aware nature of the activity captured her interest. She also provided indications for her motivation since, as she reported, during the activity she felt anticipation to move forward and to identify new data. Susan did discuss her emotional connection with the activity, as she reported that in some cases she was carried away or she felt that she was experiencing the activity as something real. Based on these statements, both students could be characterized as of high immersion.

On the other hand, Pair 2 (David and Janet) remained at the lowest level of immersion (see Table 2.3 for a summary of the assessment of their immersion experience), since the learning activity did not manage to capture their interest. Even though David had positively evaluated the user-friendliness of the app, he negatively evaluated several aspects relating to the interface of the app, such as the text-based information presented and the fidelity of the graphics. He also negatively evaluated the narrative employed in terms of its topic, the narrative plot and the lack of competition, as well as the locality, in terms of the arrangement of the hotspots and the lack of balance between the natural and the virtual world. Since most of the activity did not capture his interest, he also reported a lack of emotional connection with the activity, stating that he could hardly identify himself with the main character of the narrative-driven investigation. Hence, even though he had indicated that on some occasions he felt motivated to reach a solution to the problem, he provided no indications about his engagement with the learning process. Similarly, Janet reported that her attention and interest were hardly captured by the interface, the narrative and the locality. Therefore, as she admitted, there were times that she felt bored to engage with the learning process (e.g. examine the data sources provided). Given that these students did not provide indications of reaching the immersive states of emotion, motivation and engagement, while at the same time they adopted a, mostly, negative stance towards the content of the activity, both students could be characterized as of low immersion.

Table 2.3 shows the percentage of statements devoted to different aspects of immersion by the students in each pair. The sub-categories under each state of immersion (content, emotion, motivation, and engagement) were reached using a thematic analysis approach.

Table 2.3: Characterizing students' immersion based on post-activity interviews

		High immersion pair				**Low immersion pair**			
		Jack		**Susan**		**David**		**Janet**	
		(+)	**(-)**	**(+)**	**(-)**	**(+)**	**(-)**	**(+)**	**(-)**
Immersion State 1: Content		**55.3**	**21.3**	**33.2**	**33.2**	**10.7**	**82.1**	**14.2**	**71.6**
Interface	User-friendliness	8.5	0	8.3	0	10.7	0	0	0
	Augmentation of reality	8.5	0	8.3	0	0	0	7.1	0
	Realism, animation and interactivity of	0	4.3	0	0	0	0	0	14.3
	graphics	0	2.1	0	8.3	0	10.7	0	28.8
	Realism and fidelity of virtual characters	0	0	0	0	0	7.1	0	14.3
Narrative	Text-based information	14.8	0	8.3	0	0	7.1	0	0
	Topic of investigation	0	0	0	0	0	25	0	0
	Level of challenge	12.8	0	0	8.3	0	0	0	7.1
	Diversity and usefulness of the data	0	8.5	0	0	0	3.6	0	0
	Competition	0	8.5	0	8.3	0	0	0	0
	Agency and first-person perspective	0	0	0	0	0	14.3	0	0
Locality	Narrative plot	4.3	0	0	0	0	0	7.1	0
	Nature-based location	6.4	0	8,3	0	0	7.1	0	7.1
	Mobility and location aware nature of the	0	2.1	0	0	0	0	0	0
	activity	0	0	0	8.3	0	7.1	0	0
	Balance between the physical and virtual								

		High immersion pair				Low immersion pair			
		Jack		Susan		David		Janet	
		(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
	world								
	Hotspots' arrangement								
Immersion State 2: Emotion		**0**	**0**	**25.3**	**0**	**0**	**0**	**0**	**7.1**
Authenticity	Experience the activity as something real	0	0	8.3	0	0	0	0	0
Excitement	Carried out by the activity	0	0	17	0	0	0	0	7.1
Immersion State 3: Motivation		**4.3**	**0**	**8.3**	**0**	**7.1**	**0**	**0**	**0**
Continuous	To discover something from your data	4.3	0	0	0	7.1	0	0	0
Challenge	To discover new data	0	0	8.3	0	0	0	0	0
Anticipation									
Immersion State 4: Engagement		**19.1**	**0**	**0**	**0**	**0**	**0**	**0**	**7.1**
Data	Collecting data and new information	4.3	0	0	0	0	0	0	0
collection	Analyzing, interpreting and combining	14.8	0	0	0	0	0	0	7.1
Reflecting	your data								
TOTAL		**100**		**100**		**100**		**100**	

The above characterization of immersion was complimented through the analysis of the pairs' discourse during the learning process (see Figure 2.1). This analysis corroborated students' post-activity statements about their immersion.

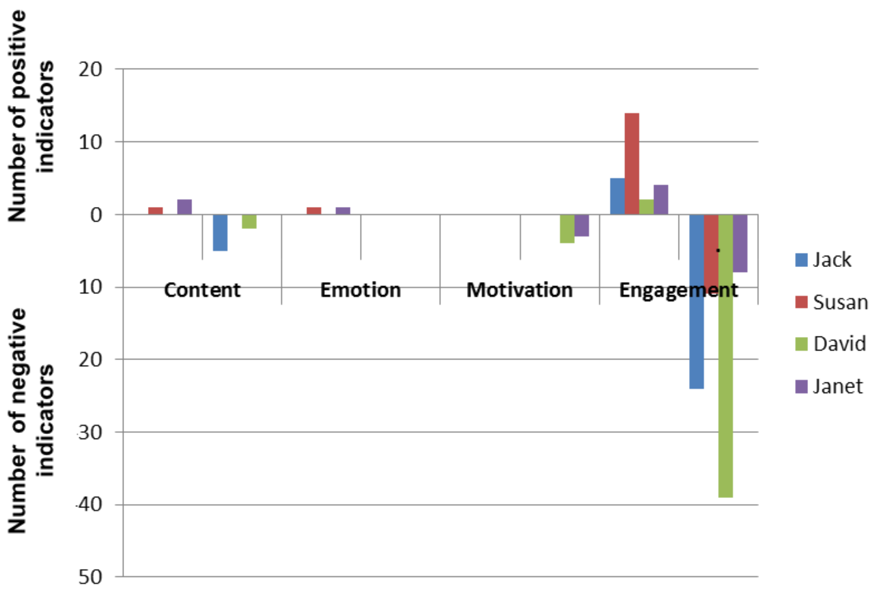

Figure 2.1: Indicators of immersion extracted from students' discourse

As shown in Figure 2.1, Pair 1 discourse (Jack and Susan) provided no indications of low motivation, Pair 2 discourse (David and Janet), offered several indications of low motivation during the activity. In addition, Pair 1 seem to be distracted and disengaged much less during the activity than Pair 2.

2.4.2 Is Immersion Related to Students' Conceptual Learning?

A descriptive analysis of the two pairs' actions, as recorded in the log file of each pair, indicated that both pairs visited all of the hotspots. However, the high immersion pair (Pair 1, Susan and Jack) differed from the low immersion pair (Pair 2, David and Janet). Pair 1 allocated almost double the time at hotspots in examining all provided data sources, and triple the time in examining specifically the data sources with inscriptions such as tables, graphs and diagrams, which needed to be analyzed and interpreted (see Figure 2.2).

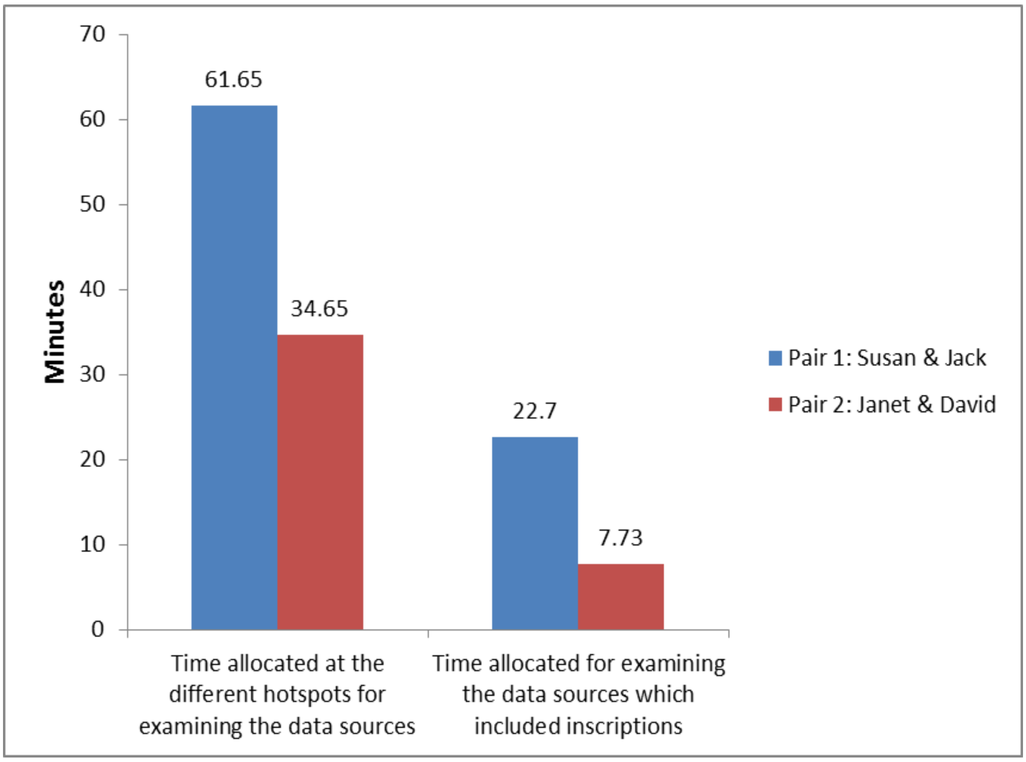

Figure 2.2: Time allocation per pair at hotspots

The analysis of each pair's discourse during the learning process indicated that the learning activity of the two pairs was also largely different: Susan and Jack (high immersion pair) seemed to be more engaged with the activity than Janet and David (low immersion pair). As shown in Figure 2.3, while for Jack and Susan (High immersion pair) the coded episodes relating to the categories of obtaining information and problem-solving covered 25% and 24% of the total discourse coded for the group respectively, in the case of David and Janet (Low immersion pair) these percentages were much lower, covering 17% and 13% of the total number of coded episodes. In addition, the percentages of the coded episodes relating to off-task discussions for Janet and David were much higher (23%) as compared to the percentages of the high immersion pair (16%).

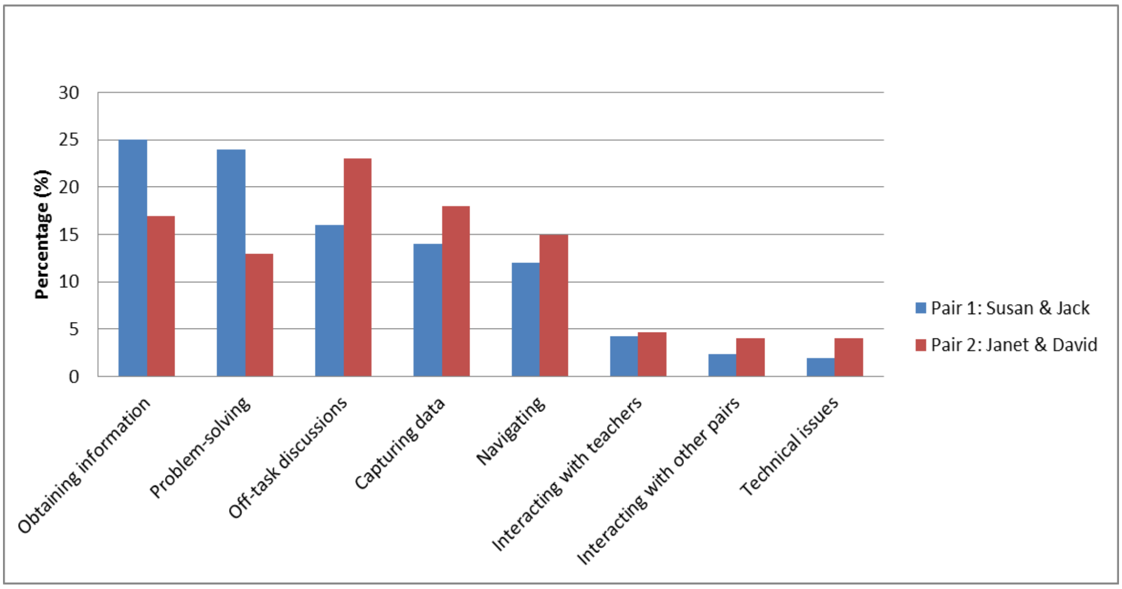

Figure 2.3: Pairs' discourse during the learning process

The analysis of students' discourse indicated that the actions of obtaining background information and engaging in problem-solving were different for the two pairs. Susan and Jack, who were highly immersed, payed more attention to the data; as shown in Excerpt 1, these students invested much effort in making sense of the information collected, by reading, for instance, the text more than once.

<u>Excerpt 1</u>

Virtual character: I have an analysis for you regarding the water quality. The analysis focuses on the detection of aquatic invertebrates of the lake…

Jack: Did you understand what he just said?

Susan: *What did he say about the aquatic invertebrates? Rewind the video for a moment…*

Jack: *Ok… Let's hear it once again from the previous point.*

In contrast, Janet and David seemed to pay less attention on making sense of the data sources when dealing with new information; as shown in Excerpt 2, students even disregarded a video or text source, before completing its study, in order to move on.

Excerpt 2

Janet: *Several chemical substances…*

David: *There is no need to give much emphasis here. Please read it more quickly.*

Janet: *Ok! Several chemical substances like DDT or lindane, bla, bla, bla…. This phenomenon is called bioaccumulation… blah, blah, blah. DDT is transferred to zooplankton… blah, blah, blah…*

Another difference was the extent to which students' discussions focused on the problem-solving action, as the two pairs approached the activity very differently. Janet and David, who were not highly immersed, not only allocated less time on reasoning about the subject but, as presented in Excerpt 3, in most of the cases they did not make an effort to interpret the information and relate it to how it could be employed as evidence to confirm or reject a hypothesis or connect new information with data they had already seen.

Excerpt 3

Janet: *So, now we have the lindane pesticide which is still used during some occasions for the agricultural crops.*

David: *Yes, ok…*

Janet: *Lindane…*

In contrast, Susan and Jack, who were highly immersed, were in continuous discussion about how the new information obtained could confirm a plausible explanation or not. As shown in Excerpt 4, students would often discuss the different emerging hypotheses regarding the cause of the decline at the duck population, such as the use of pesticides or the use of fertilizers resulting to eutrophication, trying to reach in an evidence-based decision.

Excerpt 4

Susan: *Yeah… But keep in mind that the cause for the problem is probably one… Now we are torn between the nitrates and the phosphates and the eggshell thinning.*

Jack: *Ok… Let me think… nitrates and the phosphates…*

Susan: *To what reason did we attribute the eggshell thinning?*

Jack: *To the lindane…*

Susan: *To the lindane… You see? But lindane is a pesticide…*

Jack: *Yes. They use it as a pesticide.*

Susan: *So the problem could be attributed either to spraying or to fertilizers.*

To sum up, Susan and Jack, who were characterized as a pair of high immersion, were deeply engaged in the process of interpreting and combining the collected data. On the other hand, the analysis of the low immersion pair's discourse and actions, indicated that Janet and David, defined the whole investigation process more as a scavenger hunt, by simply collecting the same data as quickly as possible, without focusing on analyzing or interpreting the collected data. Hence, while by the end of the investigation, based on the analysis of each pair's final video, Susan and Jack correctly concluded that the decline of the duck population could be attributed to bioaccumulation, Janet and David did not manage to reach an evidence-based conclusion.

2.5 Discussion and Implications

The present case study sought to investigate immersion in relation to learning in a location-based AR activity. In this context, this study was purposefully focused of two pairs of high school students, who expressed diametrically opposite views regarding their immersion, attempting to: (a) characterize students' immersive experiences, and (b) investigate the learning process of each pair, to examine the relation of immersion to students' learning.

The analysis of the two selected pairs' learning process highlighted several differences. While by the end of the investigation, the first pair correctly concluded that the decline of the duck population could be attributed to bioaccumulation, the second pair did not manage to reach an evidence-based conclusion. While the outperforming pair was immersed in the process of analyzing and interpreting the collected data, the second pair defined the whole investigation process as a scavenger hunt, by simply gathering the same data as quickly as possible, but without reflecting on the collected data. These extremes observed in the learning behaviors of the two pairs are aligned with reports of previous studies, which concluded that while in some cases some students employing location-aware AR apps could be deeply engaged with the true meaning of scientific inquiry, others could present indications of disengagement by transforming the learning process into a meaningless "treasure hunt" activity (e.g. Dunleavy, Dede, & Mitchell, 2009; Squire & Jan, 2007; Squire & Klopfer, 2007).

The observed difference between the two pairs' performance could be attributed in our case to students' immersion, as this was reflected in the Immersion Indicators emerging for each of the pairs. According to the Immersion Indicator of the outperforming pair, students were positively engaged in the immersive levels that Scoresby and Shelton (2011) suggested: content, emotion, motivation, and engagement. In contrast, the students in the second pair did not find the activity content interesting and remained at the lowest level of immersion. These findings provide empirical support for Cheng and Tsai's (2013) assumption that immersion is expected to relate to learners' behaviors in AR learning, while also extending previous research efforts in the field of game-based virtual worlds supporting that immersion may influence students' performance, such as problem-based behaviors (Cheng et al., 2015; Hsu & Cheng, 2014). However, considering that findings from this case study are based on only two pairs of students, our future work will analyze the data derived from the remaining student pairs, who also engaged with the collaborative location-based AR activity. Future work will also look at low and high immersion students, as characterized using the Immersion Indicators described in this study, to examine the role of scaffolding in fostering students' higher levels of immersion. The present study contributes to the literature by providing empirical evidence about the relation between immersion and learning in location-based augmented reality settings, which is an area that has received little attention in the literature. A better understanding of how learning occurs in informal learning contexts, such as outdoors, location-based augmented reality settings can support the creation of hybrid spaces for learning in and out of school contexts, and the development of augmented reality learning environments.

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CHAPTER 3: THE DEVELOPMENT AND VALIDATION OF THE ARI QUESTIONNAIRE

Abstract

Location-aware Augmented Reality (AR) applications are often argued to provide users with immersive experiences that are situated in the real world. Immersion, which can be seen as a form of cognitive and emotional absorption, has been asserted to promote enjoyment, engagement in a task and even learning. However, such claims remain largely unsubstantiated due to the lack of validated instruments for measuring users' immersion in location-based AR environments. Attempts to develop validated instruments for evaluating immersion have been few and non-systematic, while existing instruments are oriented towards measuring immersion in the context of non-AR digital games. At the same time, studies seeking to operationalize and measure immersion are still inconclusive; even though immersion is considered as a multi-level psychological construct, it is not yet clear whether there is multidimensionality in each level or not. This chapter presents a study focusing on the development and validation of the ARI [Augmented Reality Immersion] questionnaire: an instrument for measuring immersion in AR location-aware settings. To achieve this goal, a multi-step process was employed to develop and validate a novel instrument; analyses included exploratory factor analysis with 202 high school students, followed by a confirmatory factor analysis with 162 high school students. This multi-step process resulted in a 21-item, seven-point Likert-type instrument with satisfactory construct validity, which is based on a multi-leveled model of immersion with multidimensionality in each level. We argue that the ARI questionnaire, as a validated and tested measurement, can be highly useful for researchers and designers in the field of location-based AR.

3.1 Introduction

Immersion is a widely-used construct in the literature of digital apps, such as computer and video games, avatar-based virtual worlds or virtual reality apps. One of the most widely used definitions of immersion is that immersion is "the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (Dede, 2009, p.66). As entertainment and learning around such digital experiences are assumed to be dependent on the degree of immersion achieved, namely the degree to which users become cognitively and emotionally engaged with a given digital app (e.g. Brooks, 2003; Cheng, She & Annetta, 2015), immersion is a construct of high interest in such contexts.

Immersion has been also discussed in the context of location-aware Augmented Reality (AR) apps. These apps respond to one's position in the real world and augment physical landscapes with digital information, allowing users to explore the surrounding environment by using mobile technologies (Cheng & Tsai, 2013). Location-aware AR apps, as a new form of interactive media, have been largely embraced in the fields of gaming and education, as they have been argued to provide users with enriched and immersive experiences, which in turn are asserted to promote enjoyment, engagement in a task and even learning (e.g. Dede, 2009; De Souza E Silva & Delacruz, 2006).

While location-aware AR apps have been asserted to facilitate users' immersion, and thus their subsequent learning and entertainment, currently, there is an observed lack of validated instruments for measuring immersion in AR settings. According to McCall, Wetzel, Löschner, and Braun (2011), evaluating concepts such as immersion in AR settings is problematic, as to date, most validated instruments are oriented towards traditional non-AR digital games and have, mostly, been validated in controlled laboratory conditions.

In the absence of valid measurements, AR researchers have previously attempted to explore immersion through field trials (e.g. Dunleavy, Dede, & Mitchel, 2009; Reid, Geelhoed, Hull, Cater, & Clayton, 2005). Field trials, as a common methodological approach in the field of AR, allowed researchers to gain experience of these location-aware applications in real-world settings, while isolating different key factors assumed to impact immersion (Reid, Hull, Clayton, Melamed, & Stenton, 2011). For instance, game-based researchers have found that by incorporating real artifacts in the gameplay (Reid, 2008) or by employing narratives that are successfully blended with the game-based location (Reid et al., 2005) a location-aware AR game could become more immersive. In addition, in some cases, these research-oriented field trial studies provided empirical evidence related to the conceptualization of immersion. For instance, Reid et al. (2005) conceptualized immersion as a transient state in conjuction to different engagement and disengagement factors. However, while such research efforts provided useful frameworks related to the factors affecting immersion, they did not provide a solid theoretical model defining the nature of immersion. In addition, these studies were not focused on the development and validation of a theoretically-informed questionnaire, allowing the operationalization and measurement of immersion in the context of location-aware AR apps.

This chapter describes the development and validation of the *Augmented Reality Immersion* (ARI) questionnaire – an instrument for assessing immersion in location-aware AR apps. First, a brief overview of the literature describing the nature of AR location-aware apps as well as the nature of immersion, is presented. Second, given that immersion has been extensively studied in game-based research, a brief overview of how immersion has been previously operationalized and measured in the field of digital games, is provided. Subsequent sections discuss the process of the ARI development and present the validation of the instrument with high school students.

3.2 Defining Immersion in Location-aware AR Apps

3.2.1 Defining Augmented Reality (AR)

Researchers in computer science and educational technology have proposed different definitions for AR. One of the first definitions belongs to Azuma (1997) who defined AR as "*3-D virtual objects […] integrated into a 3-D real environment in real time*", highlighting three characteristics of AR: (1) combination of real and virtual, (2) interactive in real time, and (3) registered in 3D. However, Azuma's definition seems to be more aligned with image -based AR technologies which "require(s) specific labels to register the position of 3D objects on the real-world image" (Cheng & Tsai, 2013, p. 451). The advancements of handheld computing have nowadays opened up new venues for augmented reality, resulting in a new subset of AR: location-aware AR apps (Marti et al., 2011). Location-aware AR apps present digital media to users as they move through the physical environment with a smartphone or similar mobile device, equipped with wireless network or global positioning system (Cheng & Tsai, 2013; Dunleavy & Dede, 2013). Given that AR can nowadays be applied to varied technologies that blend real and virtual information, a broader and more encompassing definition of AR is seen as more productive for both researchers and designers (Fitzgerald, Ferguson, Adams, Gaved, Mor, & Thomas, 2013). For instance, in recent years, several studies have reported AR location-aware apps that integrate different forms of digital information within real world settings, such as videos, images, audios and texts (e.g. Dunleavy & Dede, 2013; Klopfer, 2008). The present study is focused on location-aware AR apps and coincides with the broader definition provided by Fitzgerald et al. (2013) which defines AR as including "the fusion of any digital information within real world settings, i.e. being able to augment one's immediate surroundings with electronic data or information, in a variety of media formats that include not only visual/graphic media but also text, audio, video and haptic overlays" (p. 1). Such a broader definition appears to be more applicable in the spectrum of the varied augmentation modalities of location-aware AR apps, which will be presented next.

3.2.2 Defining Augmented Reality (AR) Location-aware Apps

Recent years have witnessed an explosion in the number of apps that are facilitated by AR location-aware technologies. Such location-aware AR apps share common ground with, or even refer to the same type of apps, as "hybrid reality", "mixed reality", "location-based" , "pervasive", "alternate" or "urban" apps (Avouris & Yiannoutsou, 2012; Cheng & Tsai, 2013; De Souza E Silva & Delacruz, 2006; Grüter, McCall, Braun & Baillie, 2011).

According to Reid et al. (2011), AR location aware apps could be considered as new form of interactive media with their own set of distinctive characteristics. In particular, location-aware AR apps (1) extend the activity environment outside the limits of traditional space (the screen or the board) into the physical space, since the activity takes place in the physical world, which is augmented with digital resources (e.g. De Souza E Silva & Delacruz, 2006); (2) are mobile, since the use of mobile technologies requires users to be in motion during the activity (e.g. De Souza E Silva & Hjorth, 2009); (3) rely on spatial awareness, given that users' locations are monitored and recorded employing location-aware technologies, typically GPS (e.g. Reid et al., 2011); and (4) provide users with a rich, and potentially unlimited, range of interactions, not only with the digital mobile interface, but primarily with the real world in which they take place (e.g. McCall et al., 2011). Most importantly, as argued by De Souza E Silva and Delacruz (2006), these apps "make use of physical world immersion by merging physical and digital spaces" (p. 231).

3.2.3 Defining Immersion

Immersion is a popular term and has been widely used in the literature; the term has been mainly employed by researchers in the fields of virtual reality, narrative and digital games. Despite the widespread use of the term, there is a lack of consensus regarding the definition of immersion due to the multidisciplinary use of the concept, and due to its affinity to the concepts of flow and presence (Mount, Chambers, Weaver, & Priestnall, 2009).

The first researchers in the field of virtual reality introduced immersion as a technical concept in the design of virtual environments. Adopting this technical focus, most of the researchers in the field of virtual reality have since usually defined immersion as the "objective" and "measurable" properties of a virtual environment (e.g. Bystrom, Barfield, & Hendrix, 1999; Nash, Edwards, Thompson, & Barfield, 2000; Slater, 1999), to indicate "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997, p. 604). However, other researchers, such as Witmer and Singer (1998), challenged this technical definition arguing that immersion is a "psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (p. 227). In this context, these contradictory conceptualizations of immersion have been discussed rather heatedly in the past within the community of virtual reality researchers.

Later on, several researchers argued that immersion is not a new construct, nor is it one that is only linked to the emergence of virtual reality technologies; immersive experiences can also occur when employing desktop based environments with low image and audio realism, or even in non-technologically mediated activities, such as storytelling (Brooks, 2003; McMahan, 2003). Immersion was, therefore, re-defined as a natural human state, which emerges as people engage in an engrossing activity, such as, for instance, when reading an enjoyable book, watching a film or playing a digital game (Weibel, Wissmath, & Mast, 2010). According to Brooks (2003), to be immersed is to be involved in a given context, not only physically but also mentally and emotionally. Under these circumstances, the concept was also re-contextualized in the game-based literature, where it was operationalized and established as a psychological phenomenon (e.g. Cheng et al., 2015; Brown & Cairns, 2004; Jennett et al., 2008; McMahon & Ojeda, 2008). Immersion has been recognized as a vital part of a successful digital game (Brown & Cairns, 2004) and has been argued to have a positive impact on the gameplay experience (Örtqvist & Liljedahl, 2010).

Despite the popularity of the term, Weibel and Wissmath (2011) have commented that immersion in mediated environments has previously been explained through the constructs of "presence" and "flow", often provoking a definitional confusion. Many researchers in the field of digital games have pointed out that instead of employing these terms synonymously, flow and presence should be conceived as two optimum states of engagement, while immersion should be defined as a sub-optimal psychological process of becoming engaged in the game-playing experience (e.g. Baños, Botella, Alcañiz, Liaño, Guerrero, & Rey, 2004; Brown & Cairns, 2004; Jennett et al., 2008). More specifically, flow can be defined as the process of optimal experience, "the state in which individuals are so involved in an activity that nothing else seems to matter" (Csikszentmihalyi, 1991, p.4). On the other hand, the construct of presence has usually been restricted to non-exhaustive and loosely-stated definitions such as "the feeling of being there" (Heeter, 1992) in a digital environment, providing a sense of deep involvement. Comparing presence and immersion, Jennett et al. (2008) argued that while presence and flow are often considered as optimal "states of mind", immersion can be viewed as a gradated psychological process of engagement that may provoke flow and/or presence.

According to Scoresby and Shelton (2011), given that the confusion between immersion, presence and flow adds an unnecessary level of complexity to current research, there is a need for a clear definition and demarcation between these concepts. Agreeing with the definition of Jennet et al. (2008), we argue that the operationalization of immersion as a continuum towards flow and presence seems to be crucial in the context of AR location-aware applications. While several AR researchers have previously attempted to address AR immersive experiences through the evaluation of flow and presence (e.g. Bressler & Bodzin, 2013; McCall et al., 2011; Regenbrecht & Schubert, 2002; Von Der Pütten et al., 2012), it seems that shifting our focus towards the evaluation of immersion provides a more viable option, given that the concepts of flow and presence have often emerged as too excessive for describing the users' experience in the context of location-aware AR apps. Previous studies in the field have indicated that total immersion, in terms of flow, is a transient state, while a sense of presence could hardly be achieved and maintained in the context of AR location-aware apps (e.g. McCall et al., 2011; Reid et al., 2005). As AR researchers have often reported, various challenges might prevent users' total immersion, such as external distractions, GPS errors, hardware challenges, the screen being too bright in outdoors activities or weather adversities (Cheng & Tsai, 2013; Dunleavy et al., 2009; Svingby & Nillson, 2011). Several AR location-aware apps, such as for instance "Uncle Roy all around you" developed by the Blast Theory Group (2003), describe how they deliberately attempt to blur the boundary of apps and the physical world, so that users, for example, think that bystanders are part of the AR activity. However, unlike virtual reality or computer apps taking place in settings where many factors such as temperature, light, props and noise can be controlled, location-aware AR apps provide situated experiences where the environment is often a real public space or a physical site where these parameters remain beyond the designer's control (Reid et al., 2011). Under these circumstances, external elements like cars, insects, animals, outdoor noise and other unexpected events cannot be controlled and could act as external distractions, preventing the users' focused attention and thus disrupting the immersive experience (Dunleavy et al., 2009; McCall et al., 2011; Reid et al., 2005; Reid et al., 2011). Finally, Dede (2009) has argued that interactive media enable various degrees of immersion, indicating that location-aware AR apps could be considered as less immersive when compared to virtual reality rooms, known as CAVEs, or virtual worlds, such as MUVEs; the latter could provide immersive experiences within a completely different reality when compared to location-aware AR apps that provide immersive experiences within an enhanced and augmented version of the current reality. Therefore, in order to delineate location-aware AR experiences appropriately, a definition of immersion which considers different degrees of cognitive and affective absorption may seem more appropriate when compared to borrowing the definitions of the constructs of presence or flow.

3.3 Measuring Immersion

Given that psychological immersion has dominated the field of game-based research, it is not a surprise that all the mainstream research efforts describing the development of explanatory theoretical models, are documented in the field of digital games (e.g. Brown & Cairns, 2004; McMahon & Ojeda, 2008; Ermi & Mäyrä, 2005). However, a review of the literature indicates a lack of validated, theory-based instruments for measuring immersion. At the same time, game-based studies seeking to operationalize and measure immersion are still inconclusive; while immersion is considered as a multi-level psychological construct, it is not clear yet whether there is multidimensionality in each of the reported immersion levels or not (e.g. Cheng et al., 2015; Brown & Cairns, 2004).

Brown and Cairns (2004) carried out a qualitative study which contributed to their conceptualization of immersion; their model has been very influential in studies about immersion. Their study was based on in-depth interviews with seven gamers, asking them to describe their experiences when playing computer games. Through a grounded theory methodology, Brown and Cairns conceptualized immersion as a gradated psychological process and proposed a global model of immersion comprising of sequential levels represented as three first-order factors: engagement, engrossment, and total immersion. The first level, *engagement*, is based on access and investment. Access is related to gamers' preferences as well as to the game's controls. If gamers can access the game, then they invest time and effort, and attend to the game. From *engagement,* gamers may be able to become further involved with the game and enter *engrossment*, which is the second level of immersion. During this level, the gamers' attention to, and emotional attachment with, the game are the determinant factors. Finally, *total immersion* is the optimum level, during which gamers reach a sense of presence, in terms of being in the game world, and achieving a sense of flow in terms of feeling that the game is all that matters.

In another study, Jennett and her colleagues (2008) developed the *Immersive Experiences Questionnnaire* (IEQ) for measuring immersion in digital games. The questionnaire consists of 31 questions on a five-point Likert scale and conceptualizes immersion as a gradated process. The IEQ items are based on Brown and Cairns' (2004) model of immersion, as well as on previous studies in the related areas of *flow* (Csikszentmihalyi, 1991), *cognitive absorption* (Agarwal & Karahanna, 2000) and *presence* (Witmer & Singer, 1998). The items address a variety of aspects that could be said to constitute an immersive experience and cover five factors: cognitive involvement, emotional involvement, real world dissociation, challenge and control. Nonetheless, prior research efforts did not reflect the multi-level nature of immersion as the latter was conceptualized using a multi-factorial scale, but also as unidimensional one.

In a different approach to understanding immersion, Qin, Rau, and Salvendy (2009) argued that the game's narrative is the cause of immersion. According to Qin and colleagues, a digital game narrative can be defined as the methods and styles employed to tell the story of the game, including the plots provided by game writers and developers, and the story created by the players in the course of playing the game. In this context, they proposed a theoretical model for capturing immersion in the game narrative, composed of three levels: the *antecedents*, the *experience* and the *effects* of immersion. As Qin and his colleagues state: (a) challenge and curiosity can serve as antecedents for immersion, (b) control, concentration and comprehension can explain the experience of immersion, and (c) empathy is the main effect of immersion. Based on this model, they developed the *Immersion in Game Narrative* questionnaire (Qin et al., 2009), with the goal of measuring player immersion in the game narrative. Exploratory and confirmatory factor analyses led to the modified dimensions of *Curiosity, Concentration, Challenge and Skills, Control, Comprehension, Empathy, and Familiarity*. These seven factors accounted for 58% of the total variance, and factor loadings ranged from 0.46 to 0.7. The Cronbach's alpha value for this instrument was 0.877, while the Cronbach's alpha values of each dimension in the instrument were at about 0.70, except familiarity and control (α=0.60). However, despite the validation of Qin et al.'s (2009) questionnaire, it seems that the game narrative element is not the only one, nor the main cause, for immersion. For instance, Ermi and Mäyrä (2005) argued that, in addition to the narrative, the multimedia aspect of a computer game and game-based challenges are two other distinct contributors to gamers' immersion.

The last validated questionnaire identified in the literature is the *Game Immersion Questionnaire* (GIQ), which seeks to measure immersion in game-based virtual worlds (Cheng et al., 2015), and was also based on Brown and Cairns' grounded theory of immersion. Cheng et al.'s findings (2015) challenged the global model of Brown and Cairns and proposed a higher-order model of immersion, which organizes immersion in three levels, represented by three-second order factors: "engagement", "engrossment" and "total immersion", while suggesting that there is multidimensionality in each of the three immersion levels. According to Cheng et al., *engagement* can be broken down into the constructs of attraction, time investment and usability; *engrossment* consists of emotional attachment and decreased perceptions of the surrounding environment, while *total immersion* consists of presence and empathy. This model was validated through an exploratory factor analysis (n=257) and a confirmatory factor analysis (n=1044). Cronbach's α for each level and sub-constructs were satisfactory and ranged between

0.70 and 0.92. In addition, the statistical analysis affirmed a good model fit and confirmed the reliability of the proposed hierarchical structure of the model of immersion. The final version of the GIQ consisted of 24 items and was used successfully in a subsequent study investigating the impact of immersion in a game-based virtual world on secondary school students' science learning via the use of a serious educational game (n=260).

The *Game Immersion Questionnaire* (GIQ) seems to be the most well-structured and reliable instrument of all identified published questionnaires on immersion. Cheng et al. (2015) not only provided a validated instrument for measuring immersion in the context of game-based virtual worlds, but, at the same time, provided a sound theoretical explanation of their model of immersion. In addition, the hierarchical structure of the proposed model of immersion was validated via structural equation analysis.

However, a major limitation of the aforementioned questionnaires for measuring immersion in AR environments was that they were designed to assess students' immersion in digital games embedded in desktop-based environments. Location-aware AR apps are a unique media type that differs significantly from previous digital environments, as they occur in contexts that combine the virtual with the real (Wagner et al., 2009). These contexts render the questionnaires to assess immersion in non-AR environments incommensurable; the associated challenges are presented in the next section of this chapter, which presents a comparison between location-aware apps and non-AR digital apps, to explain our thesis that existing questionnaires are inappropriate for capturing immersion in the context of AR location-aware apps.

3.4 Location-aware AR Apps vs. Non-AR Digital Apps

As several researchers have argued, there are fundamental differences between location-aware AR apps and non-AR environments, such as computer or video games (e.g. Bunting, Hughes, & Hetland, 2012; De Souza E Silva & Delacruz, 2006). According to De Souza E Silva and Delacruz (2006) location-aware AR apps differ from other game types as they: (a) employ mobile and location-aware interfaces, (b) combine physical and digital spaces, thus creating blended spaces, and (c) transform the natural space into the activity board, rather than being unfolded exclusively in a virtual computer-based environment. As a consequence, different approaches are necessary in how one should evaluate immersive experiences in AR contexts.

First of all, the mobile interface of location-aware AR apps is not an external tool that the users employ in order to interact with and control their avatar within the virtual world (Bunting et al., 2012). Instead, participants, themselves, enter blended world, while the mobile interface, as a part of the blended world itself, facilitates the users' navigation and actions. At the same time, while in video or computer apps users' agency is generally expressed through an avatar (Bunting et al., 2012), the users' agency during a location-aware AR app is expressed through their immediate interactions with the natural space where the activity now takes place. For that, items from existing immersion scales, such as *"I can control the character to move according to my arrangement"* (Qin et al., 2009) or *"I used to feel that the avatar in the game is controlled by my will, and not by the mouse or the keyboard, so that the avatar does just what I want to do. It seems like the thoughts and consciousness of the avatar and me are connected"* (Cheng et al., 2015) do not seem capable to capture immersion in AR contexts.

Secondly, location-aware AR apps combine physical and digital spaces creating blended spaces. Benyon (2012) stated that immersion in AR experiences is not about achieving feelings of presence, as a sense of "being there" in another location, but it is rather about feeling present in the blended space of real and digital elements. Being totally immersed in AR location-aware apps reflects users' perception of feeling surrounded by a blended, yet realistic physical/virtual environment, as being in a unified and single world (Cheng & Tsai, 2013). When this occurs, users are transitioned from "existing" within a real-world environment, to "acting" within a virtually-augmented real-world environment (Yuen, Yaoyuneyong, & Johnson, 2011). However, users are still found within the real world. In this context, items from existing immersion scales, such as *"I felt detached from the outside world"* or *"I still felt as if I was in the real world whilst playing"* (Jennett et al., 2008) do not seem appropriate for assessing immersion in AR contexts.

Thirdly, in contrast to previous digital environments unfolding in carefully crafted virtual worlds, location-aware AR apps take place at the physical world, which contains also elements that can act as distracters. Previous studies have indicated for instance that elements such as the weather, external noises and human presence (e.g. others talking, a passerby, cars) or even an unexpected event (e.g. an insect or a physical barrier appears) can act as a physical distractor (e.g. Dunleavy et al., 2009; McCall et al., 2011; Reid et al., 2005; Reid et al., 2011). Hence, immersion in AR experiences is not about achieving decreased perceptions of the real world, as in the case of previous digital games (Cheng et al., 2015; Scoresby & Shelton, 2011), but it is mostly about a decreased focus on any external distractions, lying in the physical world. In other words, given that location-aware AR apps are grounded on the real world, immersion is not about getting disengaged from the real word but it is rather about a shift of attention towards the location-aware AR app, which in turn results in a decreased focus on any potential distractors. Consequently, items from existing immersion scales, such as *"My ability to perceive the environment surrounding me is decreased while playing the game"* (Cheng et al., 2015) or *"I was unaware of what was happening around me"* (Jennett et al., 2008) do not seem capable to capture immersion in AR contexts.

To sum up, location-aware AR apps provide users with a completely different digital experience. As Kim (2013) has noted, while virtual environments aim to "cut out" the users from the real context resulting in "virtual" immersion, AR environments are linked to specific contexts of the real world resulting in "context" immersion. This differentiation strengthens the goal of the present study, which was to develop and validate the ARI questionnaire on the basis of a verified theoretical model, intended to measure immersion in location-aware AR apps. The process of developing and validating the ARI questionnaire, as well as an overview of the AR location-aware learning environments employed during the validation process, are presented next.

3.5 Overview of the AR Location-aware Learning Environments

As part of the validation process, two different location-aware AR learning environments were designed and implemented using an augmented reality platform developed by the Georgiou & Kyza (2013). Both of the location-aware AR learning environments were designed to engage middle and high school students in inquiry-based science and took the form of a narrative-driven investigation. As students moved around in their physical location, a map in the augmented reality app displayed a set of virtual characters corresponding to different hotspots in the real world. The hotspots were triggered once the students were within a radius of 20 meters from each virtual character; once triggered, the app displayed a variety of multi-modal information which was relevant to the inquiry-based investigation (videos, texts, photographs, diagrams, and audio).

In the first location-aware AR learning environment, entitled “Mysterious absences”, the students were asked to investigate a hypothetical scenario of why the majority of the students in their school were absent in the last week. This AR app was used within the school premises; students worked in dyads and were asked to investigate the problem. The overall goal of the AR app was to engage students in an explanation-building process about the problem-based case, as well as to expand students’ understanding of scientific concepts related to disease symptoms, disease transmission mechanisms, foodborne bacteria, food safety and food poisoning.

In the second location-aware AR learning environment, entitled “Mystery at the lake”, students were asked to collaborate to investigate an environmental science problem regarding the decline of the mallard duck population at a local lake. During the activity students assumed the role of environmental investigators; the investigation asked them to collect and interpret a set of data provided by virtual characters in order to develop an evidence-based answer regarding the environmental problem presented. The goal of this AR location-aware learning environment was again to engage students in an explanation-building process about the problem-based case, as well as to expand students’ understanding of scientific concepts related to an aquatic ecosystem such as eutrophication and bioaccumulation. Both location-aware AR learning environments are context-based, as the designers explicitly intended to augment the students’ surroundings through additional virtual information connected to the specific place.

3.6 Development and Validation of the ARI Questionnaire

3.6.1 Stage I: Item Generation and Scale Construction

The first step for developing the ARI questionnaire was a comprehensive review of the literature, which supported the identification of the structure of immersion, and contributed to developing a pool of possible items. The literature review led to the conceptualization of immersion as a three-level construct composed by: *Engagement*, *Engrossment* and *Total Immersion*. This three-level operationalization of immersion was grounded on the theoretical model of Brown and Cairns (2004), which provided a solid basis for most of the subsequent questionnaires developed for measuring immersion in the field of game-based research (e.g. Cheng et al., 2015; Jennett et al., 2008).

Table 3.1: Scales hypothesized to compose the multi-level construct of immersion

Immersion levels	Scales	Measures
Engagement	Attraction	Attraction to the activity
	Time investment	Time investment in the activity
	Usability	Perceptions about the app's usability
Engrossment	Emotional attachment	Emotional attachment to the activity
	Focus of attention	Focus during the activity
Total Immersion	Presence	Sense of feeling surrounded by a blended, yet realistic physical/virtual environment
	Flow	Full absorption in the activity

In addition, having as a springboard the hierarchical model of immersion proposed by Cheng et al. (2015), we employed a total of seven scales, based on Cheng et al' s assumption of multi-dimensionality within each one of the three immersion levels. It was, however, necessary in some cases to adapt the names and aims of the scales (see Table 3.1). For instance, as mentioned in the previous section, given the different nature of location-aware AR applications, the scale for "Decreased perceptions" was replaced by a scale related to the "Focus of attention". Similarly, the scale of "Presence" was re-conceptualized, in terms of its scope in order to be aligned with the nature of location-aware AR apps.

After articulating the hypothetical scales of immersion, items were developed to assess them empirically. Given that the questionnaire was validated with a Greek-speaking population, all of the items were developed in Greek, with some of the items adapted and translated in Greek from published immersion questionnaires (e.g. Cheng et al., 2015; Jennett et al., 2008; Qin et al., 2009). In addition, new items were written for each sub-scale to replace the items which did not take into account the situated and hybrid nature of augmented reality. This process resulted in 42 items, representing seven potential scales. A seven point rating scale (where 1 represented "totally disagree" and 7 represented "totally agree") was employed for the evaluation of each item. This first inventory of items was further refined by: (1) simplifying statements to provide clear and concise items; (2) decreasing the number of negatively worded statements to eliminate confusion (Barnette, 2000); (3) shortening statements to achieve succinct representation of the items.

This stage was completed with a small-scale, pilot study to test the items, conducted with twelve 10th and 11th grade students. Students were of mixed academic ability, to ensure that the sample was representative of the broader student population. As part of this pilot study, the students were initially asked to participate in the "Mysterious Absences", a location-aware AR app for learning science. The duration of the "Mysterious Absences" was about 30 minutes; at the conclusion of the activity, students were asked to complete the ARI questionnaire and to participate in a semi-structured focus group that lasted about 80 minutes. The main purpose of the focus group was to investigate the comprehensibility of the items included in the questionnaire. Based on the comments received from this cohort of students some of the items were further simplified to ensure that the wording of the questionnaire was understandable and that the questionnaire could be completed within a reasonable time frame.

3.6.2 Stage II: Exploring the Underlying Factor Structure of the ARI

The second stage of this study involved an exploration of the underlying factor structure of the ARI questionnaire, employing item analysis and Exploratory Factor Analysis (EFA) for each level of immersion: "Engagement", "Engrossment" and "Total Immersion".

3.6.2.1 Sample

During this stage the questionnaire was administered to 221 high school students, who were asked to evaluate their immersive experience, by completing the ARI questionnaire individually after using the "Mysterious Absences" location-aware AR app. Nineteen questionnaires were excluded of the analysis because of missing values. As a result, 202 valid questionnaires, obtained from 78 boys and 124 girls, were used to run item analysis and exploratory factor analysis, using SPSS v. 20.0.

3.6.2.2 Item Analysis

In order to purify our scales, the item-to-total correlations were examined for items not consistent with the rest of the scales (DeVellis, 2003). The cut-off point for the correlation coefficient was 0.5 and any items below this cut-off point were eliminated from the analysis. As a result, six items (A5, A6, A11, A12, A15, A16) were deleted from the "Engagement" scales. In contrast, the results of the item analysis verified that all of the 12 items (B1-B12) in the "Engrossment" scales should be retained. Finally, the results of the item analysis indicated that three items (C1, C2 and C3) should be deleted form the "Total Immersion" Scales.

3.6.2.3 Exploratory Factor Analysis [EFA]

Three series of Principal Component Analysis [PCA] with varimax rotation were conducted to clarify the structure of the three immersion levels (Engagement, Engrossment, Total Immersion) underlying the ARI questionnaire. The Kaiser–Meyer–Olkin (KMO) and Bartlett's spherical test were further employed to explore whether the retained items in each level were appropriate for factor analysis. Any items loading below 0.4 on all factors after the rotation were removed, as only factors loading at 0.4 or greater are considered acceptable (Field, 2009; Manly, 1994). Misfitting or redundant items were also removed, if this did not change the underlying factor structure of the questionnaire: to confirm this, for each item that was removed an additional exploratory factor analysis was conducted with principal component analysis and varimax rotation on the items selected for retention. The Kaiser's eigenvalue-greater-than-one rule was employed as the criterion for defining the number of extracted factors in the EFA (Kaiser, 1960). According to this rule, only the factors that had eigenvalues greater than one were retained for interpretation. Finally, Cronbach's α was used to measure the reliability of each immersion level. The findings derived from the PCA for each of the three levels are reported next.

3.6.2.3.1 Engagement

The KMO (KMO=0.88) and the Bartlett spherical test [χ^2 (66) = 868.46, $p < 0.01$] verified the appropriateness of the 12 items included in this level of immersion. Based on the exploratory factor analysis two factors, defined as "Interest" and "Usability", were extracted. Although the 12 items were expected to load on three different factors as "Attraction", "Time Investment" and "Usability", items for "Attraction" and "Time investment" merged on the same factor. This indicated that, essentially, "Attraction" and "Time investment" could not be conceptualized as distinct, and were merged into one factor ("Interest"). Given that "Interest" was now composed by redundant items, the two items with the lowest loadings (A7 and A10) were removed step-wise, and exploratory factor analysis was re-ran twice. The KMO (KMO=0.84) and the Bartlett spherical test [χ^2 (45) = 670.48, $p < 0.01$] indicated the appropriateness of the retained ten items for the factor analysis. The two final factors of "Interest" and "Usability" consisted of six and four items respectively, and accounted for 57.9% of the variance. Cronbach's α for the two factors ranged from 0.75 to 0.85, which is an acceptable level for subscales (Field, 2009), and was at 0.80 for the immersion level (see Table 3.2).

Table 3.2: Exploratory factor analysis results for the level of "Engagement"

Item	Factor loadings			
	Factor 1 (Interest)	Factor 2 (Usability)	Cumulative variance explained (%)	Cronbach's α
A2: I liked the activity because it was novel	**0.85**	0.07	34.26%	0.85
A9: I wanted to spend time to participate in the activity	**0.79**	0.06		
A4: The topic of the activity made me want to find out more about it	**0.73**	0.03		
A8: I wanted to spend the time to complete the activity successfully	**0.72**	0.05		
A3: I liked the type of the activity	**0.71**	0.27		
A1: The AR application we employed captured my attention	**0.69**	0.16		
A18: I did not have difficulties in controlling the AR application	0.02	**0.79**	57.90%	0.75
A14: I found the AR application confusing*	0.17	**0.77**		
A13: It was easy for me to use the AR application	0.15	**0.75**		
A17: The AR application was unnecessarily complex*	0.06	**0.69**		
				0.80

[1]The highest loading for each construct is presented in bold
[2]Reverse coded items are marked with an asterisk

3.6.2.3.2 Engrossment

The KMO (KMO=0.90) and the Bartlett spherical test [χ^2 (66) = 1090.25, $p < 0.01$] verified the appropriateness of the 12 retained items for the factor analysis. The exploratory factor analysis extracted two factors: "Emotional Attachment" and "Focus of Attention". Item B12 was removed as it had the same loading in both factors, and exploratory factor analysis was re-run for the remaining the 11 items. The KMO (KMO=0.89) and the Bartlett spherical test [χ^2 (55) = 997.65, $p < 0.01$] indicated the appropriateness of the 11 retained items for the factor analysis. The two final factors of "Emotional Attachment" and "Focus of Attention", consisting of five and six items respectively, accounted for 58.9% of the variance. Cronbach's α for the two factors ranged from 0.81 to 0.85, which are acceptable (Field, 2009) (Field, 2009), and 0.89 for the immersion level of Engrossment (see Table 3.3).

Table 3.3: Exploratory factor analysis results for the level of "Engrossment"

Item	Factor loadings			
	Factor 1 (Emotional attachment)	Factor 2 (Focus of attention)	Cumulative variance explained(%)	Cronbach's α
B4: I often felt suspense by the activity	**0.82**	0.20	32.96%	0.81
B2: I was curious about how the activity would progress	**0.82**	0.12		
B1: I was impatient about completing the activity successfully	**0.65**	0.46		
B3: I was often excited since I felt as being part of the activity	**0.52**	0.49		
B5: I often felt that I was really in charge of the activity	**0.51**	0.43		
B9: Everyday thoughts and concerns faded out during the activity	0.01	**0.84**	58.86%	0.85
B7: I was more involved with the activity than with any other irrelevant thoughts	0.31	**0.74**		
B10: I was more focused on the activity rather on any external distraction	0.32	**0.74**		
B6: If interrupted, I looked forward to returning to the activity	0.42	**0.65**		
B11: During the activity, hardly anything could distract me	0.34	**0.60**		
B8: I often forgot the passage of time during the activity	0.27	**0.59**		
				0.89

[1]The highest loading for each construct is presented in bold

3.6.3.2.3 Total Immersion

The KMO (KMO=0.88) and the Bartlett spherical test [χ^2 (36) = 837.40, $p < 0.01$] verified the appropriateness of the nine retained items for the factor analysis. The exploratory factor analysis extracted two factors, defined as *"Presence"* and *"Flow"*. The two final factors consisted of five and four items respectively, and accounted for the 65.6% of the variance. Cronbach's α for the two factors ranged from 0.84 to 0.85, which are acceptable for subscales, and 0.88 for the level of "Total Immersion" (see Table 3.4).

Table 3.4: Exploratory factor analysis results for the level of "Total Immersion"

Item	Factor loadings			
	Factor 1 (Presence)	Factor 2 (Flow)	Cumulative variance explained (%)	Cronbach's α
C4: The activity felt so authentic that it made me think that the virtual characters/objects existed for real	**0.83**	0.05	33.52%	0.85
C6: I felt that what I was experiencing was something real, instead of a fictional activity	**0.80**	0.28		
C5: The activity felt more as something that I was experiencing, rather than something I was just doing	**0.77**	0.27		
C7: I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly	**0.66**	0.32		
C8: I so was involved, that I felt that my actions could affect the activity	**0.61**	0.47		
C10: The activity became the unique and only thought occupying my mind	0.11	**0.86**	65.61%	0.84
C11: I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity	0.31	**0.77**		
C9: I didn't have any	0.20	**0.74**		

irrelevant thoughts or external distractions during the activity			
C12: All of my senses were totally concentrated on the activity	0.38	**0.72**	0.88

[1]The highest loading for each construct is presented in bold

3.6.3 Stage III: Verifying the Hypothetical Factor Structure of the ARI Questionnaire

The questionnaire was subsequently revised based on the results derived from Stage II; twelve items were deleted from the ARI questionnaire according to the findings of the exploratory factor analysis. This resulted in a questionnaire of 30 items, loading in the two-factor structures of "Engagement" (10 items), "Engrossment" (11 items) and "Total Immersion" (9 items). The revised version of the ARI questionnaire was tested with a new cohort of high school students. The third stage of this study included a Confirmatory Factor Analysis [CFA] in combination with an item selection procedure to maximize scale reliability and validity.

3.6.3.1 Sample and Implementation

The new version of the ARI questionnaire was administered to 176 high school students from nine intact 10th grade classes. The students used the "Mystery at the Lake" location-aware AR environment for learning environmental science, taking place at a lake nearby an environmental science center. After the AR activity, which lasted about 90 minutes, students were asked to individually complete the ARI questionnaire. Fourteen questionnaires were excluded from the analysis because of missing values. As a result, 162 valid questionnaires, obtained from 56 boys and 106 girls, were used to run confirmatory factor analysis.

3.6.3.2 Confirmatory Factor Analysis [CFA]

The fitness of the internal structure of the ARI questionnaire was evaluated with confirmatory factor analysis, employing SPSS AMOS 21. Construct validity was evaluated by examining the value of Composite Reliability [CR>0.6] as well as the value of Average Variance Extracted [AVE>0.5] and standard factor loading for each item [>0.5] (Fornell & Larcker, 1981; Hair, Anderson, Tatham, & Black, 1998). The

Composite Reliability [CR] and the Average Variance Extracted [AVE] values were employed for evaluating convergent and discriminant validity respectively. In addition, discriminate validity was evaluated by comparing the correlation between the constructs and the square root of average variance extracted (Hair et al., 1998).

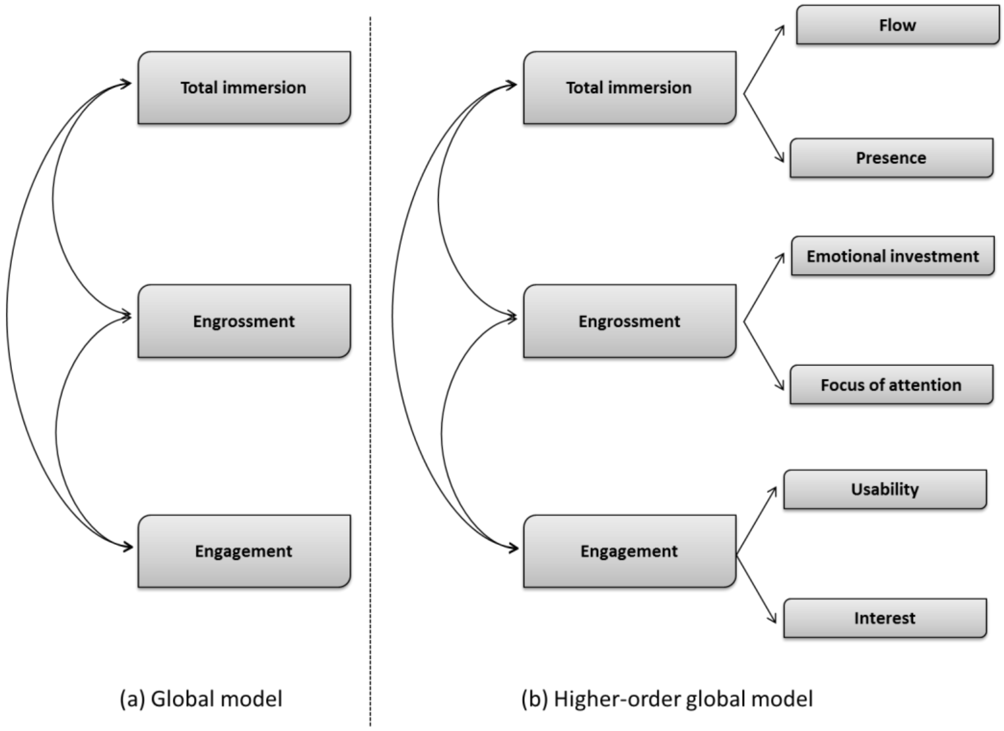

Figure 3.1: The two tested models

Two different models were then further tested (see Figure 3.1): (a) a global model of immersion, and (b) a higher-order model of immersion. Support for the global model of immersion could act in favor of the theoretical model of Brown and Cairns (2004) about the multi-level nature of immersion (Engagement, Engrossment, Total Immersion). On the other hand, support for the higher-order model could act in favor of the recent argument of Cheng et al. (2015) about the hierarchical structure of immersion and multi-dimensionality within the levels of engagement, engrossment and total immersion.

In both models, errors in the negatively-worded items for usability (A14 & A17) were correlated in order to control the negative-item effect (e.g. Barnette, 2000; Marsh, 1986). A variety of fit indices were employed for the evaluation of the factor models tested, given that the chi-square index is inadequate as a standalone fit index because of its sensitivity to sample size (Bentler& Bonett, 1980). Table 3.5 presents the recommended fit indices for evaluating the tested models (Bagozzi & Yi, 1988; Bowen & Guo, 2011; Hu & Bentler, 1998).

Table 3.5: Cut-off values for models' evaluation during confirmatory factor analysis

Fit index	Cut-off value
Normed Chi-square (χ^2/df) [CMIN]	<3
Goodness of Fit Index [GFI]	>0.9
Normed Fit Index [NFI]	>0.9
Comparative Fit Index [CFI]	>0.9
Incremental Fit Index [IFI]	>0.9
Standardized Root Mean Square Residual [SRMR]	<0.08
Root Mean Square Error of Approximation [RMSEA]	<0.08

3.6.3.2.1 Construct validity

The confirmatory factor analysis showed insufficient construct validity (See Table 3.6). Even though the variable standardized factor loading was, in most cases, greater than 0.5, items A1, B5, and B8 presented borderline values and were flagged as potentially problematic items. Similarly, composite reliability values for the scales of "Interest" and "Emotional attachment" slightly exceeded 0.6. Finally, the average variance extracted did not exceed the value of 0.5 in the scales of "Interest", "Emotional attachment" and "Presence", indicating low discriminant validity.

Table 3.6: Summative results of confirmatory factor analysis

Factors	Items	Loading	SE	CR[1]	AVE[2]	Cronbach's α
Engagement						0.77
Interest	A1: The AR application we employed captured my attention	0.52	0.15	0.64	0.41	0.79
	A2: I liked the activity because it was novel	0.61	0.24			
	A3: I liked the type of the activity	0.71	0.16			
	A4: The topic of the activity made me want to find out more about it	0.62	0.22			
	A8: I wanted to spend the time to complete the activity successfully	0.64	0.21			

Factors	Items	Loading	SE	CR[1]	AVE[2]	Cronbach's α
	A9: I wanted to spend time to participate in the activity	0.73	0.20			
Usability	A13: It was easy for me to use the AR application	0.67	0.07	0.70	0.53	0.82
	A14: I found the AR application confusing*	0.67	0.12			
	A17: The AR application was unnecessarily complex*	0.73	0.11			
	A18: I did not have difficulties in controlling the AR application	0.83	0.15			
Engrossment						0.89
Emotional attachment	B1: I was impatient about completing the activity successfully	0.66	0.16	0.63	0.43	0.79
	B2: I curious about how the activity would progress	0.73	0.21			
	B3: I was often excited since I felt as being part of the activity	0.71	0.19			
	B4: I often felt suspense by the activity	0.63	0.17			
	B5: I often felt that I was really in charge of the activity	0.55	0.17			
Focus of attention	B6: If interrupted, I looked forward to returning to the activity	0.79	0.21	0.78	0.53	0.86
	B7: I was more involved with the activity than with any other irrelevant thoughts	0.69	0.18			
	B8: I often forgot the passage of time during the activity	0.57	0.08			
	B9: Everyday thoughts and concerns faded out during the activity	0.84	0.22			
	B10: I was more focused on the activity rather on any external distraction	0.84	0.19			
	B11: During the activity,	0.61	0.19			

Factors	Items	Loading	SE	CR[1]	AVE[2]	Cronbach's α
	hardly anything could distract me					
Total immersion						0.86
Presence	C4: The activity felt so authentic that it made me think that the virtual characters/objects existed for real	0.63	0.12	0.80	0.46	0.80
	C5: The activity felt more as something that I was experiencing, rather than something I was just doing	0.60	0.11			
	C6: I felt that what I was experiencing was something real, instead of a fictional activity	0.78	0.11			
	C7: I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly	0.65	0.13			
	C8: I so was involved, that I felt that my actions could affect the activity	0.71	0.16			
Flow	C9: I didn't have any irrelevant thoughts or external distractions during the activity	0.74	0.10	0.89	0.68	0.89
	C10: The activity became the unique and only thought occupying my mind	0.84	0.11			
	C11: I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity	0.88	0.11			
	C12: All of my senses were totally concentrated on the activity	0.84	0.09			

[1]The composite reliability value calculation formula: $(\Sigma \text{ standardized factor load})^2 / [(\Sigma \text{ standardized factor load})^2 + \Sigma \text{ error variance}]$

[2]The average variance extracted value calculation formula: $(\Sigma \text{ standardized factor load}^2)/[(\Sigma \text{ standardized factor load}^2) + \Sigma \text{ error variance}]$

3.6.3.2.2 Item selection procedure

In an effort to improve construct validity, an item selection procedure was employed to maximize the convergent and discriminant validity of items in each scale (Raubenheimer, 2004; Wille, 1996). Designed for scales that have already been validated by item-total correlations or exploratory factor analysis, the item selection procedure evaluates and modifies a scale using its internal consistency (Hartlep & Lowinger, 2014). According to the procedure, an item should fulfil two criteria: (a) it should be highly correlated with its own construct and (b) it should be correlated with all other constructs to a lower degree. As suggested by Raunbenheimer (2004), both criteria were assessed simultaneously and any items violating one or both criteria were removed. The cut-off point for correlation coefficient between an item and its construct was set at 0.6 and any items below this were eliminated. In addition, an item was retained only if its correlation coefficient with its construct was at least 0.1 higher, compared to its correlation coefficient with all other constructs. The results of this item selection procedure indicated that a total of 21 items should be retained for the confirmatory factor analysis (see Table 3.10), while nine items (A1, A4, B1, B5, B7, B8, B11, C5, C12) were removed from the questionnaire.

3.6.3.2.3 Construct validity re-evaluation

After the item selection procedure, the confirmatory factor analysis was repeated; the results of this analysis indicated satisfactory construct validity for the model (see Table 3.7). More specifically, a confirmatory factor analysis of the model showed that the measurement variable standardized factor loading was greater than 0.6 in all cases, indicating that the model has strong explanatory power. The comprehensive reliability values were over 0.6, with most of the scales having values equal to, or greater than, 0.7 which indicated that the scales had very good internal consistency reliability. In addition, all the average variance extracted values were greater than the minimum value of 0.5. Cronbach's α values for each subscale were .77, .88 and .82, respectively; Cronbach's α for the whole questionnaire was .90.

Table 3.7: Summative results of confirmatory factor analysis after the item selection

Factors	Items	Loading	SE	CR[1]	AVE[2]	Cronbach's α
Engagement						0.77
Interest	A2: I liked the activity because it was novel	0.63	0.11	0.68	0.51	0.80
	A3: I liked the type of the activity	0.72	0.18			
	A8: I wanted to spend the time to complete the activity successfully	0.71	0.16			
	A9: I wanted to spend time to participate in the activity	0.78	0.15	0.70	0.53	0.82
Usability	A13: It was easy for me to use the AR application	0.67	0.08			
	A14: I found the AR application confusing*	0.67	0.12			
	A17: The AR application was unnecessarily complex*	0.73	0.11			
	A18: I did not have difficulties in controlling the AR application	0.83	0.15			
Engrossment						0.88
Emotional attachment	B2: I was curious about how the activity would progress	0.77	0.18	0.62	0.52	0.76
	B3: I was often excited since I felt as being part of the activity	0.73	0.17			
	B4: I often felt suspense by the activity	0.65	0.11			
Focus of attention	B6: If interrupted, I looked forward to returning to the activity	0.79	0.07	0.83	0.70	0.87

Factors	Items	Loading	SE	CR[1]	AVE[2]	Cronbach's α
	B9: Everyday thoughts and concerns faded out during the activity	0.87	0.09			
	B10: I was more focused on the activity rather on any external distraction	0.85	0.08			
Total immersion						0.82
Presence	C4: The activity felt so authentic that it made me think that the virtual characters/objects existed for real	0.68	0.12	0.85	0.51	0.80
	C6: I felt that what I was experiencing was something real, instead of a fictional activity	0.77	0.13			
	C7: I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly	0.66	0.15			
	C8: I so was involved, that I felt that my actions could affect the activity	0.73	0.14			
Flow	C9: I didn't have any irrelevant thoughts or external distractions during the activity	0.73	0.07	0.91	0.68	0.87
	C10: The activity became the unique and only thought occupying my mind	0.84	0.07			
	C11: I lost track of time, as if	0.90	0.11			

Factors	Items	Loading	SE	CR[1]	AVE[2]	Cronbach's α
	everything just stopped, and the only thing that I could think about was the activity					

[1]The composite reliability value calculation formula: (Σ standardized factor load)^2 /[(Σ standardized factor load)^2 + Σ error variance]
[2]The average variance extracted value calculation formula: (Σ standardized factor load^2)/[(Σ standardized factor load^2) + Σ error variance]

Finally, sufficient discriminant validity was also shown. As Table 3.8 shows, the square root of average variance extracted for each factor-based scale was greater than the inter-correlations between the average variance extracted value for each construct and the other factor-based scales.

Table 3.8: Inter-correlations between factor-based scales and AVE value of each factor

Fit index	A	B	C	D	E	F
A. Interest	**0.71**	0.20	0.56	0.60	0.31	0.56
B. Usability	0.20	**0.73**	0.13	0.17	0.16	0.22
C. Emotion	0.56	0.13	**0.72**	0.68	0.49	0.55
D. Focus	0.60	0.17	0.68	**0.84**	0.36	0.79
E. Presence	0.31	0.16	0.49	0.36	**0.71**	0.36
F. Flow	0.56	0.22	0.55	0.79	0.36	**0.82**

3.6.3.2.4 Fitness of the internal structure

Results of the structural equation modelling analysis did not provide support for the global model of immersion of Brown and Cairns (2004), who conceptualized immersion as a three-level construct composed of the levels of *engagement*, *engrossment* and *total immersion*. All cut-off values were above the cut-off level for this global model. In contrast, the results of the structural equation modelling analysis provided support for the higher-order model suggested by Cheng et al. (2015), who argued for a hierarchical structure of immersion and multi-dimensionality within the levels of *engagement*, *engrossment* and *total immersion* separately. More specifically, the higher-order global model had a more acceptable model fit in comparison to the global one, since all recommended fit indices satisfied the cut-off values, except Goodness of Fit Index [GFI] and Normed Fit Index [NFI] which were below the cut-off value. Hence, even though it was not optimal, the fitness of the higher-order global model was more acceptable. The fit statistics for each of the two tested models are presented in Table 3.9.

Table 3.9: Goodness-of-fit statistics for each of the two tested models

Fit index	χ^2	χ^2/df	GFI	NFI	CFI	IFI	SRMR	RMSEA
Global	663.16**	3.53	0.69	0.65	0.72	0.72	0.12	0.13
Higher-order global	290.16**	**1.62**	0.87	0.85	**0.93**	**0.94**	**0.07**	**0.06**

[1]Acceptable values are presented in bold

Overall, the structural equation modelling analysis supported the internal structure of the model of immersion as a hierarchical and multi-leveled construct, indicating that each level is composed of different factors: "Interest" and "Usability" compose the level of "Engagement", "Focus of attention" and "Emotional attachment" compose the level of "Engrossment", while "Flow" and "Presence" compose the level of "Total Immersion". This process, as described, yielded the final, well-defined questionnaire, composed of 21 seven-point Likert items (see Table 3.10 for the final version of ARI), which is based on a higher order global model of immersion.

3.7 Discussion

This study led to the development and validation of the ARI [Augmented Reality Immersion] questionnaire: an instrument for measuring immersion in the context of AR location-aware applications (see Table 3.10). To achieve this goal, the study adopted a multi-stage approach to instrument construction and validation. This multi-step process yielded a well-structured questionnaire with satisfactory reliability and validity, which is based on a hierarchical model of immersion, operationalizing immersion as a multi-level construct. The ARI questionnaire, thus, captures immersion as a gradated psychological construct with different levels of cognitive and emotional involvement and provides a valid and reliable method for evaluating immersion when employing a location-aware AR application for entertainment and learning.

Table 3.10
The Development and Validation of the ARI Questionnaire

	SI	SII	Questionnaire Items	**Stage I:** Item generation and scales construction	**Stage II:** Item analysis and EFA	**Stage III:** Item selection and CFA
Engagement	Attraction	Interest	A1: The AR application we employed captured my attention	√	√	x
Engagement	Attraction	Interest	A2: I liked the activity because it was novel	√	√	√
Engagement	Attraction	Interest	A3: I liked the type of the activity	√	√	√
Engagement	Attraction	Interest	A4: The topic of the activity made me want to find out more about it	√	√	x
Engagement	Attraction	Interest	A5: The space in which the activity took place was interesting	√	x	x
Engagement	Attraction	Interest	A6: I liked the design and the appearance of the AR application	√	x	x
Engagement	Time investment	Interest	A7: I wanted to spend time to familiarize myself with the AR application	√	x	x
Engagement	Time investment	Interest	A8: I wanted to spend the time to complete the activity successfully	√	√	√
Engagement	Time investment	Interest	A9: I wanted to spend time to participate in the activity	√	√	√
Engagement	Time investment	Interest	A10: I wanted to spend time collecting the information provided	√	x	x
Engagement	Time investment	Interest	A11: The time I spent for the activity was more than I expected	√	x	x
Engagement	Time investment	Interest	A12: I think that participating in this activity was a waste of my time*	√	x	x
Engagement	Usability	Usability	A13: It was easy for me to use the AR application	√	√	√
Engagement	Usability	Usability	A14: I found the AR application confusing*	√	√	√
Engagement	Usability	Usability	A15: I felt confident since I knew how to use the AR application	√	x	x
Engagement	Usability	Usability	A16: I felt that I could use the AR application to find the information I wanted	√	x	x

	SI	SII	Questionnaire Items	**Stage I:** Item generation and scales construction	**Stage II:** Item analysis and EFA	**Stage III:** Item selection and CFA
			A17: The AR application was unnecessarily complex*	√	√	√
			A18: I did not have difficulties in controlling the AR application	√	√	√
Engrossment	Emotional attachment	Emotional attachment	B1: I was impatient about completing the activity successfully	√	√	x
			B2: I was curious about how the activity would progress	√	√	√
			B3: I was often excited since I felt as being part of the activity	√	√	√
			B4: I often felt suspense by the activity	√	√	√
			B5: I often felt that I was really in charge of the activity	√	√	x
	Focus of attention	Focus of attention	B6: If interrupted, I looked forward to returning to the activity	√	√	√
			B7: I was more involved with the activity than with any other irrelevant thoughts	√	√	x
			B8: I often forgot the passage of time during the activity	√	√	x
			B9: Everyday thoughts and concerns faded out during the activity	√	√	√
			B10: I was more focused on the activity rather on any external distraction	√	√	√
			B11: During the activity, hardly anything could distract me	√	√	x
			B12: Time went by quickly during the activity	√	x	x
Total immersion	Presence	Presence	C1: I felt I was the main character in the activity, as the activity could be shaped according to my actions	√	x	x
			C2: I felt that I was in a highly realistic activity, in which I could hardly separate what was virtual or real	√	x	x
			C3: During the activity, I felt that I was the protagonist	√	x	x
			C4: The activity felt so authentic that it made me think that the virtual characters/objects existed for real	√	√	√

	SI	SII	Questionnaire Items	**Stage I:** Item generation and scales construction	**Stage II:** Item analysis and EFA	**Stage III:** Item selection and CFA
			C5: The activity felt more as something that I was experiencing, rather than something I was just doing	√	√	x
			C6: I felt that what I was experiencing was something real, instead of a fictional activity	√	√	√
			C7: I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly	√	√	√
			C8: I so was involved, that I felt that my actions could affect the activity	√	√	√
	Flow	Flow	C9: I didn't have any irrelevant thoughts or external distractions during the activity	√	√	√
			C10: The activity became the unique and only thought occupying my mind	√	√	√
			C11: I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity	√	√	√
			C12: All of my senses were totally concentrated on the activity	√	√	x

[1]SI and SII stand for "Stage I" and "Stage II" accordingly

[2]Reverse coded items are marked with an asterisk

[3]Retained items are marked with √ while removed items with x

[4]The questionnaire was addressed to a Greek population and, as a result, all of the items were presented to the study participants in Greek

3.7.1 Study contribution

Existing validated instruments for evaluating immersion have been developed in the context of non-AR digital games (Cheng et al., 2015; Brown & Cairns, 2004; Jennett et al., 2008); as a result, many of the items included in such questionnaires do not apply to location-aware AR environments. AR researchers have used field research as an exploratory, bottom-up methodology; using this approach they have primarily focused on examining which aspects may affect immersion with the goal of improving game design, rather than conceptualizing and theorizing immersion (Reid et al., 2011).

To our knowledge, none of the existing studies provided and validated a consolidated, theoretical model of immersion in location-aware AR environments up to now. The results of employing the ARI instrument with participants in location-aware AR settings can be used both to establish the participants' immersion level, as a variable in the investigation of several, immersion-related issues, and to provide insights that can contribute to improved location-aware AR designs. We believe that the development and validation of the ARI questionnaire will support AR researchers and designers, as it provides a validated and theoretically-driven assessment of immersion.

3.7.2 Limitations and Next Steps

Although the ARI questionnaire appears to be a promising tool for assessing immersion in the context of location-aware AR apps, we do not argue that it should be utilized without caution.

The process for constructing the ARI questionnaire followed widely-accepted norms about questionnaire development and validation. One concern though is related to the sample size required for conducting the EFA and the CFA research. Both EFA and CFA have often been reported as large sample techniques (e.g. Costello & Osborne, 2005; Bentler & Chou, 1987; West, Finch, & Curran, 1995). Over the years a variety of recommendations have been suggested for sufficient sample sizes in order to achieve adequate results, including a ratio of sample size of at least 5:1 to the number of variables and model parameters, or at least 200 participants as a lower limit of the sample size (Bentler & Chou, 1987; Costello & Osborne, 2005). These recommendations imply that the CFA findings of the present study may be compromised by its sample size ($n<200$). However, an increasing number of CFA simulation studies have challenged strict variable-based and parameter-based sample size guidelines; these studies have investigated the required minimum sample needed to yield reliable factor recovery and suggested that CFA model convergence is also affected by the measurement quality of the factor loadings magnitudes in relation to the indicators per factor (Marsh, Hau, Balla, & Grayson, 1998; Gagné & Hancock, 2006). Harrington (2009) has discussed that confirmatory factor analysis can still be used with small sample sizes, while a number of published empirical studies reported on CFA employing samples with even less than 150 participants (e.g. Apostolou, 2013; Henriksson, Andershed, Benzein & Årestedt, 2011). In accordance with the recommendations of simulation research for CFA-based analyses (Marsh et al., 1998; Gagné & Hancock, 2006), the sample size of the present study appears to be sufficient. In addition, among the diverse goodness-of-fit indices that were employed in the present study, RMSA, which is less sensitive to sample size (Brown, 2006), indicated good fit between the model and the data. Future research could examine the psychometric properties of the ARI questionnaire with larger samples and diverse populations, given that additional testing is needed in order to validate the questionnaire in other languages, with different age samples, and in contexts other than learning.

In addition, a limitation of the present study is that the validated ARI questionnaire has focused on the evaluation of immersion in the context of location-aware AR applications for learning or entertainment rather with other types of AR applications (e.g. image-based AR applications with an emphasis on 3D object augmentation and manipulation).

Finally, a limitation of this study, which is a recurrent theme with all subjective instruments, is the self-report, post-intervention nature of the questionnaire. Similarly to the approaches adopted during the development of other questionnaires on immersion, presence, or flow asking participants to respond retrospectively after the immersive experience, the ARI questionnaire could be criticized for simply achieving an overall post-test rating, rather than fully capturing the temporal nature of immersion (Chung & Gardner, 2012; Ijsselsteijn, de Ridder, Freeman, & Avons, 2000). Even though, undoubtedly, the questionnaire data could not capture the exact moments when feelings of immersion were experienced, currently there is no better way to investigate immersion-in-action, as any form of measurement during the AR experience could disrupt psychological immersion (Cheng et al., 2015). On the same note, it is often argued that post-test questionnaires are potentially subjected to inaccurate recall, which can even distort the experience of immersion (Chung & Gardner, 2012; Ijsselsteijn et al., 2000). In this study, we have attempted to eliminate the distortion effects by administering the questionnaire right after the AR experience. In addition, we argue that the relatively short duration of the intervention contributed in keeping the immersive experience in the students' memory. However, future studies should investigate immersion with different types of measurement, including qualitative techniques such as direct observation, semi-structured interviews and analysis of discourse and actions, with an emphasis on triangulation approaches. Such mixed-method studies will be critical in providing deeper and more reliable insights of immersion in the context of location-aware augmented reality applications.

3.7.3 Conclusions

This chapter contributes to the literature by (a) offering a validated instrument to assess immersion in location-aware AR environments, and (b) verifying the existence of a multi-level, hierarchical nature of immersion and validating this in such AR settings. We argue that the ARI questionnaire is a promising tool for measuring immersion in the context of location-aware AR applications for learning or entertainment, and can support future research of the construct of immersion.

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CHAPTER 4: TRANSLATION, ADAPTATION, AND VALIDATION OF THE NEED FOR COGNITION SCALE (NfC-SF)

Abstract

This chapter presents the adaptation and validation the Need for Cognition Scale–Short Form (NfC-SF) in the Greek language. A multistep process was followed, including: (a) the translation and adaptation of the questionnaire, (b) a reliability analysis of the instrument's items in combination with an exploratory factor analysis with 177 secondary school students, and (c) a confirmatory factor analysis for defining the underlying structure of the scale, using a sample of 532 secondary school students. The statistical analyses validated a 14-item version of the NfC-SF for measuring the cognitive motivation of secondary school, Greek-speaking students. The present research effort also extends previous research about the underlying structure of the NfC, by suggesting that method effects should be considered in measurement models for improving scale validity.

4.1 Introduction

Need for Cognition (NfC), represents a stable individual trait, which relates to the dispositional motivation to engage in cognitively demanding efforts. Since its introduction, NfC has been examined in a vast corpus of research studies; in a comprehensive review study published two decades ago there were already more than 100 empirical studies focusing on NfC (Cacioppo, Petty, Feinstein, & Jarvis. 1996), while two decades later about 1,900 studies have cited the original study of Cacioppo and Petty (1982), who introduced and defined the concept of NfC. Although there are numerous studies investigating NfC, Petty, Briñol, Loersch, and McCaslin (2009) discussed the utility and significance of NfC, in relation to the following four domains: (a) Individual beliefs and attitudes, (b) Decision-making processes, (c) Interpersonal interactions and (d) Other applied areas such as survey research, advertising, media, law and health.

This ever-increasing corpus of NfC-related empirical studies would not be feasible, if a validated instrument for measuring NfC did not exist in the first place. Cacioppo and Petty (1982), who have defined need for cognition as "an individual's tendency to engage in and enjoy thinking" (p. 116), have developed the NfC scale for differentiating cognitive motivation among adults. The NfC scale consists of 34 items, scored on a 5-point Likert-type scale. Half of the items are positively worded (e.g., "The notion of thinking abstractly is appealing to me"), while the remaining items are negatively worded (e.g., "I like tasks that require little thought once I've learned them"). A short form of the NSC also exists, as described in the Cacioppo, Petty and Kao (1984) study, and consists of 18 items scored on a 9-point Likert-type scale.

Previous studies have supported the validity of both NfC scales across different cultures and languages, including: Chinese, French, German, Spanish, and Turkish. However, none of the NfC scales has been validated in Greek, even though the underlying factor structure of the scale and the responses to the scale can be differentiated among cultures (Fosterlee & Ho, 1999). In addition, most of the validation studies are focused on adults, with few studies validating the NfC scales for children or adolescents (Preckel, 2014). Validating scales with subjects from the intended target population is important, since if the items do not represent the same factors at different ages, a shift in the internal structure of the measure might occur (Soubelet & Salthouse, 2016).

Another reason to continue investigating the NfC scale is to provide more data about its underlying factor structure, which is still debated. In particular, the most reported competing NfC factor structures relate to (a) a unidimensional NfC factor model, which assumes that there is one underlying dominant factor, (b) "trait-method models", which take into account the potential effect of positively and negatively worded items comprising the scale, and (c) two-factor models, which assume that the NfC-SF is composed of two factors, defined by the polarity of items (Fosterlee & Ho, 1999; Hevey et al., 2012).

Taking into account the research areas that still need to be investigated, the present study was guided by two research goals. The first goal was to translate, adapt and validate the NfC-SF in a different cultural context and age group, that is, in the Greek language to be used with secondary school Greek-speaking students in Cyprus. The second goal was to build on previous research in relation to the hypothesized internal structure of the NfC-SF, and employ confirmatory factor analyses to evaluate a set of competing NfC models. We next present the methodological steps which were adopted to address these goals.

4.2 Stage I: Translation and Adaptation

The translation and adaptation of the NfC-SF to Greek (NfC-SF-GR) employed a systematic approach, using forward and backward translation procedures to preserve the meaning, denotation, and conceptual equivalence of each item (Sumathipala & Murray, 2000). As a result of this process, the items were translated, adapted and refined by simplifying the wording to enhance clarity and conciseness. This stage was completed with a 30-minute focus group to test the items with twelve 10^{th} and 11^{th} grade students, of mixed academic ability. Based on the comments received from this cohort of students, some of the items were further simplified to ensure that the wording of the scale was understandable to the target age group.

4.3 Stage II: Exploring the Underlying Factor Structure of the NfC-SF-GR

The second stage of this study involved an exploration of the underlying factor structure of the NfC-SF-GR, employing Exploratory Factor Analysis (EFA), as a form of a replication analysis.

4.3.1 Sample and Materials

The sample was comprised of 177 Greek-Cypriot high school students (40.7% boys and 59.3% girls). The students attended 10^{th} and 11^{th} grades (mean age = 15.35) at an urban high school. Participants responded to the NfC-SF-GR, which was composed of the 18-item NfC-SF Scale (Cacioppo et al., 1984).

4.3.2 Data analysis and Results

After reversing the nine negative polarity items, the item-to-total correlations were examined for items not consistent with the rest of the scale, in order to purify the NfC-SF-GR (DeVellis, 2003). The cut-off point for the correlation coefficient was 0.4; any items below this cut-off point were eliminated from the analysis. As a result, two positively worded items (P10, P18) as well as two negatively-worded items (N7, N12) were deleted from the scale.

The KMO (KMO=0.89) and the Bartlett spherical test [χ^2 (91) = 1022.99, $p < 0.01$] verified the appropriateness of the 14 items, which were retained for the factor analysis. The PCA extracted two factors with eigenvalues greater than 1, which were subjected to varimax rotation. The rotated component matrix indicated that the 14 retained items correlated highly and evenly on the two factors. The first rotated factor comprised of all seven positive-polarity items and the second rotated factor consisted of all seven negative-polarity items. An examination of the rotated component matrix for the first factor showed satisfactory coefficients for all of the seven positively-worded items, which ranged from .63 to .77. In addition, the coefficients for all seven negatively-worded items was also satisfactory, as it ranged from .53 to .70. The Cronbach's α for the two factors was 0.81 and 0.86, respectively; Cronbach's α for the complete NfC-SF-GR was 0.89 (see Table 4.1).

Table 4.1: Exploratory Factor Analysis for the NfC-SF-GR

Item	Factor loadings			
	Factor 1 (Positively-worded items)	Factor 2 (Negatively-worded items)	Percentage of variance explained	Cronbach's α
P14: The notion of thinking abstractly is appealing to me	**0.77**	0.29	29.17%	0.86
P11: I really enjoy a task that involves coming up with new solutions to problems	**0.75**	0.05		
P13: I prefer my life to be filled with puzzles that I must solve	**0.73**	0.19		
P6: I find satisfaction in deliberating hard and for long hours	**0.67**	0.20		
P2: I like to have the responsibility of handling a situation that requires a lot of thinking	**0.64**	0.19		
P15: I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought	**0.63**	0.47		
P1: I would prefer complex to simple problems	**0.63**	0.34		
N16: I feel relief rather than satisfaction after	0.08	**0.70**	23.64%	0.82

Item	Factor loadings			
	Factor 1 (Positively-worded items)	Factor 2 (Negatively-worded items)	Percentage of variance explained	Cronbach's α
completing a task that required a lot of mental effort				
N9: I like tasks that require little thought once I've learned them	0.29	**0.67**		
N17: It's enough for me that something gets the job done; I don't care how or why it works	0.06	**0.65**		
N5: I try to anticipate and avoid situations where there is likely chance I will have to think in depth about something	0.31	**0.65**		
N8: I prefer to think only about small, daily projects to long-term ones	0.35	**0.62**		
N4: I would rather do something that requires little thought than something that is sure to challenge my thinking abilities	0.53	**0.57**		
N3: Thinking is not my idea of fun	0.40	**0.53**		
				0.89

The highest loading for each factor is presented in bold

4.4 Stage III: Verifying the Factor Structure of the NfC-SF-GR

The third stage of this study consisted of a Confirmatory Factor Analysis (CFA) in an effort to verify the factor of the NfC-SF-GR, by evaluating nine competing factor structures (see Figure 4.1), as follows: (a) Model 1, a unidimensional model, (b) Model 2, with two correlated factors defined by the polarity of items, (c) Model 3, with two independent factors defined by the polarity of items, (d) Model 4, a unidimensional model with correlated errors

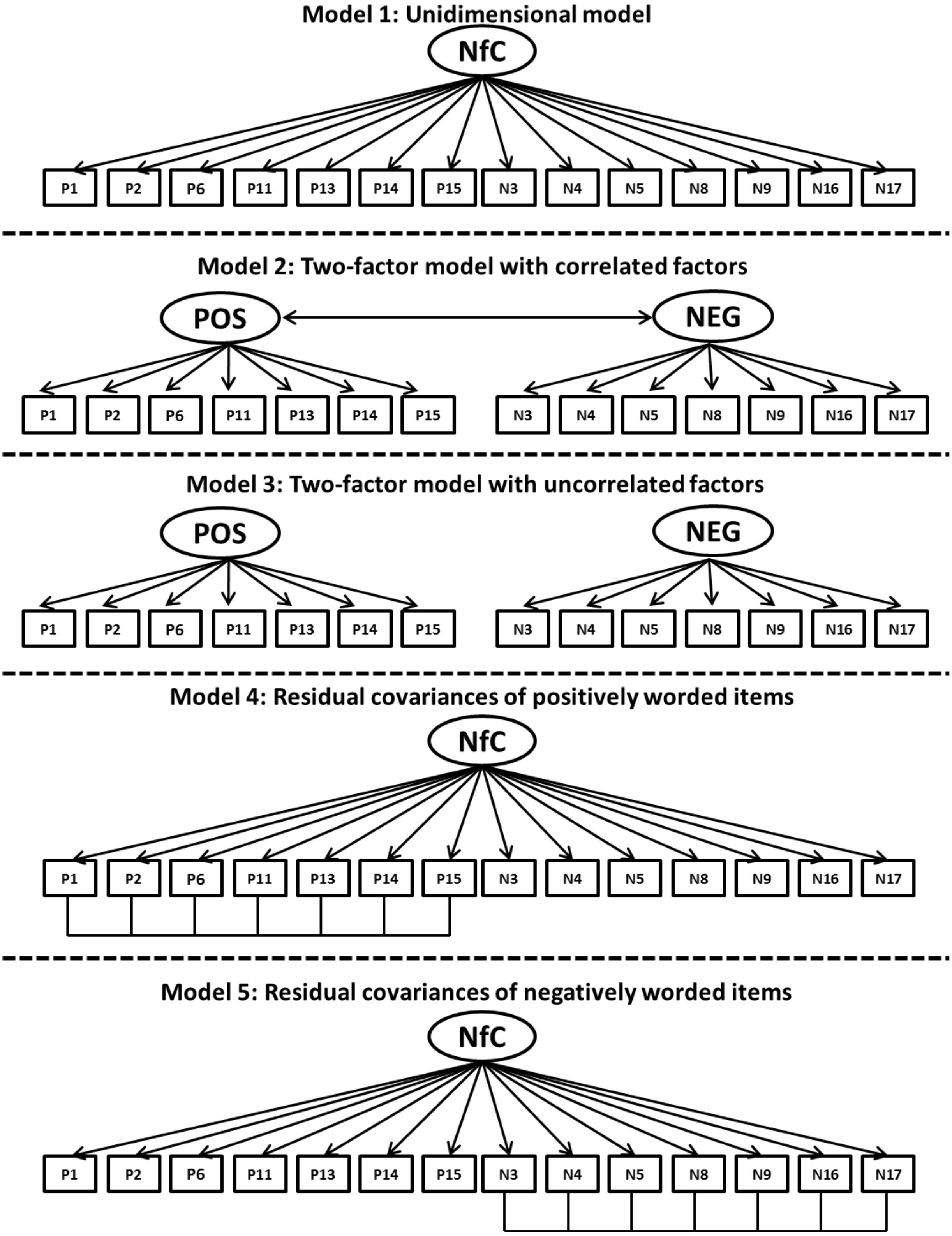

Figure 4.1. The nine factor models of the Need for Cognition (NfC) scale *(Part I)*

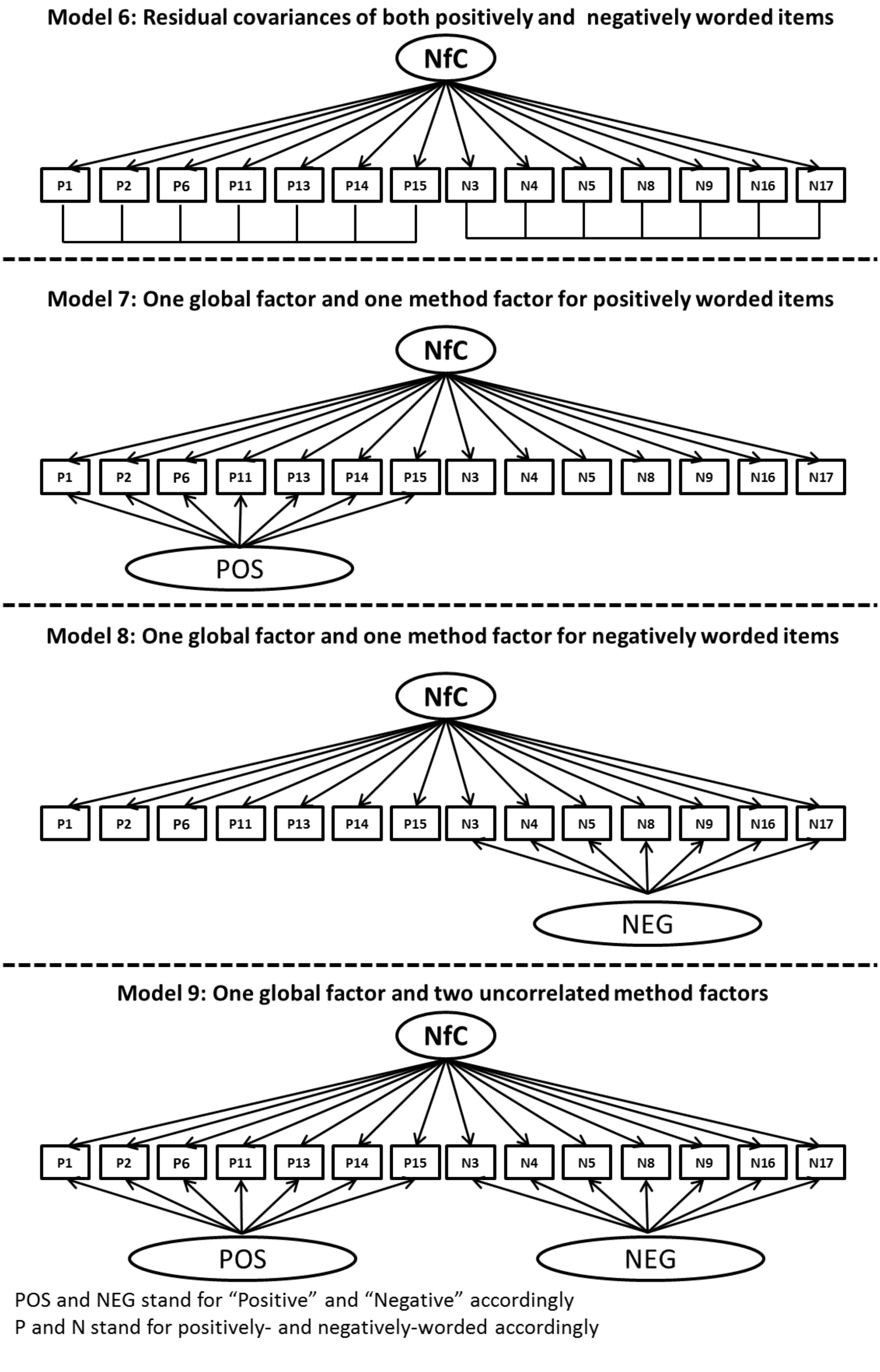

Figure 4.1. The nine factor models of the Need for Cognition (NfC) scale *(Part II)*

among the positively worded items, (e) Model 5, a unidimensional model with correlated errors among the negatively worded items, (f) Model 6, a unidimensional model with correlated errors among the negatively as well as among the positively worded items, (g) Model 7 that includes one global NfC factor and one method factor containing the positively worded items, (h) Model 8, which includes one global NfC factor and one method factor containing the negatively worded items (i) Model 9, which includes one global NfC factor and two uncorrelated method factors defined by the polarity of items.

Overall, two different approaches were employed to account for method effects in the trait-method models (Models 4-9): Correlated Traits-Correlated Uniqueness (CTCU) and Correlated Traits-Correlated Methods (CTCM) (Marsh & Grayson, 1995). The CTCU approach evaluates method effects, taking into account the error covariance among positively worded items (Model 4), the negatively worded items (Model 5), or both (Model 6). The CTCM approach, in addition to a substantive factor, employs latent method factors for controlling the variance of items worded in the same direction: a method factor for positively worded items (Model 7), for negatively worded items (Model 8), or both (Model 9).

4.4.1 Sample and Materials

The sample comprised of 532 Greek-Cypriot high school students (35.2% boys and 64.8% girls), from thirty-one 10^{th} and 11^{th} grade classrooms from five urban high schools (mean student age = 15.68). Participants responded to the revised 14-item version of the NfC-SF-GR.

4.4.2 Data Analysis and Results

The fitness of the internal structure of the NfC-SF-GR was evaluated for the nine tested models. In particular, a variety of fit indices were employed, given that the chi-square index is inadequate as a standalone fit index because of its sensitivity to sample size: Goodness-of-Fit Index (GFI), Incremental Fit Index (IFI), Normed Fit Index (NFI) and Comparative Fit Index (CFI), which should all be higher than 0.90 for an acceptable model fit (Bentler & Bonett, 1980). The Standardized Root Mean Square Residual (SRMR) and Root Mean Square Error of Approximation (RMSEA) were also reported, with values below 0.08 indicating sufficient fit.

Results of the Structural Equation Modeling (SEM) analysis did not provide support for two of the nine tested models (Table 4.2). Model 1, which assumes a unidimensional model, had unacceptable fit indices. Model 3, which assumes two independent factors defined by the polarity of items, had the worst fit. In addition, in Model 6 the solution was unidentified and inadmissible after imposing equality constraints among similar error covariances (Model 6a). On the other hand, the results of the SEM analysis provided support for the Model 2, which assumes two correlated factors defined by the polarity of items. However, although the model of the two correlated factors had acceptable fit indices, the rest of the trait-method Models (4, 5, 7, 8 and 9) provided better fit indices. The best fit indices were observed for Model 4, which represents a unidimensional model with correlated errors among the positively worded items, followed by Model 5, which represents a unidimensional model with correlated errors among the negatively worded items.

Table 4.2: Goodness-of-fit Statistics for each of the tested models

Fit index	χ^2	df	GFI	NFI	CFI	IFI	SRMR	RMSEA (90% CI)
Model 1	348.22**	77	**0.908**	0.871	0.896	0.896	**0.050**	0.081 (0.073-0.090)
Model 2	225.13**	76	**0.944**	**0.916**	**0.943**	**0.943**	**0.039**	**0.061** (0.052-0.070)
Model 3	564.48**	77	0.890	0.790	0.813	0.814	0.224	0.109 (0.101-0.108)
Model 4	132.63**	56	**0.964**	**0.951**	**0.971**	**0.971**	**0.031**	**0.051** (0.040-0.062)
Model 5	163.30**	56	**0.960**	**0.939**	**0.959**	**0.959**	**0.031**	**0.060** (0.049-0.071)
Model 6	Unidentified							
Model 6a	Inadmissible							
Model 7	205.75**	70	**0.948**	**0.924**	**0.948**	**0.948**	**0.036**	**0.060** (0.051-0.070)
Model 8	221.33**	70	**0.945**	**0.918**	**0.942**	**0.942**	**0.038**	**0.064** (0.054-0.073)
Model 9	175.19**	63	**0.955**	**0.935**	**0.957**	**0.957**	**0.035**	**0.058** (0.048-0.068)

Notes. **$p < 0.01$. / Acceptable values are presented in bold

4.5 Discussion

The present study adapted and validated the NfC-SF questionnaire with participants from a different cultural context and age group (Greek-Cypriot secondary school students), while also seeking to verify the NfC-SF's internal structure.

The process for adapting and validating the NfC-SF-GR followed widely-accepted norms about questionnaire translation and adaptation, and validated this questionnaire using sufficiently large sample sizes. As part of the validation process, four items [N7, P10, N12, P18] were initially removed, due to their low item-to-total correlations. These findings coincide with previous studies validating NfC-SF, which also reported on the need to remove items in different cultural settings such as the Chinese (Kuang, Shi & Kai, 2005), the Turkish (Gülgöz & Sadowski, 1995), or the Australian (Fosterlee & Ho, 1999).

An exploratory factor analysis with the retained fourteen items was in accordance to the study of Fosterlee and Ho (1999), indicating two distinct factors, defined by the polarity of items. However, the findings of our confirmatory factor analysis indicated that this two-factor structure was simply an artifact of method effects, related to the wording of the items. According to our confirmatory factor analysis, the NfC-SF-GR provides a unidimensional measure for cognitive motivation. However, the present study found that all of the trait-method factor models, except model 6, provided acceptable fit indices, indicating that ratings from this scale are affected by method effects. In particular, according to the two best fitting models (Model 4 and Model 5), it seems that the factorial structure of the NfC-SF-GR is affected by response styles, depending on item wording. These findings are aligned with previous studies, which explored the underlying NfC structure with secondary school students (Bors et al., 2006; Preckel, 2014), suggesting that the underlying factor structure of the NfC could better be explained by a unidimensional trait-method effect model, as method effects should be considered for improving scale validity.

Overall, beyond confirming the factor structure of the NfC-SF-GR, the findings of the present study bear important implications on the topic of data collection through rating scales with both negative and positive items. Specifically, the present study supports previous research suggesting that the negative-item method effects may be received as threat for the factorial structure of a given scale (Dodeen, 2015). Prior research has, nonetheless, presented several suggestions on how to deal with this methods effect problem. Marsh (1992) suggested solutions such as eliminating the negatively-worded items from rating scales or including fewer negative items, whose presence will contribute towards controlling for possible response bias. In this context, it seems that the method effects related to the NfC-SF could be further researched. Until then, it seems that confirmatory factor analysis could provide a methodological tool which considers both the factorial structure of the NfC construct as well as the method effects, thus contributing to the construct validation of NfC.

Table 4.3: NfC-SF validation process

	Scale items	Stage I: Adaptation & Translation	Stage II: Item analysis & EFA	Stage III: CFA
Positively-worded items	P1: I would prefer complex to simple problems	√	√	√
	P2: I like to have the responsibility of handling a situation that requires a lot of thinking	√	√	√
	P6: I find satisfaction in deliberating hard and for long hours	√	√	√
	P10: The idea of relying on thought to make my way to the top appeals to me	√	x	x
	P11: I really enjoy a task that involves coming up with new solutions to problems	√	√	√
	P13: I prefer my life to be filled with puzzles that I must solve	√	√	√
	P14: The notion of thinking abstractly is appealing to me	√	√	√
	P15: I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought	√	√	√
	P18: I usually end up deliberating about issues even they do not affect me personally	√	x	x
Negatively-worded items	N3: Thinking is not my idea of fun	√	√	√
	N4: I would rather do something that requires little thought than something that is sure to challenge my thinking abilities	√	√	√
	N5: I try to anticipate and avoid situations where there is likely chance I will have to think in depth about something	√	√	√
	N7: I only think as hard, as I have to	√	x	x
	N8: I prefer to think only about small, daily projects to long-term ones	√	√	√
	N9: I like tasks that require little thought once I've learned them	√	√	√
	N12: Learning new ways to think doesn't excite me very much	√	x	x
	N16: I feel relief rather than satisfaction after completing a task that required a lot of mental effort	√	√	√
	N17: It's enough for me that something gets the job done; I don't care how or why it works	√	√	√

[1]Retained items are marked with √ while removed items with x

[2] The questionnaire was addressed to a Greek population and, as a result, all of the items were presented to the study participants in Greek

4.6 Conclusions and Future Research

The present study resulted in a 14-item version of the NfC-SF-GR, as a validated measurement of cognitive motivation, for use with secondary school Greek-speaking students (Table 4.3). Future studies could be conducted to collect additional data on validity, such as the investigation of the relationship of NfC and the big five personality traits (see Ypofanti et al., 2015), or how NfC is related to other personality traits, such as self-esteem (see Michaelides, Koutsogiorgi, & Panayiotou, 2016). Future research could also investigate the applicability of the NfC-SF-GR with subjects of other ages, such as younger children.

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CHAPTER 5: A COGNITIVE MODEL OF IMMERSION IN RELATION TO STUDENTS' CONCEPTUAL LEARNING IN ENVIRONMENTAL SCIENCE

Abstract

Immersion, which can be defined as a multi-level process of cognitive and emotional involvement, resulting in the subjective impression that someone participates in a realistic and cognitively absorbing experience, is assumed to facilitate science learning. However, while many studies have speculated the positive impact of immersive digital environments on science learning outcomes, only a handful of studies have explored the relationship between immersion and conceptual learning in science. These studies have been limited to the field of virtual reality and game-based virtual worlds, and have provided contradictory empirical evidence. Under these circumstances, many researchers have argued that the relationship between immersion and conceptual learning might be more complex than initially expected, speculating that the impact of immersion might be mediated by students' characteristics and cognitive load. No studies have proposed a model for specifying and investigating such complex relationships. The present study is situated in the field of location-based Augmented Reality (AR) and seeks to address this gap by proposing a cognitive model of immersion in science learning. According to this model, immersion is assumed to be positively related to conceptual learning, while domain-specific motivation, cognitive motivation and cognitive load are considered as potential predictors of immersion. The model was empirically investigated with 135 10th graders, who used a location-aware AR app for environmental science learning. Statistical analyses, which included pre- and post-test comparisons, correlations, multiple regressions and cluster analysis techniques, contributed to the model's validation. This work provides empirical substantiation that immersion is positively predicted by students' domain-specific motivation and cognitive motivation, and negatively predicted cognitive load. In turn, conceptual learning gains seem to relate to the level of immersion that students achieve. Implications are discussed in combination with future research pathways.

5.1 Introduction

Learning environments incorporating immersive technologies, such as location-aware Augmented Reality (AR) technologies, have only recently been introduced to science education (Cheng & Tsai, 2013). The advent of immersive digital environments, along with a more sophisticated understanding of how people learn, is argued to provide greater opportunities to engage students in transformative ways of learning science (Barab & Dede, 2007; Dede, 2009). Immersion, which can be defined as a multi-level continuum of cognitive and emotional involvement, has been claimed to be one of the main driving forces fostering students' science learning in digital learning environments (Cheng, She, & Annetta, 2015). Dede (2009), who defined immersion "as the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (p.66), has stated that immersion can enhance science education in at least three ways by allowing: (a) multiple and complementary insights of complex scientific phenomena, (b) situated learning, and (c) the transfer skills in real world situations.

Despite these claims, empirical studies investigating the relation between immersion and science learning are still limited, contradictory and inconclusive. Although many studies have speculated on the positive impact of immersive digital environments on conceptual learning outcomes, only few have empirically investigated the relationship between immersion and students' conceptual understanding in science, often providing contradictory empirical evidence. While some researchers have found positive relations between immersive experiences and students' conceptual learning in science (Rowe, Shores, Mott, & Lester, 2011; Schrader & Bastiaens, 2012a; Winn, Windschitl, Fruland, & Lee, 2002), other studies found no relation between immersion and learning outcomes in science. Recent empirical studies have found positive relationships between immersion and game-based performance in virtual worlds, but they reported weak or no relationship between immersion and students' learning gains, suggesting that digital learning environments may provoke high levels of cognitive load, negatively affecting students' immersion (Cheng et al., 2015; Hsu & Cheng, 2014). Another explanation, which may account for such findings, is the subjective nature of immersion, which can be influenced by individual student characteristics, such as prior knowledge (Cheng, Lin, She, & Kuo, 2016) or immersive tendencies (Schrader & Bastiaens, 2012b). However, we identified no published studies investigating a possible model specifying relationships between students' individual differences, cognitive load and immersion in relation to conceptual learning in science.

According to a review study of Cheng and Tsai (2013), there is also lack of empirical studies investigating how immersion affects science learning in location-based AR settings. Previous empirical studies on immersion in relation to science learning were only identified in the fields of virtual reality and game-based virtual worlds. While virtual environments seek to replace reality, location-based AR settings attempt to supplement it, by blending the real world with virtual elements (Klopfer, 2008). This augmentation of reality is achieved as mobile and context-aware technologies respond to students' position in the real world and enrich physical landscapes with digital information (Cheng & Tsai, 2013). Location-based AR settings are, thus, hypothesized to foster learning, as they allow students' immersion in blended spaces of educational interest.

This study examined immersion in the context of location-based AR settings. In particular, the present study puts forth a cognitive model of immersion in relation to conceptual learning in environmental science, which acknowledges the potential mediating effects of cognitive load and of domain-specific motivation and cognitive motivation on students' immersion. Based on our review of the literature, the investigation of immersion and science learning using augmented reality technologies is an under-researched topic, and, thus, the contribution of the present study will enhance the current understanding of this topic.

5.2 Theoretical framework

5.2.1 Immersion in Location-based Augmented Reality (AR) Contexts

Location-based AR learning contexts have been gaining ground in the field of science education, as they are assumed to provoke immersion and support learning, due to a set of unique characteristics (Cabiria, 2012; Dede, 2009; Dunleavy, Dede, & Mitchel, 2009). Location-based AR settings differ from other digital immersive environments, as they: (a) employ mobile and location-aware interfaces, (b) combine physical and digital spaces, thus creating blended spaces, (c) extend the activity outside the limits of traditional digital space (e.g. the screen) into the physical space, and (d) provide students with rich interaction possibilities, especially interactions with the physical world and with virtual elements augmenting it (de Souza e Silva & Delacruz, 2006; Squire & Jan, 2009).

High levels of immersion may provoke the optimal states of "flow" –a sense of full absorption in the AR activity– and "presence" – a sense of feeling surrounded by a blended, yet realistic physical/virtual environment (Authors, 2016; Cheng & Tsai, 2013). When highly immersed, "students quickly enter a state of suspended disbelief, accept the blended real and digital environment, give their attention over to it, and engage in the variety of options available to them to access content related to the topic being addressed" (Cabiria, 2011, p. 240).

Georgiou and Kyza (2017a) have previously described immersion in the context of location-based AR settings as a multi-level continuum of cognitive and emotional involvement, comprised of three sequential stages: engagement, engrossment and total immersion. The first level, "engagement", is based on interest and usability; to enter this level students need to first like the activity and become familiar with using the AR app. If students are interested in the activity and find the location-aware AR app user-friendly, then they may be able to become further involved and enter "engrossment", which is the second level of immersion. At this level, focused attention and emotional attachment are the determinant factors, as the AR activity becomes the most important part of students' attention. Finally, to enter the "total immersion" stage, students should reach *presence*, a sense of feeling that one is surrounded by the blended environment, and *flow*, a feeling of being fully absorbed in the activity.

AR researchers have previously attempted to explore the affordances and limitations of location-aware AR apps through field trials (Dunleavy et al., 2009; Reid, Geelhoed, Hull, Cater, & Clayton, 2005). Field trials allowed researchers to gain experience of location-aware apps in real-world settings, while isolating different key factors assumed to impact users' experience (Reid, Hull, Clayton, Melamed, & Stenton, 2011). Dunleavy et al. (2009), who conducted multiple case studies in middle schools, as part of design-based research projects, have reported, for instance, that the technological affordances, along with the interactive, situated, collaborative problem-solving affordances of location-based AR settings, were highly engaging features. At the same time, they also reported that contextual factors (e.g. weather, temperature, and noise), students' cognitive load, or hardware and software bugs (e.g. lack of GPS accuracy) were included among the main limitations of location-based AR activities for science learning. However, while such research efforts have provided useful insights on a variety of potential factors affecting the learning experience, these studies did not propose a model defining the relation of immersion and science learning in augmented reality settings, while taking into consideration the impact of these factors on students' immersive experience.

The present study aims to add to the literature by empirically validating a cognitive model of immersion in relation to conceptual learning in location-based AR settings. Drawing from the extant literature regarding the nature of location-based AR tasks, and relevant empirical studies from the field of immersive virtual environments, this model takes into consideration that the impact of location-based AR settings may be not directly related to students' immersion, due to the potential effects of cognitive load and students' motivation, in terms of domain-specific motivation and cognitive motivation. In the following, we review empirical and theoretical support for the potential relationships between these three variables and immersion.

5.2.2 Motivation

Theoretical models of immersion have defined immersion as a process of cognitive and emotional involvement, during which users may voluntarily allocate their attention towards a media product; however, for this to occur, users' motivation has been hypothesized as a significant determinant (e.g. Brown & Cairns, 2004; Jennett et al., 2008; Scoresby & Shelton, 2011). Motivation has also been considered as a prerequisite to experience the immersive states of presence or flow (Lombard & Ditton, 1997; Weibel & Wissmath, 2011; Wirth et al., 2007). To date, convincing empirical substantiation for these claims is missing.

As part of this study, we have assumed that domain-specific motivation and cognitive motivation may positively predict students' immersion in location-based AR settings. We, next, discuss the potential relationship of these two types of motivation to students' immersion in location-based AR learning environments.

5.2.2.1 Domain-specific Motivation

O'Shea, Dede and Cherian (2011) have argued that the design of augmented reality environments can be informed by game design principles (e.g. interactive narratives, role-playing, game mechanics). Instructional designers have recurrently emphasized that the design of games can provide valuable insights for the development of learning environments which may influence students' immersion (Dickey, 2006; Warren, Stein, Dondlinger, & Barab, 2009). Squire and Jan (2009) discuss five game design principles that location-aware

AR apps for learning science usually employ: (a) role-playing, (b) task-based challenges integrated within compelling narratives, (c) interactive spaces, (d) authentic tools and resources, (e) social interaction.

Previous research on games has indicated that a substantial difference between immersive learning environments and popular digital games is the educational content embedded within an immersive learning environment, which, in many cases, can act as an obtrusive element reducing students' immersion (Kickmeier-Rust & Albert, 2010). While selecting a popular digital game is a highly voluntary and self-selected experience, immersive educational environments are, in many cases, "mandatory learning experiences that are equivalent to assigned lab experiments, interactive training videos, simulation exercises, etc." (Heeter, Lee, Magerko, & Medler, 2011, p. 35).

Under these circumstances, even the most well-designed, immersive educational activities may fail to engage all students in a classroom (Blasko, Lum, White, & Drabik, 2013; Magerko, Heeter, & Medler, 2010). Instead, it has been proposed that an immersive learning environment can be more appealing to a student, if the student has high domain-specific motivation and topic interest (Scoresby & Shelton, 2011; Wirth et al., 2007). Domain-specific motivation has been previously argued to direct and sustain goal-oriented behavior and is manifested through students' active involvement in the learning process (Dermitzaki, Stavroussi, Vavougios, & Kotsis, 2013; Pintrich & De Groot, 2003; Tuan, Chin, & Shieh, 2005). Taking into consideration that students' immersion during a location-based AR activity assumes that students need to first like the activity (Georgiou & Kyza,, 2017a, Brown & Cairns, 2004; Cheng et al., 2015; Jannett et al., 2008), we hypothesize that domain-specific motivation may positively predict immersion.

5.2.2.2 Cognitive Motivation

Digital immersive environments are often media rich and complex. Location-based AR settings for learning science are, often, structured around complex and authentic real-world problems; for their solution students are asked to collect and synthesize relevant data as they progress through multiple data sources located in the virtual or physical realm (Dunleavy et al., 2009; Klopfer & Squire, 2008; O'Shea, Mitchell, Johnston, & Dede, 2009, O'Shea et al., 2009) while also responding to a set of directions related to navigating in the physical space.

In addition, the naturalistic settings, in which location-based AR activities take place, increase their complexity to a greater degree. Unlike virtual environments taking place in controlled settings, location-based AR activities provide situated experiences in which environmental parameters remain beyond the designer's control (Reid et al., 2011). Under these circumstances, external elements like cars, insects, animals, or outdoor noise, cannot be controlled, and could act as distractors, thus disrupting the immersive experience (Dunleavy et al., 2009; Reid et al., 2011).

In such contexts, cognitive motivation, as a stable personality trait reflecting an individual's tendency to invest cognitive effort in challenging tasks (Cacioppo, Petty, & Kao, 1984; Cacioppo, Petty, Feinstein, & Jarvis, 1996; Petty, Briñol, Loersch, & McCaslin, 2009), can define the extent to which a student will invest his/her cognitive resources during a location-based AR activity. Students of high cognitive motivation, who are accustomed to thinking carefully and engaging in ill-structured problems, may be cognitively motivated to engage with a location-based AR activity. We hypothesize that this motivation may positively predict students' immersion (Georgiou & Kyza, 2017a, Brown & Cairns, 2004; Cheng et al., 2015; Jannett et al., 2008).

5.2.3 Cognitive Load

Cognitive load theory assumes that human working memory can only handle a very limited number of new elements (Baddeley, 1992; van Merrienboer & Sweller, 2005). According to the theory, learning can be facilitated by managing cognitive load that is imposed by the learning materials (intrinsic load) and by the way those materials are presented (extraneous load), to maximize the working memory resources required for processing the new information (productive or germane load) to foster learning (Paas, Tuovinen, Tabbers, & van Gerven, 2003; Sweller, van Merrienboer, & Paas, 1998).

As a result, limitations in working memory capacity may play an important role in learning in location-based AR settings. When learning in such settings, students are expected to consider multiple sources of information, stemming from digital information augmenting the physical environment and the physical environment itself. However, findings from research on mobile learning environments suggest that the availability of multiple channels of information also bear disadvantages related to split-attention and redundancy effects (Liu, Lin, & Paas, 2013, 2014). First, according to the split-attention effect, students have to divide their attention between information on the mobile device and information from the physical environment, in order to develop representations that synthesize physically-separated information. Second, a redundancy effect might occur as the learning materials are composed of multiple information sources that are self-contained and can be used without reference to each other. Both effects are discussed as two extraneous-load inducing factors, which may “overload the capacity of the visual/pictorial channel and negatively affect students’ comprehension and learning efficiency” (Liu, Lin, Tsai & Paas, 2012, p. 173).

In addition, learning in location-based AR settings has also been discussed in relation to intrinsic cognitive load. Researchers have highlighted the inherent difficulty of the AR learning process, as students are required to respond to a variety of tasks while alternating between different identities: as characters within the activity, as strategic reflective thinkers, and as navigators (Facer et al., 2004; Nilsson & Svingby, 2009). According to Dunleavy et al. (2009), location-aware AR apps require students to apply a set of complex skills, such as problem-solving skills, inquiry-based skills, geo-spatial navigation, handheld manipulation and often, collaborative skills. The simultaneous deployment of such skills may overburden students and increase their intrinsic cognitive load.

Eliminating or reducing the extraneous and intrinsic cognitive load experienced in immersive learning environments may be critical for the students’ experienced immersion. Immersion can help students focus their attention on the educational content to be learned (Cabiria, 2010; Cheng et al., 2015; Jennett et al., 2008). On the other hand, extraneous and intrinsic cognitive load limits students’ cognitive capacity to successfully deal with the learning process (Paas, Tuovinen, Tabbers, & van Gerven, 2003; Sweller, van Merrienboer, & Paas, 1998). As a result, an emergent hypothesis is that cognitive load may be inversely related to immersion that supports the processes involved in gaining attention and achieving deeper understanding of the learning materials.

5.3 The Hypothesized Cognitive Model of Immersion

The review of the extant literature led to the development of a cognitive model of immersion in relation to conceptual learning in science, shown in Figure 5.1.

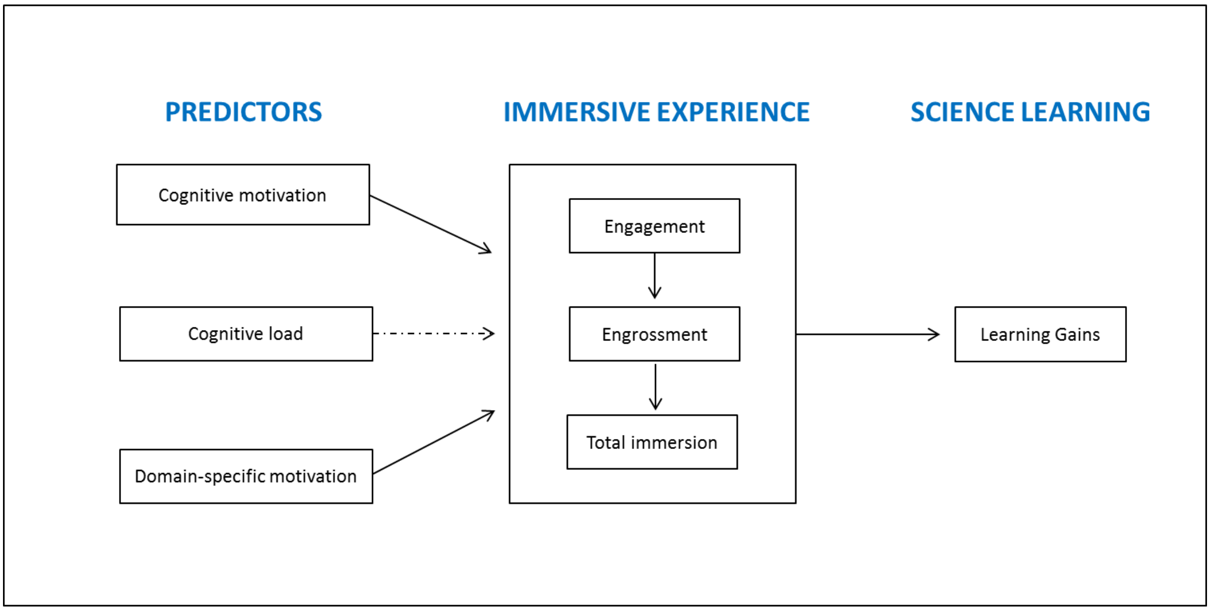

Figure 5.1: The hypothesized cognitive model of immersion

Note. Dotted lines indicate negative relations, whereas solid lines indicate positive relations.

As shown in Figure 5.1, we expect that students' participation in a well-designed location-based AR activity can promote their science learning. However, we assume that learning gains are dependent on students' level of immersion. As shown in Figure 5.1, immersion, which is comprised of three sequential levels (engagement, engrossment and total immersion), is expected to be positively related to conceptual understanding learning outcomes. In addition, given that immersion is defined as a subjective experience, we also expect students will reach different levels of immersion. We assume that immersion, as a process of cognitive and emotional involvement in a location-based AR activity, can be defined according to students' motivation and experienced cognitive load. In particular, students' cognitive motivation and domain-specific motivation are expected to positively predict immersion. In contrast, extraneous and intrinsic cognitive load is expected to be inversely related to immersion.

According to this hypothesized cognitive model of immersion, this study explores the following research questions:

1. Do domain-specific motivation, cognitive motivation and cognitive load predict students' immersion in location-based augmented reality settings?

2. How does immersion relate to conceptual understanding in environmental science, in location-based augmented reality settings?
3. Does immersion and its predictors yield differentiated student immersive profiles? If so, how do these student profiles affect conceptual understanding in environmental science?

5.4 Methodology

We next present the methodological aspects related to the empirical investigation of the research questions guiding the validation of the hypothesized model.

5.4.1 Participants

One hundred and seventy-six Greek-speaking 10th graders in Cyprus, from nine intact classes of an urban, public school, participated in the study. After data were collected from all students, we employed a data screening procedure (Meade & Graig, 2012), which included a missing data analysis, identification of careless responders, and an assessment of outliers; as a result, 41 students were excluded from the analyses. The final sample considered for this study was a total of 135 students, composed of 86 girls (63.7 %) and 49 boys (36.3 %).

Students were of mixed academic ability, ensuring that the sample was representative of the broader student population. None of the students were honor students and none of them had previous experiences with augmented reality tools; this was the first time students had the opportunity to participate in a location-based AR activity for learning environmental science. Given than environmental science topics are usually taught at the school, through lectures and demonstrations, students' participation in this outdoor learning experience could be considered as a departure from the traditional science education instruction. Even though students were expected to have some prior knowledge on the topic of eutrophication, as this topic is included in the Ministry of Education and Culture's lower secondary education curriculum, students had no prior knowledge on the topic of bioaccumulation; this was their first encounter with the topic.

5.4.2 Intervention

The intervention took place at a lake and lasted for about 90 minutes. During the intervention, students worked in pairs, using the "Mystery at the Lake" location-aware learning AR app, which was designed and implemented using the *TraceReaders* AR platform (Georgiou & Kyza, 2013). "Mystery at the lake" took the form of a problem-based multimedia investigation played on tablets. Each pair was asked to investigate a problem-based case related to the mysterious decline of the lake's mallard ducks. The learning goals targeted students' understanding of scientific concepts related to the lake ecosystem, such as food chains, eutrophication, and bioaccumulation.

As part of the learning intervention, students were provided a tablet with the AR app; the app was equipped with an interactive map of the area indicating that they should explore eight hotspots in order to collect all the necessary information to complete their mission. Multimedia data (e.g. videos, interviews, diagrams, tables, images) were activated at each hotspot using the tablet's integrated GPS system. A virtual character presented in the form of videos at each hotspot, provided information and prompted students to reflect and connect the data with the lake ecosystem.

5.4.3 Instruments

To investigate the hypothesized cognitive model of immersion we used the following five instruments: a conceptual assessment test, the AR Immersion [ARI] questionnaire (Georgiou & Kyza, 2017a), the Student Motivation Towards Science Learning [SMTSL] questionnaire (Tuan, Chin & Shieh, 2005), the Need for Cognition [NfC] questionnaire (Cacioppo et al., 1984) and Paas' cognitive load scale (Paas, 1992). All of the instruments employed are presented in the following sections.

5.4.3.1 Conceptual Assessment Test

After completing the "Mystery at the lake" learning activity students were expected to gain deeper understanding of the ecological phenomena of eutrophication and bioaccumulation, including their main causes and consequences on an aquatic ecosystem. The test to assess students' learning gains was composed of eight multiple-choice items and three open-ended questions; the test was developed by the authors in collaboration with two biology education experts, to ensure expert and face validity. The open-ended questions consisted of three complex problem solving activities, in which students were presented with problem-based tasks structured around the notion of eutrophication or bioaccumulation; students were asked to identify the targeted ecological phenomenon, and report its causes and consequences in the lake ecosystem. A scoring rubric was constructed to evaluate students' performance on the open-ended questions; the maximum score of the test was 20 marks.

5.4.3.2 Augmented Reality Immersion questionnaire [ARI]

The ARI questionnaire (Georgiou & Kyza, 2017a) consisted of 21 items and was employed to measure students' individual immersion. These items can be classified in three distinct scales, each relevant to an immersion level: engagement (8 items), engrossment (6 items) and total immersion (7 items). A seven-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*) was adopted for the evaluation of each item. The construct validity of the ARI was evaluated through a rigorous process, which included exploratory and confirmatory factor analysis, which was reported in a previous publication (Georgiou & Kyza, 2017a). Cronbach's α value for the entire questionnaire was 0.90, while the Cronbach's α for each of the three subscales ranged from 0.77 to 0.88, which indicates satisfactory scale reliability.

5.4.3.3 Student Motivation Towards Science Learning questionnaire [SMTSL]

The *Student Motivation Towards Science Learning* [SMTSL] questionnaire (Tuan et al., 2005), was used to measure domain-specific motivation. The Tuan et al. questionnaire consisted of 35 items, organized in six scales: self-efficacy (7 items), science learning value (8 items), active learning strategies (5 items), performance goals (4 items), achievement goals (5 items), and learning environment stimulation (6 items). For our study, we used the Greek version of SMTSL, as adapted and validated by Dermitzaki et al. (2013). Only five of the six scales were used; the scale of learning environment stimulation was excluded due to its low Cronbach α value in the present study. A five-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) was adopted for the evaluation of each item in the remaining five scales. Cronbach's α value for the entire instrument was 0.88; Cronbach's α for each of the five subscales ranged from 0.66 to 0.83, indicating satisfactory reliability.

5.4.3.4 Need for Cognition questionnaire [NfC]

Cognitive motivation was measured using a 14-item questionnaire, which was based on the 18-item abbreviated "Need for Cognition" [NfC] scale (Cacioppo et al., 1984). This 14-item NfC was derived after validating the original 18-item abbreviated NfC in Greek (Georgiou & Kyza, 2017b). The NFC statements were organized using a Likert-based rating scheme, ranging from 1 (Strongly Disagree) to 9 (Strongly Agree). Cronbach's α value for the NfC Greek scale was 0.89, which indicates satisfactory scale reliability.

5.4.3.5 Cognitive Load

We measured students' cognitive load with a self-report scale, as put forth by Paas (1992). This scale is composed of one item and is one of the most popular methods for measuring cognitive load (de Jong, 2010). The item asked students to respond to the following question, using a 7-point Likert-scale: "How difficult was it for you to investigate and solve the problem-based situation which you were assigned as your mission?" Possible answers ranged from 1-"extremely easy" to 7-"extremely difficult".

5.4.4 Procedure

An overview of the procedures employed is presented in Table 5.1.

Table 5.1: Procedure Overview

#	Phases	Activity	Duration (in minutes)
1	Prior to the intervention	SMTSL	20'
		NfC	10'
		Conceptual pre-test	30'
	BREAK		30'
2	Intervention	Introductory presentation	30'
		Mystery at the lake	90'
	BREAK		15'
3	After the Intervention	ARI	20'
		Cognitive load	5'
		Conceptual post-test	35'
		Debriefing-Reflection	15'
	Total duration		5 hours

The 135 10th graders, who participated in the present study, formed nine cohorts, each corresponding to an intact class; each cohort participated in the intervention on a different day and time. Each intervention lasted for five hours, including the administration of research instruments. Initially, students were asked to complete the SMTSL and the NfC questionnaires, as well as the conceptual assessment pre-test. During the intervention phase, students attended a presentation, which introduced them to the problem-based case about the decline of the mallard ducks inhabiting the nearby lake. Furthermore, a set of instructions about the use of the location-aware AR app were presented to familiarize students with the app. At the end of the presentation students were divided in pairs and each pair was equipped with a tablet. Once at the lake, students had 90 minutes to investigate the problem-based case and develop an evidence-based explanation. Finally, after the intervention, students were asked to complete the ARI questionnaire, the cognitive load instrument and the conceptual assessment post-test. The process was completed with a debriefing activity, during which students were asked to present and discuss their evidence, thus reflecting on the topic collectively.

5.4.5 Data Analysis

The data analysis for the investigation of the proposed model was conducted in three phases. The first phase aimed at testing the predictors of immersion. The second phase aimed at investigating conceptual learning gains in relation to immersion. The third and final phase aimed at identifying student immersive profiles (based on their immersion, domain-specific motivation, cognitive motivation and cognitive load), as well as their impact on conceptual learning in environmental science.

All variables involved in the study were analyzed to first assess the normality of the data, in order to select the most appropriate statistical tests. Descriptive statistics for all measured variables are displayed in Table 5.2, indicating that, except for students' pre-test and post-test scores, all other variables followed a normal distribution.

Table 5.2: Descriptive Statistics for Measured Variables

	Mean *(SD)*	Skewness *(SE)*	Kurtosis *(SE)*	Min.	Max.
Pre-test scores	1.39 *(1.61)*	1.02 *(.21)*	.08 *(.41)*	0	5.75
Post-test scores	6.09 *(2.74)*	.43 *(.21)*	-.39 *(.41)*	1.5	14.25
Learning gains (Post-Pre)	4.69 *(2.81)*	-.07*(.21)*	-.20*(.41)*	-1.75	11.75
Engagement	5.77 *(.69)*	-.40*(.21)*	-.01 *(.41)*	3.75	7
Engrossment	5.18 *(.89)*	-.15 *(.21)*	-.81 *(.41)*	3.33	6.83
Total Immersion	4.91 *(.93)*	-.34 *(.21)*	-.66 *(.41)*	2.86	6.43
Need for Cognition	5.27 *(1.24)*	.05 *(.21)*	.02 *(.41)*	2.21	8.64
Motivation	3.98 *(.41)*	-.24 *(.21)*	-.27 *(.41)*	3.00	4.89
Cognitive load	2.99 *(1.14)*	.29 *(.21)*	-.06 *(.41)*	1	6

The following section provides a brief description of the statistical analyses for each one of the three data analysis phases.

5.4.5.1 Testing the Predictors of Immersion

To investigate whether students' domain-specific motivation, cognitive motivation and cognitive load can predict immersion, we conducted three multiple linear regression analyses, as the main assumptions of normality, homoscedacity of residuals, multicollinearity and autocorrelation of errors were not violated (Tabanchnick & Fidell, 2014). The analyses included one multiple linear regression analysis for each immersive level (engagement, engrossment and total immersion). For each multiple linear regression analysis, students' domain-specific motivation, cognitive motivation and cognitive load were defined as the independent variables, with each immersive level serving as the dependent variable. The main predictor(s) per immersive level were identified through stepwise regression analyses, with variables entered at the .05 significance level and removed at the .01 significance level.

5.4.5.2 Investigating Students' Conceptual Learning Gains and their Relationship with Immersion

Before analyzing students' learning gains, the inter-rater agreement was assessed by comparing two independent evaluators' ratings on 20% of the students' pre-tests and 20% of the post-tests (the author of this doctoral dissertation and a second independent researcher). The conceptual test employed, its goals and evaluation was presented and explained by the author to the second independent researcher. Both researchers employed the scoring rubric developed for evaluating students' responses to the open-ended questions. For investigating the inter-rater agreement, Cohen's kappa was evaluated and assessed based on the following values: 0.00 (no agreement), 0.00–0.20 (poor), 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and 0.81–1.00 (nearly perfect). The inter-rater agreement for both pre-tests and post-tests was satisfactory (kappa coefficient=.73 and .77 respectively). The differences in students' learning scores were investigated using the Wilcoxon signed-rank test, as students' pre- and post-test scores did not follow a normal distribution. Pearson's correlation coefficients were used to investigate the relationship between students' conceptual learning gains and immersion.

5.4.5.3 Identifying Students' Immersive Profiles and their Impact on Conceptual Learning

To identify student immersive profiles, students' responses for each level of immersion (engagement, engrossment, total immersion) and its predictors (domain-specific motivation, cognitive motivation, cognitive load) were used as attributes, in an effort to investigate the creation of meaningful clusters. The K-means algorithm was employed as a cluster analysis technique, as in this approach subjects are classified in homogenous groups, according to similarities in the profiles (Han & Kamber, 2001; Jain, Murty, & Flynn, 1999). Given that there is a need to identify the most suitable number of clusters to perform the K-means algorithm, the appropriate number of clusters was decided by parameter exploration. The criteria for the selection of cluster number were the smallest distance between the features in a same cluster, as well as the largest distance between the features in different clusters. Two core clusters presenting meaningful immersive profiles were obtained, dividing students in two subgroups. Finally, students' conceptual learning gains were compared per cluster, employing the t-test for independent samples analysis.

5.5 Findings

The results of the analyses are organized according to each research question: (a) testing the predictors of immersion, (b) investigating students' conceptual learning gains and their relationship with immersion, and (c) identifying student immersive profiles and their impact on conceptual learning in environmental science. The section concludes with the presentation of the validated cognitive model of immersion.

5.5.1 Predictors of Immersion

To identify the predictors of students' immersive experience we employed multiple linear regression analyses. Before conducting the analyses, we first checked that the pre-requisite assumptions, as reported by Myers (1990), for the analyses were not violated. In particular, the normality of all of the variables employed was confirmed. Similarly, multicollinearity did not appear to be a problem since no Variance Inflation Factor (VIF) was over the acceptable level of 10, while all tolerance values were lower than .10. Normal p-p plots of standardized residuals and scatter plots were employed to ensure the normality of the distribution of errors and heteroscedasticity accordingly, which were confirmed in all the regression analyses reported in the study. Finally, the Durbin-Watson test produced values within the limits of $1.5<d<2.5$, indicating no problem with respect to autocorrelation of errors.

The next step included running multiple linear regressions analyses; these identified that students' domain-specific motivation, cognitive motivation and cognitive load could predict immersion (see Table 5.3).

Table 5.3: Summary of stepwise multiple regression analyses

	Engagement	Engrossment	Total immersion
Predictors	β	β	β
Domain-specific motivation	.28***		
Cognitive motivation		.36***	.23**
Cognitive load	-.17*		-.17*
F Value	*9.63****	*19.41****	*7.79***
R^2	*.13*	*.13*	*.11*

Note. *p < .05, ** p < .01. ***p < .001

The statistical analysis resulted in different predictors for each level of immersion. First, domain-specific motivation (β=.28) and cognitive load (β=.-17) appeared as the main predictors of students' engagement, accounting for 13% of the variance. Second, cognitive motivation (β=.36) appeared as the main predictor for engrossment, accounting for 13% of the variance. Third, cognitive load (β=-.17) and cognitive motivation (β=.23) appeared as the main predictors for total immersion, accounting for 11% of the variance.

5.5.2 Students' Conceptual Learning Gains and their Relationship with Immersion

A Wilcoxon signed-rank test examined whether the differences in student learning scores reached significance; results showed significant differences in students' pre- and post-test scores, as students' performance had significantly improved ($z=-9.86$, $p<.001$).
Further, Cohen's effect size value (*d* =.60) represented a medium effect size. Bivariate correlations between engagement, engrossment and total immersion were, as expected, significantly positive. In addition, bivariate correlations indicated a positive relationship between all three levels of immersion and students' conceptual learning gains (Table 5.4). However, while engagement was related to students' conceptual learning gains with a

moderate positive relationship (r=.32, p<.001), students' learning gains were related with a weak positive relationship to engrossment (r=.22, p<.01) and total immersion (r=.19, p<.05).

Table 5.4: Intercorrelations between students' learning gains and levels of immersion

Variables	Engagement	Engrossment	Total Immersion	Learning Gains
Engagement	--------			
Engrossment	$.413^{***}$	--------		
Total Immersion	$.380^{***}$	$.724^{***}$	--------	
Learning Gains	$.320^{***}$	$.223^{**}$	$.194^{*}$	--------

Note. *p < .05, ** p < .01. ***p < .001

5.5.3 Students' Immersive Profiles and their Impact on Conceptual Learning

A cluster analysis classified students in two homogenous groups (clusters), allowing the emergence of two student immersive profiles: a High Immersion student profile (HI, *n*=65 students) and a Low Immersion student profile (LI 2, *n*=70 students). Students of the HI profile indicated higher levels of engagement, engrossment and total immersion. These students also had comparatively higher domain-specific motivation and cognitive motivation, but lower cognitive load, in comparison to the students of the LI profile (Table 5.5).

Table 5.5: Summary of cluster analysis findings

	HI profile (n = 65)		LI profile (n = 70)	
	Mean	SD	Mean	SD
Engagement	6.10	.58	5.47	.65
Engrossment	5.73	.74	4.68	.69
Total Immersion	5.49	.66	4.38	.81
Cognitive motivation	5.98	1.07	4.62	1.00
Domain-specific motivation	4.13	.41	3.84	.36
Cognitive load	2.31	.81	3.63	1.02

The comparison of the conceptual learning gains between the students of the first and second profile indicated that there was a statistically significant difference between the two groups of students. In particular, the HI students, who had higher immersion, domain-specific motivation, cognitive motivation and lower cognitive load, outperformed the LI students, who had lower immersion, domain-specific motivation, cognitive motivation and higher cognitive load (HI: $\bar{x}=5.27$, SD=2.93; LI: $\bar{x}=4.16$, SD=2.60; $t(133)=2.33$, $p<.05$). To sum up, the statistical analyses employed, have indicated that students reached different degrees of immersion according to their domain-specific motivation, cognitive motivation and cognitive load; students of higher immersion had greater learning gains and vice-versa.

5.5.4 The Validated Cognitive Model of Immersion

The statistical analyses yielded the empirically validated the cognitive model of immersion, shown in Figure 5.2.

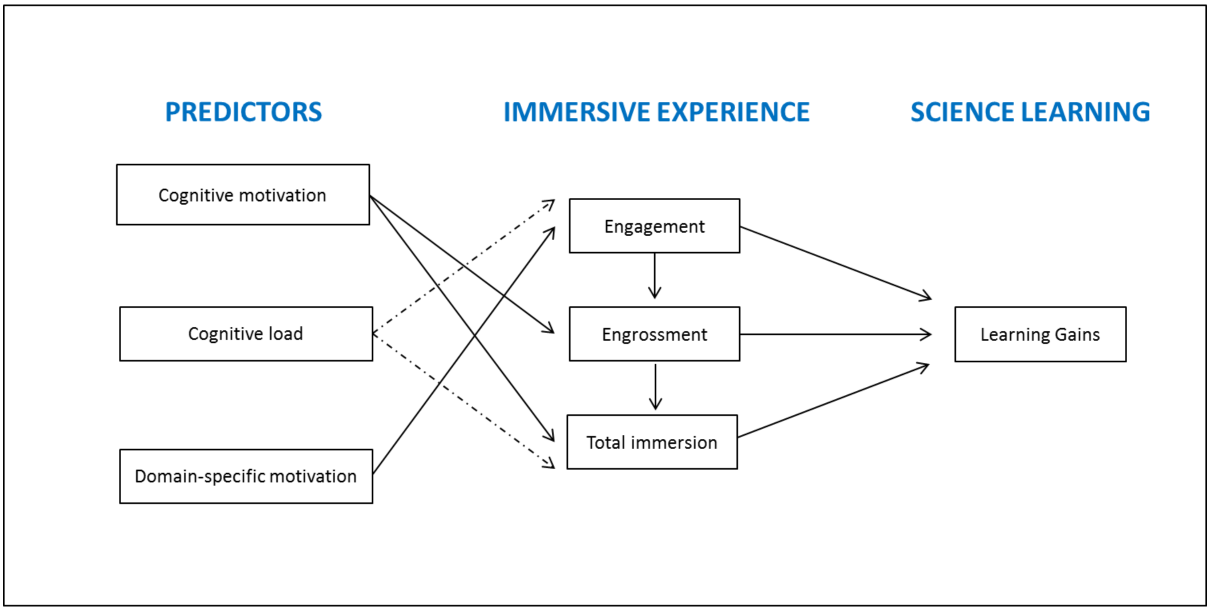

Figure 5.2: The validated cognitive model of immersion

Note. Dotted lines indicate negative relations, whereas solid lines indicate positive relations.

As illustrated in the model, domain-specific motivation emerged as a positive predictor of engagement, while cognitive motivation emerged as a positive predictor of engrossment and total immersion. In contrast, cognitive load emerged as a negative predictor of engagement and total immersion.

The three levels of immersion were, as expected highly related, and were also positively related to students' conceptual learning gains. As expected, not all students managed to equally experience all three immersive levels. Students who reported low cognitive load, high domain-specific motivation and high cognitive motivation evaluated their immersive experience higher, and vice-versa. In turn, while the location-based AR activity seems to have contributed to students' conceptual learning in environmental science, students who evaluated their immersive experience higher also displayed greater learning gains and vice-versa.

5.5 Discussion

This study seeks to contribute to theory building efforts about the relation of immersion to conceptual learning, through the development and testing of a cognitive model of immersion. To our knowledge this is the first time that a model that specifies relationships between domain-specific motivation, cognitive motivation, cognitive load, immersion and conceptual learning outcomes, has been proposed and empirically tested; it therefore represents a unique extension of prior work in this area.

As part of this study, we, first, investigated the impact of domain-specific motivation, cognitive motivation and cognitive load on immersion, as a set of variables which, as we hypothesized, predicted immersion in the context of location-based AR settings for learning in environmental science. Second, we investigated the relation of immersion to conceptual learning, taking into account students' motivation and cognitive load, thus extending prior research on the topic. We, now, first turn to a discussion of the conclusions stemming from our findings; we, then, discuss the implications derived from our work, the limitations of the present study, as well as future research pathways.

To begin with, as expected, domain-specific motivation, cognitive motivation and cognitive load were identified as significant predictors of immersion. However, according to our findings, each level of immersion was dependent on different predictors.

Domain-specific motivation was a positive predictor for engagement, which is the entry level of immersion. This finding is consistent with prior studies claiming that to enter the level of engagement students first, need to like the type of the activity (Georgiou & Kyza, 2017a, Brown & Cairns, 2004; Cheng et al., 2015; Jennett et al., 2008). Our findings also provide empirical support to previous studies suggesting that the choice of learning content can pose a barrier for students' engagement with an immersive learning environment if this does not appeal to students (Kickmeier-Rust & Albert, 2010; Scoresby & Shelton, 2011). In addition, our study expands the findings of Bressler and Bodzin (2013), who investigated the relation between flow, as the higher level of immersion, and students' attitudes towards science learning in the context of a mobile augmented reality science game. Bressler and Bodzin (2013) concluded that students' motivation for science learning was not a significant predictor of the higher level of immersion (flow). However, in our study, students' motivation for science learning, in terms of their domain-specific motivation, appeared as a predictor for students' engagement, which is the lowest level of immersion.

Cognitive motivation was identified as a positive predictor for the two higher levels of immersion (engrossment and total immersion). According to prior conceptualizations of immersion, the experience of engrossment and total immersion requires students' focused attention (Georgiou & Kyza, 2017a, Brown & Cairns, 2004; Cheng et al., 2015; Jennett et al., 2008). Our study provides empirical support to the claim that students of high cognitive motivation are more likely to focus on the learning activity and, thus, reach higher levels of immersion. These students are more accustomed to investing greater cognitive effort to challenging learning tasks (such as location-based AR activities), and are not easily influenced by environmental distractions (Cacioppo et al., 1984; Cacioppo et al., 1996; Petty et al., 2009). Our findings coincide with the study of Zwarun and Hall (2012), who investigated the immersion of university students in the context of fictional, multimedia narratives employed in a less distractive computer laboratory, with or without headphones, which meant that participants had to block out the noise of the other participants' computer in the lab. The researchers concluded that, in the highly distracting laboratory settings, increased cognitive motivation facilitated the university students in blocking the external distractions, thus positively affecting their immersion.

Finally, cognitive load was identified as a negative predictor for engagement (the lowest, entry level of immersion), as well as for total immersion (the highest level of immersion). This finding can be explained by reference to intrinsic and extraneous cognitive load. In particular, to enter the first level of immersion (Engagement), students should be attracted by the topic and activity type, but at the same time they need to invest time in understanding how to navigate within the immersive interface employed (Georgiou & Kyza, 2017, Brown & Cairns, 2004; Cheng et al., 2015; Jennett et al., 2008). However, this process of familiarization with the AR system may result in high levels of intrinsic cognitive load, given that this process may increase the difficulty of the learning process. Our findings are aligned with concerns raised by other researchers supporting that students may be easily overburdened at the beginning of an AR activity, as they are required to quickly become familiarized with the app and apply skills such as geo-spatial navigation skills and handheld manipulation, while also participating in a complex problem-based investigation (Dunleavy et al., 2009; O'Shea et al., 2009). On the other hand, to reach the highest level of immersion, students should enter a state of suspended disbelief, which requires the acceptance of the blended real and digital environment as a unified and single world (Cabiria, 2010; Cheng & Tsai, 2013; Yuen, Yaoyuneyong, & Johnson, 2011). Increased extraneous cognitive load, which is often provoked by redundancy and split-attention effects (Liu et al., 2012; Liu et al., 2013, 2014), could prevent students from developing a perception of being in a unified world, in which one can hardly separate what is virtual and what is real. Dunleavy and Dede (2013) have argued that cognitive load can be included among the main limitations of location-aware AR apps. The present study provides empirical to support this argument.

Further, the present study contributes to a more refined understanding of how immersion relates to students' conceptual learning gains, in the context of environmental science. Findings showed a statistically significant increase in students' conceptual learning outcomes as a result of their participation in the location-based AR activity employed. Our findings agree with previous studies arguing that immersion is positively related to students' conceptual learning (Rowe et al., 2011; Schrader & Bastiaens, 2012a; Winn et al., 2002). However, engrossment and total immersion, which are the higher levels of immersion, had a weaker relationship to students' learning gains, while engagement, which we view as the lower level of immersion, had a stronger relationship with them. From this point of view, our findings are in partial agreement with the findings of Cheng et al. (2015), who investigated immersion in a game-based virtual world in relation to middle school students' science learning. As they found, while engagement, as the lowest level of immersion, was positively related to students' conceptual learning outcomes, engrossment and total immersion had no significant relationship with conceptual learning. Cheng et al. (2015) have speculated that the impact of these higher levels of immersion on science learning outcomes could not be determined, as not all of the students might have experienced engrossment and total immersion at a high degree. This speculation is empirically supported by our findings, as we have also found that students in this study evaluated lower their immersive experience in terms of engrossment and total immersion. In addition, the cluster analysis has contributed to the identification of two student immersive profiles, indicating that only half of the students could be characterized as students of high immersion. These students, who were also characterized by high domain-specific motivation and cognitive motivation, and experienced low levels of cognitive load, outperformed their counterparts, who were characterized of low domain-specific motivation and cognitive motivation, and experienced high levels of cognitive load, thus evaluating lower their immersive experience.

Overall, we believe that this study contributes to theory building efforts for understanding immersion in relation to conceptual learning by investigating a cognitive model of immersion in location-based AR settings for learning in environmental science and providing empirical substantiation for two claims. First, immersion is positively predicted by students' domain-specific motivation and cognitive motivation, but negatively predicted by cognitive load. Second, conceptual learning gains are dependent on the level of immersion that students achieve.

5.6.1 Implications and Future Research

Several educational and design implications can be drawn based on the findings of this study. First, given that cognitive load has emerged as a negative predictor of students' immersion in location-based AR activities, maintaining cognitive load at low levels can be important for achieving higher levels of immersion and promoting conceptual learning gains. In terms of intrinsic cognitive load, the location-based AR activity we have employed could be considered of high complexity, given its focus on both eutrophication and bioaccumulation, which are two complex ecological phenomena. This required students to participate in an extensive field-based investigation during which they were asked to collect, interpret, and synthesize a significant corpus of data. To maintain intrinsic cognitive load at lower levels and facilitate students' greater levels of immersion, we propose the following set of design-based principles: (1) decreasing the scientific content of the AR-based activity by focusing on one phenomenon, and (2) limiting the number of hotspots and available data sources that students are required to visit.

Moreover, our findings may alert researchers and instructional designers to the importance of decreasing extraneous cognitive load in location-based AR settings. In this study, extraneous cognitive load might have been provoked due to split-attention and redundancy effects (Liu, Lin, Tsai, & Paas, 2012; Liu, Lin & Paas, 2013, 2014). In particular, as part of the location-based AR app employed, students were receiving multimedia or text-based information according to their location that were next attempting to relate to their surrounding environment. This may have resulted in a split attention effect, as students divided their attention between the real and the virtual world, as well as in a redundancy effect, in cases students were receiving identical information, which could have collected either from the real or from the virtual world. Laine et al. (2016) have recently presented an AR platform for the development of AR apps, which can afford not only location-based augmentation but also virtual-based augmentation on physical objects in the natural environment. As they supported, this combination allows students to connect virtual and real-world contents much more effectively, as it decreases the distance between the real world and the virtual information augmenting the reality. In turn, it seems that this combination can decrease extraneous cognitive load in location-based AR settings and thus can provide a plausible solution to AR instructional designers for supporting students' immersion.

Finally, our findings may inform educators, researchers and instructional designers about student characteristics, which may facilitate the development of adaptive location-based AR learning environments. Given that cognitive motivation is a fixed personality trait (Cacioppo et al., 1984; Cacioppo et al., 1996; Petty et al., 2009), we agree with other researchers in that some adaptability is required on the part of the system-side rather than user-side (Mokhtari, Davarpanah, Dayyani, & Ahanchian, 2013), in order to foster students' immersion and subsequent conceptual learning. Hence, rather than asking all students to participate in the same highly complex AR activity, a location-aware AR app can be structured around individual challenges. Laine et al. (2016) presented an AR app, which combines interactive narratives with multiple paths responding to students' progress as well as game-based challenges at different difficulty levels; the transition from one level to another is possible only if the earlier levels are accomplished. On the other hand, although cognitive motivation may be considered as a more stable personality trait, domain-specific motivation is malleable through systematic instructional efforts. For example, many researchers have previously reported on pre-post differences of students' domain-specific motivation, demonstrating how students' motivation for learning science can be affected due to a variety of factors, such as for instance the learning environments employed, the instructional approaches adopted or even the assessment methods implemented (Nikou & Economides, 2016; Walczak & Walczak, 2009). As such, it seems that immersion can be fostered through investing on systematic instructional efforts, which may contribute to students' motivation for learning in science.

5.6.2 Study Limitations

Although our findings may help flesh out a more comprehensive model of how immersion unfolds in location-based AR settings, some limitations of this work are also important to note.

First, questions about causality may have not been adequately addressed by the statistical analyses presented in this study. The bivariate correlations among the three levels of immersion and conceptual learning gains, as well as the cluster analysis technique, cannot identify causal relationships between conceptual learning and immersion. In addition, even though the multiple regression analysis, which is certainly framed in causal terminology, has identified relationships between immersive levels and the hypothesized predictors, such an analysis does not imply that these relationships are causal. A strong relationship among variables can be derived from many other causes (Jeon, 2015), including the influence of other unmeasured variables, such as other individual students' characteristics or other factors related to the design of the AR app and its affordances, students' collaboration, as well as by a variety of contextual factors (Dunleavy et al., 2009; Reid et al., 2005). Extending our findings, one plausible assumption is that students with prior expertise in using location-aware AR apps, as well as students of increased inquiry-based skills and prior knowledge on the scientific topic, may experience lower levels of intrinsic cognitive load, thus achieving higher levels of immersion. Future theory building efforts of immersion in relation to AR science learning should take into consideration the potential mediating effects of such additional student-related variables as well as other possible factors relating to the design of the AR app when trying to substantiate theory.

Second, this study relied on self-report measures, which may be regarded as a limitation, especially for evaluating students' immersion. Similarly to existing measurements of immersive experiences, asking participants to respond retrospectively after a specific activity can be criticized as not being capable of fully capturing the temporal nature of immersion or distorting the immersive experience (Chung & Gardner, 2012; Ijsselsteijn, de Ridder, Freeman, & Avons, 2000). However, even though currently there is no better way to investigate AR immersion-in-action (Cheng et al., 2015), it is worth mentioning that in a subsequent methodological study, Ttakka (2015) employed discourse analysis to investigate whether students' discussions, when employing "Mystery at the lake", were correlated with their answers on the ARI questionnaire. Her findings corroborate the validity of the ARI questionnaire, as they indicated that students' perception of their immersive state was aligned to the analysis of students' discourse.

On the same note, researchers in the learning sciences (de Jong, 2010) have critiqued the single cognitive load measurement, such as the one-item scale of Paas (1992) which was employed in this study. According to Schrader and Bastiaens (2012a) such subjective scales can be potentially unstable. However, alternative measurements of cognitive load, such as dual tasks for estimating cognitive load, or physiological measures, could not be employed due to the naturalistic settings in which location-based AR activities took place as well as due to their obtrusive nature, which could interfere with students' immersion. In future studies, cognitive load in AR settings should be investigated with online instruments that can distinguish the types of cognitive load experienced (Brünken, Plaas, & Moreno, 2010; Schrader & Bastiaens, 2012a). However, such instruments are not available yet and need to be developed.

Third, our findings are most relevant to the Greek-speaking sample of 10^{th} graders who participated in this study, as well as by the specific location-based AR activity we have employed. The latter is only one example of a wide range of educational location-aware AR apps for learning science, which differ in their design, duration and subsequent affordances. Therefore, the affordances of the specific learning activity may have affected, for instance, cognitive load in comparison to other designs of location-based AR activities for learning science. Future studies could employ different educational location-aware AR apps to investigate the validity of the reported findings.

Another limitation of this study is the relatively low number of students involved. Under these circumstances, the results of the statistical analyses employed should be treated with caution, as the smaller the sample the higher the possibility that results are dependent on the specific database (Ercikan & Roth, 2008; McMillan, 2012). Further research should replicate the findings to examine the stability of conclusions extracted in this study with more students. In addition, future studies could employ different student populations in terms of age or characteristics.

A final limitation of our study may relate to the investigation of students' learning gains, in terms conceptual understanding of ecological phenomena. Even though we have found that immersion is positively related to students' conceptual understanding, it is possible the impact of immersion can differentiate in different learning contexts. Winn et al. (2002) found, for instance, that immersion in a virtual environment, which simulated water movement and salinity in the ocean, helped students improve their understanding of dynamic three-dimensional processes. However, according to their findings, immersion did not help students understand processes that can be represented statically in two dimensions, for which a desktop simulation would suffice. It is also possible that immersion might be associated with different cognitive effects. For instance, Hsu and Cheng (2014) identified significant correlations between high levels of immersion and students' problem-solving patterns. Future studies should, therefore, continue to investigate immersion in different learning contexts as well as to other types of learning outcomes, such as inquiry-based skills, problem-solving skills, interest and motivation for learning science.

5.6.3 Conclusions

Despite the limitations of the present study, we sincerely believe that the outcomes of the present study have a significant contribution in science education. The present study extends prior research through providing a validated cognitive model for immersion in location-based AR settings according to which domain-specific motivation, cognitive motivation and cognitive load have emerged as significant predictors of immersion, thus affecting the subsequent relationship between immersion and conceptual learning. In addition, conceptualizing immersion as a gradated psychological process of cognitive and emotional involvement, we have investigated the impact of these variables on the different levels of immersion, thus providing a more fine-tuned understanding of how immersion evolves in the light of these variables.

Overall, our results suggest that immersion in location-based AR settings for learning science is a complex psychological process; high levels of immersion may contribute to increased conceptual learning gains. As such, immersion may be facilitated through managing intrinsic and extraneous cognitive load, systematically fostering students' domain specific motivation, or through developing adaptive learning environments responding to students' levels of cognitive motivation.

Future studies should continue to contribute to theory building efforts of immersion in relation to science learning through the development and testing of elaborated theoretical models, which take into account additional significant factors that may predict the impact of immersion on students' learning gains.

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DISCUSSION

Location-based Augmented Reality (AR) apps are increasingly being used in the field of science education, as they are assumed to provoke immersion and foster learning (Cabiria, 2012; Dede, 2009). According to Dunleavy, Dede, and Mitchell (2009, p. 20), AR's most significant advantage is its "unique ability to create immersive hybrid learning environments that combine digital and physical objects, thereby facilitating the development of processing skills such as critical thinking, problem solving, and communicating through interdependent collaborative exercises." (p. 20).

Dede (2009), who defined immersion "as the participant's suspension of disbelief that she or he is 'inside' a digitally enhanced setting" (p.66), argued that immersive educational apps can provide students with engaging learning experiences – something crucial to all location-aware AR educational activities. However, while immersion has been often assumed as a crucial experience affecting students' learning in the field of location-aware AR, at the moment, there is an unprecedented lack of studies investigating how immersion relates to learning in science (Cheng & Tsai, 2013).

Although many studies have speculated on the positive impact of immersive digital environments on science learning outcomes, only few have explored the relationship between immersion and conceptual learning in science through virtual environments, often providing contradictory empirical evidence. While some researchers have found positive relations between immersive experiences and conceptual learning outcomes (Rowe, Shores, Mott, & Lester, 2011; Schrader & Bastiaens, 2012; Winn, Windschitl, Fruland, & Lee, 2002), other studies have found no relation between immersion and conceptual learning. Recent empirical studies have found no relation between high levels of immersion and science learning in virtual worlds (Cheng et al., 2015; Hsu & Cheng, 2014). Researchers have explained this finding by suggesting that immersion may be mediated, at the first place, by students' characteristics or experienced cognitive load. However, no published studies investigating a possible model specifying relationships between students' individual differences, cognitive load and immersion in relation to conceptual learning in environmental science have been retrieved.

The present doctoral dissertation developed and tested a cognitive model of immersion in relation to science learning in location-based AR settings, while acknowledging the potential impact of cognitive load and students' individual differences, in terms of domain-specific motivation and cognitive motivation, on immersion. According to the model, immersion is comprised of three sequential stages (engagement, engrossment and total immersion), is predicted by domain-specific motivation, cognitive motivation, and cognitive load, and is expected to positively predict conceptual learning outcomes, in the context of environmental science.

To investigate the proposed cognitive model, three methodological challenges were primarily addressed; these challenges were mainly related to the target group of the present study, which is Greek-speaking high-school students. First, an AR development platform was designed, which allowed the development of a location-aware AR app in Greek, supporting scaffolded inquiry-based science learning. Second, the Augmented Reality Immersion (ARI) questionnaire was developed for measuring high-school students' immersion in location-based AR settings. Third, the Need for Cognition Scale - Short Form (NCS-SF) questionnaire was adapted and validated in the Greek language, thus ensuring a reliable instrument for measuring high school students' cognitive motivation. This chapter discusses the main research goals, set and accomplished as part of this doctoral study, highlighting the contribution of this research work. This chapter continues with the main limitations derived from this work and concludes with the its educational implications and future research pathways.

1. Contribution

This work has several contributions, namely, to: theory development (through the validation of the cognitive model of immersion in AR settings); methodology (through the validation of the ARI and NCS-SF GR questionnaires); and design (through the development of the *TraceReaders* AR platform). Each of these contributions is explained next.

1.1 The Development of the *TraceReaders* AR Platform

The first research goal of the present study relates to the development of an AR platform which can support (a) the development of location-aware AR apps in Greek, (b) can run in outdoor spaces in an offline mode, and (c) allows users to engage in reflective inquiry in informal, outdoors spaces.

Even though location-aware AR apps have started to gain attention since the turn of the new millennium (FitzGerald, Ferguson, Adams, Gaved, Mor, & Thomas, 2013; Wu, Lee, Chang, & Liang., 2011; Yuen, Yaoyuneyong, & Johnson, 2011), relatively few research and development teams actively explore how location-aware AR apps can be employed to foster K-12 science learning (Cheng & Tsai, 2013; Dunleavy & Dede, 2013). As a result, it is not a surprise that according to Dede and Dunleavy (2013), "there are relatively few stand-alone AR development platforms that enable educators and instructional designers to create custom AR without programming skills" (p. 743). Although some AR platforms exist, they are, in many cases, inaccessible and unavailable in non-English languages; similarly, there is lack of studies discussing how these augmented reality learning technologies are informed by learning sciences theories. Other educationally-minded AR authoring platforms, such as AURASMA, only run when Wi-Fi is present. Such limitations severely constraint access to, and research of, such environments in many contexts, leading to important obstacles to making AR technologies for learning more widely accessible (FitzGerald et al., 2013). In addition, even though existing AR platforms provide a variety of functions for the development of narrative and/or game-based apps augmenting students' physical environment, there is lack of AR development platforms, which provide scaffoldings tools supporting students' reflection and sense-making on the available virtual/real data during the learning process.

The present doctoral study began with the development of *TraceReaders* AR platform (Georgiou & Kyza, 2013), which served as springboard for pursuing the overarching research goal posed: the investigation of immersion in relation to science learning in location-based AR settings. The *TraceReaders* platform is a bi-lingual, location-based AR platform that works with both Greek and English content. The platform consists of an authoring tool, that allows the development of custom AR learning environments for problem-based inquiry learning, and a location-aware AR app, which allows the students to access multimedia content (text, videos, images or graphs) in situ, using the GPS coordinates set by the designer of the AR learning environment; each set of coordinates can be considered a hotspot; when students, using a mobile device, such as a tablet, approach the hotspot, the app triggers the augmentation with pre-selected information that is relevant to that specific location. The app is also equipped with a set of different tools, such as a data capture tool, a notepad and ta concept map tools, designed to support the students' learning experience. Finally, Trace Readers location-aware AR apps also support the collection of research data during the students' learning activity.

Despite the affordances of the *TraceReaders* AR platform, it should be mentioned that the platform has also many limitations, when compared to existing AR platforms allowing the design of collaborative and interactive AR apps. For instance, the platform does not support the design of location-aware AR apps, which can allow (a) the assignment of different participant roles enabling individualized and/or collaborative experiences, (b) the integration of dynamic triggers, which can enable and make visible digital objects according to users' actions, (c) device-to-device communication, according to which app users will experience a single shared world with other users, in which changes in one user's experience will generalize changes to other users' experiences, (d) the integration of instant feedback and rewards (e.g. scoring system) responding to users' actions, and (e) the integration of gradated leaning challenges responding to users' skills.

The integration of such features could allow the development of more game-based and narrative driven location-aware AR apps, which could possibly provide more immersive learning experiences to students. These features are reported as future improvements, which could upgrade the *TraceReaders* AR platform.

1.2 The Development and Validation of the ARI Questionnaire

The second research goal of the present study related to the development and validation of a carefully crafted instrument, allowing the measurement of immersion in location-based AR settings.

Attempts to develop validated instruments for evaluating immersion so far have been few and non-systematic, while existing instruments are oriented towards traditional non-AR digital environments and have, mostly, been validated in controlled laboratory conditions (e.g. Cheng et al., 2015; Jennett et al., 2008; Qin, Rau, & Salvendy, 2009). However, location-aware AR apps are a unique media type that differs significantly from previous digital environments, as they occur in physical contexts that combine the virtual with the real (Wagner et al., 2009). As Kim (2013) has noted, while virtual environments aim to "cut out" the users from the real world resulting in "virtual" immersion, location-based AR environments are linked to specific contexts of the real world, resulting in a form of "contextual" immersion. Immersion in virtual environments can often be attributed to Head Mounted Displays (HMDs) or large interfaces, which attempt to dissociate users from the real world, via a combination of high-resolution visuals and realistic sounds (Isgro, Trucco, Kauff, & Schreer, 2004). However, location-aware AR apps are usually confined in very small interfaces and therefore might produce a different type of immersion (Kim, 2013). According to McCall, Wetzel, Löschner, and Braun (2011), while immersive experiences in the context of non-AR digital apps depend on the idea of sensory substitution, this is not the case in the case of location-aware AR apps. These contexts render the instruments to assess immersion in non-AR environments incommensurable.

According to McCall et al. (2011), evaluating concepts such as immersion in location-aware AR settings is problematic. The present doctoral study contributes to existing knowledge on how to assess immersion in location-based AR settings through the development and validation of Augmented Reality Immersion (ARI) questionnaire (Georgiou & Kyza, 2017a). To achieve this goal, a multi-step process was employed to develop and validate a novel instrument; analyses included exploratory factor analysis with 202 high school students, followed by a confirmatory factor analysis with 162 high school students. This multi-step process resulted in a 21-item, seven-point Likert-type instrument with satisfactory construct validity, which is based on a multi-leveled model of immersion with multidimensionality in each level. The ARI questionnaire is a promising tool for measuring immersion in the context of location-aware AR applications for learning or entertainment, and can support future research on the construct of immersion.

Despite the significance of the ARI questionnaire, two of its main limitations relate to the self-report nature of scale, which results in the subjective measurement of the experience, as well as to the post-intervention nature of the questionnaire, which may result to inaccurate recall, distorting the experience of immersion (Chung & Gardner, 2012; Ijsselsteijn, de Ridder, Freeman, & Avons, 2000). In future research, we plan to combine the ARI questionnaire with different types of measurement, including qualitative techniques such as direct observation, semi-structured interviews and analysis of discourse and actions, with an emphasis on triangulation approaches. Such mixed-method studies will be critical in providing deeper insights of immersion in the context of location-aware augmented reality apps.

1.3 The Adaptation and Validation of the Need for Cognition (NfC-SF) in Greek

The third research goal of the present study was related to the translation, adaptation and validation of the Need for Cognition (NfC-SF), allowing the measurement of cognitive motivation for investigating the hypothesized cognitive model of immersion.

Cognitive motivation is theorized in the literature as a relatively stable trait that relates to the degree to which an individual enjoys tasks involving deep thinking. The 18-item Need for Cognition Scale–Short Form (NfC–SF), developed by Cacioppo and Petty (1984), has been often used to assess individual differences in cognitive motivation. Even though the NfC-SF has become a standard measurement in behavioral sciences and has been adapted in different languages, the NfC-SF has not been validated in Greek yet, while research regarding its validity with young children and adolescents, is still limited.

The present doctoral study contributes to this research gap through the translation, adaptation and validation of Need for Cognition (NfC-SF) in Greek (Georgiou & Kyza, 2017b). To achieve this goal, a multi-step process was followed, including: (a) the translation and adaptation of the questionnaire, (b) a reliability analysis of the instrument's items in combination with an exploratory factor analysis with 177 secondary school students, and (c) a confirmatory factor analysis for defining the underlying structure of the scale, using a sample of 532 secondary school students. The statistical analyses validated a 14-item version of the NfC-SF for measuring the cognitive motivation of secondary school, Greek-speaking students. In addition, this effort also extends previous research about the underlying structure of the NfC, by suggesting that method effects should be considered in measurement models for improving scale validity.

In this way, this doctoral study has produced a validated instrument for the measurement of cognitive motivation, which can be useful for educational researchers and cognitive psychologists. However, given that this instrument is addressed to secondary school students, future research could also investigate the applicability of the NfC-SF-GR with subjects of other ages, such as younger children or adults.

1.4 The Investigation of a Cognitive model for Immersion

The final and overarching research goal of the present doctoral study was related to the development and validation of a cognitive model of immersion in relation to conceptual learning in environmental science through location-aware AR apps.

Cheng and Tsai (2013) have supported that it remains unclear whether and how immersion can actually affect students' science learning in location-based AR settings (Cheng & Tsai, 2013). In particular, the evidence remained lacking on whether one needs to be totally immersed in a location-based AR activity for successful conceptual learning, or what levels of immersion are required to generate conceptual learning gains in science. In addition, given that immersion appears as a subjective experience, a crucial question related to the potential individual differences and student traits, which can differentiate the immersive AR experience, and therefore students' conceptual learning in science. The intricate relationship between immersion and science learning is of increasing interest to researchers (Cheng, Lin, She, & Kuo, 2016); however, to better understand this relationship more empirical studies are needed, which can contribute to an evidence-based, explanatory framework of immersion in relation to conceptual learning in science.

The present study contributes to the literature by proposing a cognitive model of immersion in relation to conceptual learning in environmental science. According to this model, immersion was assumed to be positively related to conceptual learning, while domain-specific motivation, cognitive motivation and cognitive load were considered as potential predictors of immersion. The model was empirically investigated with 135 10^{th} graders, who used a location-aware AR app for learning environmental science. Statistical analyses, which included pre- and post-test comparisons, correlations, multiple regressions and cluster analysis techniques, contributed to the model's validation, which provided empirical substantiation that immersion is positively predicted by students' domain-specific motivation and cognitive motivation, and negatively predicted cognitive load. In turn, conceptual learning gains were related to the level of immersion that students achieved.

To sum up, the findings of the present study support a more fine-tuned understanding of how immersion relates to conceptual learning in environmental science and how immersion evolves in location-based AR settings, in the light of domain-specific motivation, cognitive motivation and cognitive load. However, this study is just the beginning; future studies should continue to contribute to theory building efforts of immersion in relation to science learning through the development and testing of different theoretical models (e.g. investigating on different potential predictors of immersion or the relation of immersion to different types of learning outcomes).

2. Study Limitations and Future Research

Despite the contributions of this doctoral dissertation, some limitations need to be acknowledged. These limitations are related to the research approach followed for investigating the relation of immersion with science learning in location-based AR settings.

First, the present doctoral study, conceptualizes immersion as a linear and gradated process of cognitive and emotional involvement, comprising of three sequential stages (engagement, engrossment, total immersion). Despite this argument, the ARI questionnaire as a post-activity measurement of immersion was unable to capture this temporal nature of immersion, as this was progressing during the learning activity. In this context, a potential concern relates to whether the ARI questionnaire could provide evidence for the different gradated "levels", or whether it simply provides evidence for different "dimensions" of immersion. This concern is also fueled by the high inter-correlation between the different levels of immersion as well as between all six factors comprising the three levels of immersion. For instance, the greater inter-correlation is observed between flow (characterizing the "total immersion" level) and focused attention (characterizing the "engrossment" level).

However, one can address this concern at two levels: at the technical level (the discriminant validity acceptable based on the norms for the statistics performed), and then at the conceptual level of whether the distinct conceptualizations are meaningful. From a technical point of view, the square root of the average variance extracted for each factor-based scale was greater than the inter-correlations between the Average Variance Extracted (AVE) value for each construct and the other factor-based scales (also for the scales of flow and focus of attention). Therefore, despite the significant overlap between the two scales, discriminant validity is acceptable based on the inter-correlations between the factor-based scales and AVE value of each factor. On the other hand, given that from a conceptual point of view we have conceptualized immersion as a gradated psychological construct with different levels of cognitive and emotional involvement, we have also attempted to capture this gradation in our questionnaire by including similar items that differ in valence. Thus, items such as "I didn't have any irrelevant thoughts or external distractions during the activity" (at the "flow" scale) and "I was more focused on the activity rather on any external distraction" (at the "focused attention" scale), even though quite similar, in their essence differ in that the first item is more "absolute" and more "powerful" than the latter one; this is the reason why the first item is included in the third level of immersion, while the latter in the second.

Second, this doctoral dissertation is focused on the investigation of students' conceptual understanding in the field of environmental science and its relation to immersion; a brief inquiry-based investigation was used to engage students with environmental science concepts. In this context, a significant concern is the extent to which the findings of this dissertation are specific to the location-aware AR employed and the specific content, especially with such a short unit. "Mystery at the lake" is only one example of a wide range of educational location-aware AR apps for learning science, which differ in their design, duration and subsequent affordances. Future studies could employ different educational location-aware AR apps to investigate the validity of the reported findings.

Overall both limitations could be efficiently addressed in future research. Such a research design could allow the measurement of students' immersion employing the ARI questionnaire at multiple time intervals, or collecting rich data, such as video, or interviews. This could provide more supporting evidence regarding the dynamic and linear nature of immersion, as it could capture its temporal dimension. In addition, such a research design could contribute to the validity and generalizability of the proposed cognitive model for immersion.

3. Educational Implications

Despite the limitations, we sincerely believe that the outcomes of this doctoral dissertation, in addition to their theoretical significance, may afford some important educational implications.

Overall, our results suggest that immersion in location-based AR settings for learning science is a complex psychological process; high levels of immersion may contribute to increased students' learning gains. As such, immersion may be scaffolded through managing intrinsic and extraneous cognitive load, systematically fostering students' domain specific motivation, or through developing adaptive learning environments responding to students' levels of cognitive motivation.

For instance, to maintain intrinsic cognitive load at lower levels and facilitate students' greater levels of immersion, a new version of "Mystery at the lake" could focus only on one ecological phenomenon (e.g. eutrophication or bioaccumulation). In turn, this could result to a limited number of hotspots, thus also decreasing the available data sources that students are required to visit. In addition, intrinsic cognitive load could be reduced by decreasing the number of inscriptions, such as graphs, diagrams and tables that students are asked to interpret while working in the field. Alternatively, a different strategy which could contribute to decreasing students' intrinsic cognitive load would be to supplement the students' AR investigation with a classroom-based culminating activity that allows for a reflective synthesis of the collected data.

Aligned with this line of this reasoning, we envision that this work can be used by other designers and researchers of location-based AR settings for the investigation and development of more efficient AR settings, allowing higher levels of immersion and thus higher levels of science learning.

4. Conclusions

Overall, the findings of this doctoral study can be seen as contributing to theory development about the construct of immersion in location-based augmented reality settings, research methodology and design-based research.

From a theoretical point of view, the present doctoral study has resulted in a validated cognitive model of immersion in relation to environmental science learning in location-based AR settings. Developing and validating a model for understanding and predicting the relationship of immersion and learning in science contributes to theory building efforts (Cheng et al., 2016). To our knowledge this is the first time a model that specifies relationships between domain-specific motivation, cognitive motivation, cognitive load, immersion and science learning outcomes has been generated and tested empirically to examine such complex relationships collectively; it therefore represents a novel extension of prior work in the area.

From a design-based point of view, this work led to the development of the *TraceReaders* AR platform, which allows the design of location-aware inquiry AR apps in Greek. This platform can support future AR research through the development and investigation of different location-aware apps. In particular, even though studies on AR learning environments are increasing (Wu et al. 2013), there are still many open areas for investigation as researchers begin to grapple with issues of technological and instructional design to promote learning. This presumes the availability of educationally-oriented AR platforms allowing the development, testing and scalability of pedagogically-driven AR learning environments. The *TraceReaders* AR platform can play a significant role towards this direction. It is worth mentioning for instance, that the *TraceReaders* AR platform is currently used by master's students in the "New Technologies for Communication and Learning" program at the Cyprus University of Technology, as part of their master's dissertation work. This work has been used to develop additional augmented reality environments on the *TraceReaders* platform, and is currently being adopted by several elementary schools in Cyprus.

Finally, from a methodological point of view, the present study has resulted in the development and validation of an innovative measurement of immersion in location-based AR settings (ARI questionnaire), as well as into a validated instrument for the measurement of cognitive motivation in the Greek context (NfC-SF-GR). Both instruments may equip the research community (e.g. learning scientists, instructional designers, and psychologists) and support the methodology of future empirical studies.

To sup up, the present doctoral study has a novel contribution in the emergent field of immersion in location-based AR settings, as it has approached this topic from a theoretical, methodological and design-based point of view.

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APPENDIX I

Data collection instruments [English translation]

A. Conceptual Assessment Test

For each of the questions below there are four possible answers. Choose the correct answer. One mark is allotted for each correct answer.

Exercise 1 (8 marks)

1. Eutrophication is caused by the use of:

   A. Fertilizers
   B. Insecticides
   C. Pesticides
   D. All of the above

2. Bioaccumulation mostly affects:

   A. Plants
   B. Herbivores
   C. Carnivores
   D. Super-predators (e.g. Hawks or eagles which are at the top of the food pyramid and are not eaten by other organisms)

3. Smaller amounts of dissolved oxygen can be found in:

   A. An oligotrophic lake
   B. A mesotrophic lake
   C. A eutrophic lake
   D. A hypertrophic lake

4. The phenomenon of bioaccumulation could be caused by the use of:

   A. Fertilizers
   B. Insecticides
   C. Pesticides
   D. Insecticides and pesticides

5. Choose the correct statement:

   A. The increase of nitrates in a lake leads to the increase of phosphate
   B. The increase of nitrates and phosphates in a lake leads to the increase of dissolved oxygen
   C. The increase of nitrates and phosphates in a lake leads to the decrease of dissolved oxygen
   D. The increase of nitrates in a lake leads to the decrease of phosphates

6. The appearance of reproductive problems in frogs at a lake could be associated with the phenomena of:

A. Eutrophication
B. Poaching
C. Bioaccumulation
D. Eutrophication and bioaccumulation

7. The existence of algae on the surface of a lake could be associated with the phenomena of:

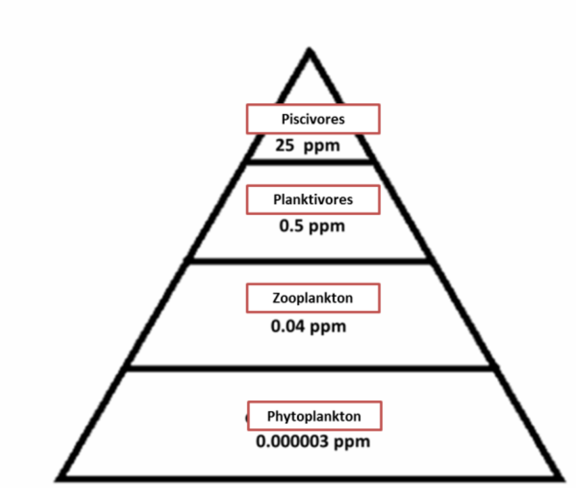
A. Eutrophication
B. Poaching
C. Bioaccumulation
D. Eutrophication and bioaccumulation

8. Greater amounts of nitrates and phosphates exist in:

A. An oligotrophic lake
B. A mesotrophic lake
C. A eutrophic lake
D. A hypertrophic lake

Exercise 2 (3 marks)

The ecosystem of a lake includes the following trophic levels: phytoplankton, zooplankton, planktivores and piscivores. Researchers have identified different amounts of insecticide in each of these trophic levels of the food chain shown in the diagram. Based on these values answer the following questions:



**ppm: Unit of concentration*

a) Are the researchers' findings normal or are they indicative of a problematic situation? Explain. (1 mark)

b) To what extent are the amounts of identified insecticide threatening the food web of the lake? Explain. (2 marks)

Exercise 3 (6 marks)

Researchers have identified large amounts of fertilizer in a lake, and have also spotted green algae covering the surface of the lake.

a) Are the researchers' findings normal or do they point to a particularly problematic situation? Explain. (1 mark)

b) To what extent can the large quantities of fertilizers, and the green algae, threaten the lake's food web? Explain. (2 marks)

c) The lake is inhabited by herons and mallard ducks. The herons feed exclusively on small fish. The mallard ducks feed on the lake's aquatic invertebrates, but also on worms, seeds and plants which can be found near the lake. Given the researchers' findings, do you believe that either of the two populations of birds will be affected? Explain. (3 marks)

Exercise 4 (3 marks)

In the summer of 1999 several vineyards in Crete were infected by the grape berry moth (an insect that feeds on the fruit of the grape). In an effort to combat the pest, the farmers used toxic insecticides. During the same year an alarming decline in the population of hawks was observed.

a) To which phenomenon would you attribute the reduction of the hawk population? (1 mark)

b) Explain what might have had happened to the population of hawks based on this phenomenon. (2 marks)

B. Student Motivation Towards Science Learning [SMTSL] questionnaire

	Totally disagree	Disagree	No opinion	Agree	Totally agree
1. Whether the science content is difficult or easy, I am sure that I can understand it.	1	2	3	4	5
2. I am not confident about understanding difficult science concepts	1	2	3	4	5
3. I am sure that I can do well on science tests.	1	2	3	4	5
4. No matter how much effort I put in, I cannot learn science.	1	2	3	4	5
5. When science activities are too difficult, I give up or only do the easy parts.	1	2	3	4	5
6. During science activities, I prefer to ask other people for the answer rather than think for myself.	1	2	3	4	5
7. When I find the science content difficult, I do not try to learn it.	1	2	3	4	5
8. When learning new science concepts, I attempt to understand them.	1	2	3	4	5
9. When learning new science concepts, I connect them to my previous experiences.	1	2	3	4	5
10. When I do not understand a science concept, I find relevant resources that will help me.	1	2	3	4	5
11. When I do not understand a science concept, I would discuss with the teacher or other students to clarify my understanding.	1	2	3	4	5
12. During the learning processes, I attempt to make connections between the concepts that I learn.	1	2	3	4	5
13. When I make a mistake, I try to find out why.	1	2	3	4	5
14. When I meet science concepts that I do not understand, I still try to learn them.	1	2	3	4	5
15. When new science concepts that I have learned conflict with my previous understanding, I try to understand why.	1	2	3	4	5
16. I think that learning science is important because I can use it in my daily life.	1	2	3	4	5
17. I think that learning science is important because it stimulates my thinking.	1	2	3	4	5
18. In science, I think that it is important to learn to solve problems.	1	2	3	4	5
19. In science, I think it is important to participate in inquiry activities.	1	2	3	4	5

	Totally disagree	Disagree	No opinion	Agree	Totally agree
20. It is important to have the opportunity to satisfy my own curiosity when learning science.	1	2	3	4	5
21. I participate in science courses to get a good grade.	1	2	3	4	5
22. I participate in science courses to perform better than other students.	1	2	3	4	5
23. I participate in science courses so that other students think that I'm smart.	1	2	3	4	5
24. I participate in science courses so that the teacher pays attention to me.	1	2	3	4	5
25. During a science course, I feel most fulfilled when I attain a good score in a test.	1	2	3	4	5
26. I feel most fulfilled when I feel confident about the content in a science course.	1	2	3	4	5
27. During a science course, I feel most fulfilled when I am able to solve a difficult problem.	1	2	3	4	5
28. During a science course, I feel most fulfilled when the teacher accepts my ideas.	1	2	3	4	5
29. During a science course, I feel most fulfilled when other students accept my ideas.	1	2	3	4	5
30. I am willing to participate in this science course because the content is exciting and changeable.	1	2	3	4	5
31. I am willing to participate in this science course because the teacher uses a variety of teaching methods.	1	2	3	4	5
32. I am willing to participate in this science course because the teacher does not put a lot of pressure on me.	1	2	3	4	5
33. I am willing to participate in this science course because the teacher pays attention to me.	1	2	3	4	5
34. I am willing to participate in this science course because it is challenging.	1	2	3	4	5
35. I am willing to participate in this science course because the students are involved in discussions.	1	2	3	4	5

C. Need for Cognition [NfC] questionnaire

	Very strong disagreement	Strong disagreement	Moderate disagreement	Slight Disagreement	Neutral	Slight agreement	Moderate agreement	String agreement	Vert strong agreement
1. I would prefer complex to simple problems	1	2	3	4	5	6	7	8	9
2. I like to have the responsibility of handling a situation that requires a lot of thinking	1	2	3	4	5	6	7	8	9
3. I find satisfaction in deliberating hard and for long hours	1	2	3	4	5	6	7	8	9
4. I really enjoy a task that involves coming up with new solutions to problems	1	2	3	4	5	6	7	8	9
5. I prefer my life to be filled with puzzles that I must solve	1	2	3	4	5	6	7	8	9
6. The notion of thinking abstractly is appealing to me	1	2	3	4	5	6	7	8	9
7. I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought	1	2	3	4	5	6	7	8	9
8. Thinking is not my idea of fun	1	2	3	4	5	6	7	8	9
9. I would rather do something that requires little thought than something that is sure to challenge my thinking abilities	1	2	3	4	5	6	7	8	9
10. I try to anticipate and avoid situations where there is likely chance I will have to think in depth about something	1	2	3	4	5	6	7	8	9
11. I prefer to think only about small, daily projects to long-term ones	1	2	3	4	5	6	7	8	9
12. I like tasks that require little thought once I've learned them	1	2	3	4	5	6	7	8	9
13. I feel relief rather than satisfaction after completing a task that required a lot of mental effort	1	2	3	4	5	6	7	8	9
14. It's enough for me that something gets the job done; I don't care how or why it works	1	2	3	4	5	6	7	8	9

D. Augmented Reality Questionnaire [ARI] questionnaire

	Totally disagree	Strongly disagree	Disagree	No opinion	Agree	Strongly agree	Strongly agree
1. It was easy for me to use the AR application	1	2	3	4	5	6	7
2. I wanted to spend the time to complete the activity successfully	1	2	3	4	5	6	7
3. I didn't have any irrelevant thoughts or external distractions during the activity	1	2	3	4	5	6	7
4. I liked the activity because it was novel	1	2	3	4	5	6	7
5. I found the AR application confusing*	1	2	3	4	5	6	7
6. I was more focused on the activity rather on any external distraction	1	2	3	4	5	6	7
7. If interrupted, I looked forward to returning to the activity	1	2	3	4	5	6	7
8. The activity became the unique and only thought occupying my mind	1	2	3	4	5	6	7
9. I liked the type of the activity	1	2	3	4	5	6	7
10. I wanted to spend time to participate in the activity	1	2	3	4	5	6	7
11. I was curious about how the activity would progress	1	2	3	4	5	6	7
12. Everyday thoughts and concerns faded out during the activity	1	2	3	4	5	6	7
13. I lost track of time, as if everything just stopped, and the only thing that I could think about was the activity	1	2	3	4	5	6	7
14. I was often excited since I felt as being part of the activity	1	2	3	4	5	6	7
15. The activity felt so authentic that it made me think that the virtual characters/objects existed for real	1	2	3	4	5	6	7
16. The AR application was unnecessarily complex	1	2	3	4	5	6	7
17. I often felt suspense by the activity	1	2	3	4	5	6	7
18. I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly	1	2	3	4	5	6	7

	Totally disagree	Strongly disagree	Disagree	No opinion	Agree	Strongly agree	Strongly agree
19. I did not have difficulties in controlling the AR application	1	2	3	4	5	6	7
20. I felt that what I was experiencing was something real, instead of a fictional activity	1	2	3	4	5	6	7
21. I so was involved, that I felt that my actions could affect the activity	1	2	3	4	5	6	7

E. Cognitive load [Paas' scale (1992)]

"How difficult was it for you to complete the learning activity and solve the problem-based case?"

Very difficult						**Very easy**

1------------------2------------------3------------------4------------------5------------------6------------------7

Paas, F. G. W. C. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429-434.

Data collection instruments [In Greek]

A. Conceptual Assessment Test

Για κάθε μια από τις ερωτήσεις που ακολουθούν δίνονται τέσσερις πιθανές απαντήσεις. Να επιλέξετε την ορθή απάντηση. Κάθε σωστή απάντηση βαθμολογείται με μια μονάδα. (μον. 8)

Άσκηση 1 (μον. 8)

α) Το φαινόμενο του ευτροφισμού προκαλείται από τη χρήση:
Α. Λιπασμάτων
Β. Εντομοκτόνων ψεκαστικών
Γ. Παρασιτοκτόνων ψεκαστικών
Δ. Όλων των πιο πάνω

β) Το φαινόμενο της βιοσσυσώρευσης επηρεάζει περισσότερο:
Α. Τα φυτά
Β. Τους φυτοφάγους οργανισμούς
Γ. Τους σαρκοφάγους οργανισμούς
Δ. Τους κορυφαίους θηρευτές (π.χ. γεράκια, αετούς που βρίσκονται στην κορυφή της τροφικής πυραμίδας και δεν τρώγονται από κάποιον άλλο οργανισμό)

γ) Μικρότερες ποσότητες διαλυμένου οξυγόνου υπάρχουν:
Α. Σε μια ολιγοτροφική λίμνη
Β. Σε μια μεσοτροφική λίμνη
Γ. Σε μια ευτροφική λίμνη
Δ. Σε μια υπερευτροφική λίμνη

δ) Το φαινόμενο της βιοσυσσώρευσης θα μπορούσε να προκληθεί από τη χρήση:
Α. Λιπασμάτων
Β. Εντομοκτόνων ψεκαστικών
Γ. Παρασιτοκτόνων ψεκαστικών
Δ. Εντομοκτόνων και παρασιτοκτόνων ψεκαστικών

ε) Επιλέξτε την ορθή δήλωση:
Α. Η αύξηση νιτρικών αλάτων σε μια λίμνη οδηγεί στην αύξηση φωσφορικών αλάτων
Β. Η αύξηση νιτρικών και φωσφορικών αλάτων σε μια λίμνη οδηγεί στην αύξηση του διαλυμένου οξυγόνου
Γ. Η αύξηση νιτρικών και φωσφορικών αλάτων σε μια λίμνη οδηγεί στην μείωση του διαλυμένου οξυγόνου
Δ. Η αύξηση νιτρικών αλάτων σε μια λίμνη οδηγεί στην μείωση των φωσφορικών αλάτων

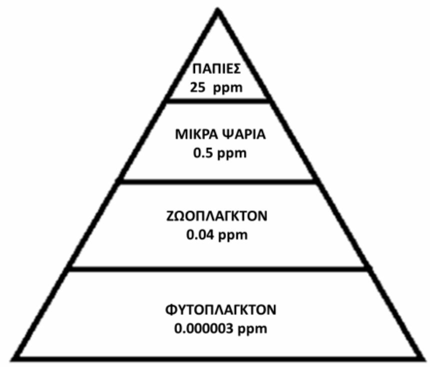
στ) Η εμφάνιση αναπαραγωγικών προβλημάτων στα βατράχια μιας λίμνης θα μπορούσε να συσχετιστεί:
Α. Με το φαινόμενο του ευτροφισμού
Β. Με το φαινόμενο της λαθροθηρίας
Γ. Με το φαινόμενο της βιοσυσσώρευσης
Δ. Με τα φαινόμενα της βιοσυσσώρευσης και του ευτροφισμού

ζ) Η παρουσίαση φυκών (άλγων) στην επιφάνεια μιας λίμνης θα μπορούσε να συσχετιστεί:
Α. Με το φαινόμενο του ευτροφισμού
Β. Με το φαινόμενο της λαθροθηρίας
Γ. Με το φαινόμενο της βιοσυσσώρευσης
Δ. Με τα φαινόμενα της βιοσυσσώρευσης και του ευτροφισμού

η) Μεγαλύτερες ποσότητες νιτρικών και φωσφορικών αλάτων υπάρχουν:
Α. Σε μια ολιγοτροφική λίμνη
Β. Σε μια μεσοτροφική λίμνη
Γ. Σε μια ευτροφική λίμνη
Δ. Σε μια υπερευτροφική λίμνη

Άσκηση 2 (μον. 3)

Το οικοσύστημα μιας λίμνης περιλαμβάνει τα εξής τροφικά επίπεδα: φυτοπλαγκτόν, ζωοπλαγκτόν, μικρά ψάρια και πάπιες. Ερευνητές έχουν εντοπίσει διαφορετικές ποσότητες εντομοκτόνου σε κάθε ένα από τα τροφικά αυτά επίπεδα της διπλανής τροφικής πυραμίδας.



**ppm: Μονάδα μέτρησης που δηλώνει την περιεκτικότητα*

α) Κατά πόσο τα ευρήματα των ερευνητών είναι φυσιολογικά ή παραπέμπουν σε κάποια συγκεκριμένη προβληματική κατάσταση; Εξηγήστε. (μον. 1)

β) Σε ποιο βαθμό οι ποσότητες εντομοκτόνου που έχουν εντοπιστεί είναι ανησυχητικές για το τροφικό πλέγμα της λίμνης; Εξηγήστε. (μον. 2)

Άσκηση 3 (μον. 6)

Ερευνητές έχουν εντοπίσει μεγάλες ποσότητες λιπασμάτων στο νερό μιας λίμνης καθώς και επικάλυψη της επιφάνειας της λίμνης με πράσινα φύκη (άλγη).

α) Κατά πόσο τα ευρήματα των ερευνητών είναι φυσιολογικά ή παραπέμπουν σε κάποια συγκεκριμένη προβληματική κατάσταση; Εξηγήστε. (μον. 1)

β) Σε ποιο βαθμό οι μεγάλες ποσότητες λιπασμάτων και τα πράσινα φύκη που έχουν επικαλύψει τη λίμνη μπορούν να επηρεάσουν το τροφικό πλέγμα της λίμνης; Εξηγήστε. (μον. 2) γ) Στη λίμνη αυτή συναντώνται δύο διαφορετικά είδη πτηνών: οι ερωδιοί και οι πρασινοκέφαλες πάπιες. Οι ερωδιοί τρέφονται αποκλειστικά με μικρά ψαράκια. Οι πρασινοκέφαλες πάπιες τρέφονται με υδρόβια ασπόνδυλα από τη λίμνη, αλλά και με σκουλήκια, σπόρους και φυτά που βρίσκουν γύρω από τη λίμνη. Λαμβάνοντας υπόψη τα ευρήματα των ερευνητών, κατά πόσο οι δύο πληθυσμοί των πουλιών θα επηρεαστούν; (μον. 1)

δ) Εξηγήστε την απάντησή σας. (μον. 2)

Άσκηση 4 (μον. 3)

Το καλοκαίρι του 1999 αρκετές αμπελοκαλλιέργειες στην Κρήτη πλήγηκαν από την ευδεμίδα (έντομο που τρέφεται με τον καρπό του σταφυλιού). Στη προσπάθεια καταπολέμησης του εντόμου, οι αγρότες προχώρησαν σε ψεκασμούς με χρήση τοξικών εντομοκτόνων. Κατά τη διάρκεια της ίδιας χρονιάς παρατηρήθηκε ανησυχητική μείωση στον πληθυσμό των γερακιών.

α) Σε ποιο φαινόμενο θα μπορούσε να αποδοθεί η μείωση των γερακιών; (μον. 1)

β) Εξηγήστε τι μπορεί να συνέβηκε στον πληθυσμό των γερακιών σύμφωνα με το φαινόμενο αυτό (μον. 2)

B. Student Motivation Towards Science Learning [SMTSL] questionnaire

	Διαφωνώ απόλυτα	Διαφωνώ	Δεν έχω άποψη	Συμφωνώ	Συμφωνώ απόλυτα
1. Είτε το περιεχόμενο του μαθήματος βιολογίας είναι εύκολο είτε είναι δύσκολο, είμαι σίγουρος/η ότι μπορώ να το καταλάβω.	1	2	3	4	5
2. Δεν έχω τη σιγουριά ότι μπορώ να καταλάβω δύσκολες έννοιες της βιολογίας.	1	2	3	4	5
3. Είμαι σίγουρος/η ότι μπορώ να τα πάω καλά σε διαγωνίσματα της βιολογίας.	1	2	3	4	5
4. Όσο και να προσπαθήσω, δεν μπορώ να μάθω βιολογία.	1	2	3	4	5
5. Όταν οι δραστηριότητες στη βιολογία είναι δύσκολες, τα παρατάω ή κάνω μόνο τα εύκολα κομμάτια.	1	2	3	4	5
6. Στις δραστηριότητες στη βιολογία προτιμώ να ρωτώ κάποιους άλλους για τις λύσεις παρά να τις σκεφτώ ο/η ίδιος/α.	1	2	3	4	5
7. Όταν βρίσκω το περιεχόμενο του μαθήματος της βιολογίας δύσκολο, δεν προσπαθώ να το μάθω.	1	2	3	4	5
8. Όταν διδάσκομαι νέες έννοιες της βιολογίας προσπαθώ να τις καταλάβω.	1	2	3	4	5
9. Όταν μαθαίνω νέες έννοιες της βιολογίας τις συνδέω με τις προηγούμενες εμπειρίες μου.	1	2	3	4	5
10. Όταν δεν καταλαβαίνω μια έννοια της βιολογίας, βρίσκω σχετικές πηγές για να με βοηθήσουν.	1	2	3	4	5
11. Όταν δεν καταλαβαίνω μια έννοια της βιολογίας, τότε συζητάω με τον/την καθηγητή/τριά μου ή με τους συμμαθητές μου για να την καταλάβω καλύτερα.	1	2	3	4	5
12. Κατά τη διάρκεια της μάθησης προσπαθώ να συνδέω μεταξύ τους τις έννοιες που διδάσκομαι.	1	2	3	4	5
13. Όταν κάνω ένα λάθος, προσπαθώ να βρω το γιατί.	1	2	3	4	5
14. Όταν συναντώ έννοιες της βιολογίας που δεν καταλαβαίνω, προσπαθώ παρ' όλα αυτά να τις μάθω.	1	2	3	4	5
15. Όταν νέες έννοιες της βιολογίας έρχονται σε αντίθεση με αυτά που ήδη ξέρω από πριν, προσπαθώ να καταλάβω το γιατί συμβαίνει αυτό.	1	2	3	4	5
16. Νομίζω ότι το να μαθαίνω βιολογία είναι σημαντικό, επειδή μπορώ να τη χρησιμοποιήσω στην καθημερινή μου ζωή.	1	2	3	4	5
17. Νομίζω ότι το να μαθαίνω βιολογία είναι σημαντικό, επειδή ενεργοποιεί τη σκέψη μου.	1	2	3	4	5

	Διαφωνώ απόλυτα	Διαφωνώ	Δεν έχω άποψη	Συμφωνώ	Συμφωνώ απόλυτα
18. Στη βιολογία νομίζω ότι το σημαντικό είναι να μάθει κάποιος το πώς να λύνει προβλήματα.	1	2	3	4	5
19. Στη βιολογία νομίζω ότι το σημαντικό είναι να συμμετέχω σε ερευνητικές δραστηριότητες.	1	2	3	4	5
20. Όταν μαθαίνω κάτι στη βιολογία είναι σημαντικό να έχω την ευκαιρία να ικανοποιώ την περιέργειά μου.	1	2	3	4	5
21. Συμμετέχω στα μαθήματα βιολογίας για να πάρω ένα καλό βαθμό.	1	2	3	4	5
22. Συμμετέχω στα μαθήματα βιολογίας για να έχω καλύτερη επίδοση από τους άλλους συμμαθητές μου.	1	2	3	4	5
23. Συμμετέχω στα μαθήματα βιολογίας ώστε οι συμμαθητές μου να με θεωρούν έξυπνο/η.	1	2	3	4	5
24. Συμμετέχω στα μαθήματα βιολογίας για να με προσέχει ο/η καθηγητής/τρια μου.	1	2	3	4	5
25. Σε ένα μάθημα βιολογίας νιώθω πολύ μεγάλη ικανοποίηση όταν πάρω καλό βαθμό σε ένα διαγώνισμα.	1	2	3	4	5
26. Νιώθω πολύ μεγάλη ικανοποίηση όταν αισθάνομαι σιγουριά για το περιεχόμενο ενός μαθήματος βιολογίας.	1	2	3	4	5
27. Σε ένα μάθημα βιολογίας νιώθω πολύ μεγάλη ικανοποίηση όταν μπορώ να λύσω ένα δύσκολο πρόβλημα.	1	2	3	4	5
28. Σε ένα μάθημα βιολογίας νιώθω πολύ μεγάλη ικανοποίηση όταν ο/η καθηγητής/τρια μου. αποδέχεται τις ιδέες μου.	1	2	3	4	5
29. Σε ένα μάθημα βιολογίας νιώθω πολύ μεγάλη ικανοποίηση όταν τα άλλα παιδιά στο μάθημα αποδέχονται τις ιδέες μου.	1	2	3	4	5
30. Με ενδιαφέρει να συμμετάσχω στο μάθημα βιολογίας, επειδή το περιεχόμενο είναι πολύ ενδιαφέρον και έχει μια ποικιλία θεμάτων.	1	2	3	4	5
31. Με ενδιαφέρει να συμμετάσχω στο μάθημα βιολογίας, επειδή ο/η καθηγητής/τρια χρησιμοποιεί πολλές διαφορετικές διδακτικές μεθόδους.	1	2	3	4	5
32. Με ενδιαφέρει να συμμετάσχω στο μάθημα βιολογίας, επειδή ο/η καθηγητής/τρια δε με πιέζει πολύ.	1	2	3	4	5
33. Με ενδιαφέρει να συμμετάσχω στο μάθημα βιολογίας, επειδή ο/η καθηγητής/τρια με προσέχει.	1	2	3	4	5
34. Με ενδιαφέρει να συμμετάσχω στο μάθημα βιολογίας, επειδή αποτελεί μια πρόκληση.	1	2	3	4	5
35. Με ενδιαφέρει να συμμετάσχω στο μάθημα βιολογίας, επειδή γίνονται συζητήσεις με τους συμμαθητές μου.	1	2	3	4	5

C. Need for Cognition [NfC] questionnaire

	Διαφωνώ απόλυτα	Διαφωνώ πάρα πολύ	Διαφωνώ πολύ	Διαφωνώ	Δεν έχω άποψη	Συμφωνώ	Συμφωνώ πολύ	Συμφωνώ πάρα πολύ	Συμφωνώ απόλυτα
1. Θα προτιμούσα πολύπλοκα παρά απλά προβλήματα	1	2	3	4	5	6	7	8	9
2. Μου αρέσει να έχω την ευθύνη να χειρίζομαι μια κατάσταση, η οποία απαιτεί αρκετή σκέψη	1	2	3	4	5	6	7	8	9
3. Το να σκέφτομαι δεν είναι κάτι το οποίο βρίσκω διασκεδαστικό	1	2	3	4	5	6	7	8	9
4. Θα προτιμούσα να κάνω κάτι το οποίο απαιτεί λιγότερη σκέψη, παρά κάτι το οποίο θα με δυσκολέψει καθώς απαιτεί περισσότερη σκέψη	1	2	3	4	5	6	7	8	9
5. Προσπαθώ να προβλέπω και να αποφεύγω καταστάσεις στις οποίες θα χρειαστεί να σκεφτώ κάτι σε βάθος	1	2	3	4	5	6	7	8	9
6. Το να μελετώ κάτι σε βάθος και για πολύ χρόνο είναι κάτι που με ικανοποιεί	1	2	3	4	5	6	7	8	9
7. Προτιμώ να σκέφτομαι για μικρές, καθημερινές εργασίες παρά για μακροπρόθεσμες	1	2	3	4	5	6	7	8	9
8. Μου αρέσουν οι εργασίες που απαιτούν λίγη σκέψη, αφού τις έχω μάθει και μου έχουν γίνει πλέον ρουτίνα	1	2	3	4	5	6	7	8	9
9. Απολαμβάνω πραγματικά μια εργασία η οποία περιλαμβάνει την εύρεση καινούριων λύσεων σε προβλήματα	1	2	3	4	5	6	7	8	9
10. Προτιμώ η ζωή μου να είναι γεμάτη με γρίφους τους οποίους πρέπει να λύσω	1	2	3	4	5	6	7	8	9
11. Η ιδέα του να σκέφτομαι βαθύτερα είναι κάτι που με ελκύει	1	2	3	4	5	6	7	8	9
12. Θα προτιμούσα μια εργασία η οποία είναι δύσκολη, σημαντική και απαιτεί αρκετή σκέψη παρά μια εργασία που είναι λιγότερο σημαντική και απαιτεί λιγότερη σκέψη	1	2	3	4	5	6	7	8	9

	Διαφωνώ απόλυτα	Διαφωνώ πάρα πολύ	Διαφωνώ πολύ	Διαφωνώ	Δεν έχω άποψη	Συμφωνώ	Συμφωνώ πολύ	Συμφωνώ πάρα πολύ	Συμφωνώ απόλυτα
13. Νιώθω ανακούφιση αντί ικανοποίηση όταν ολοκληρώνω μια εργασία που απαιτούσε αρκετή σκέψη	1	2	3	4	5	6	7	8	9
14. Για μένα είναι αρκετό κάτι να λειτουργεί σωστά - δεν με ενδιαφέρει το πώς ή το γιατί λειτουργεί	1	2	3	4	5	6	7	8	9

D. Augmented Reality Questionnaire [ARI] questionnaire

	Διαφωνώ απόλυτα	Διαφωνώ πολύ	Διαφωνώ	Δεν έχω άποψη	Συμφωνώ	Συμφωνώ πολύ	Συμφωνώ απόλυτα
1. Ήταν εύκολο για μένα να χρησιμοποιήσω την εφαρμογή	1	2	3	4	5	6	7
2. Ήθελα να αφιερώσω χρόνο ώστε να ολοκληρώσω τη δραστηριότητα με επιτυχία	1	2	3	4	5	6	7
3. Δεν είχα οποιεσδήποτε άσχετες σκέψεις ή εξωτερικές ενοχλήσεις κατά τη διάρκεια της δραστηριότητας	1	2	3	4	5	6	7
4. Μου άρεσε η δραστηριότητα γιατί ήταν κάτι το καινούριο	1	2	3	4	5	6	7
5. Η χρήση της εφαρμογής με μπέρδευε	1	2	3	4	5	6	7
6. Ήμουν πιο επικεντρωμένος/η στη δραστηριότητα παρά σε οποιοσδήποτε εξωτερικές ενοχλήσεις	1	2	3	4	5	6	7
7. Αν κάτι με διέκοπτε, ανυπομονούσα να επιστρέψω και πάλι στη δραστηριότητα	1	2	3	4	5	6	7
8. Η δραστηριότητα έγινε η μία και μοναδική σκέψη που απασχολούσε το μυαλό μου	1	2	3	4	5	6	7
9. Μου άρεσε το είδος της δραστηριότητας	1	2	3	4	5	6	7
10. Ήθελα να αφιερώσω χρόνο για να συμμετέχω στη δραστηριότητα	1	2	3	4	5	6	7
11. Είχα περιέργεια για τον τρόπο με τον οποίο θα εξελισσόταν η δραστηριότητα	1	2	3	4	5	6	7
12. Ξεχνούσα τις καθημερινές μου σκέψεις και ανησυχίες κατά τη διάρκεια της δραστηριότητας	1	2	3	4	5	6	7
13. Έχασα την αίσθηση του χρόνο και το μοναδικό πράγμα το οποίο μπορούσα να σκεφτώ ήταν η δραστηριότητα	1	2	3	4	5	6	7
14. Αρκετά συχνά ένιωθα ενθουσιασμό καθώς αισθανόμουν ως μέρος της δραστηριότητας	1	2	3	4	5	6	7
15. Η δραστηριότητα έμοιαζε τόσο αληθινή που με έκανε να πιστέψω ότι οι ψηφιακοί χαρακτήρες/τα ψηφιακά αντικείμενα υπήρχαν στα αλήθεια	1	2	3	4	5	6	7
16. Η εφαρμογή ήταν πολύπλοκη χωρίς λόγο	1	2	3	4	5	6	7
17. Αρκετά συχνά είχα αγωνία για τη δραστηριότητα	1	2	3	4	5	6	7

	Διαφωνώ απόλυτα	Διαφωνώ πολύ	Διαφωνώ	Δεν έχω άποψη	Συμφωνώ	Συμφωνώ πολύ	Συμφωνώ απόλυτα
18. Ήμουν τόσο απορροφημένος/η στη δραστηριότητα, που σε κάποιες περιπτώσεις, ήθελα να αλληλεπιδράσω με τους ψηφιακούς χαρακτήρες /τα ψηφιακά αντικείμενα κατ' ευθείαν	1	2	3	4	5	6	7
19. Δεν είχα οποιεσδήποτε δυσκολίες στον χειρισμό της εφαρμογής	1	2	3	4	5	6	7
20. Ένιωσα πως αυτό που ζούσα ήταν κάτι περισσότερο πραγματικό, παρά μια φανταστική δραστηριότητα	1	2	3	4	5	6	7
21. Ήμουν τόσο απορροφημένος/η, που ένιωθα ότι οι δράσεις μου μπορούσαν να επηρεάσουν την εξέλιξη της δραστηριότητας	1	2	3	4	5	6	7

E. Cognitive load [Paas' scale (1992)]

"Πόσο δύσκολο ήταν για σένα να ολοκληρώσεις τη μαθησιακή δραστηριότητα και να επιλύσεις το υπό διερεύνηση πρόβλημα;"

Πολύ δύσκολο	**Πολύ εύκολο**

1------------------2------------------3------------------4------------------5------------------6------------------7

Paas, F. G. W. C. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429-434.