Investigating Immersion in Relation to Students' Learning During a Collaborative Location-Based Augmented Reality Activity

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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 present case study 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-activity interviews, yielded a coherent indicator of immersion. To investigate whether each pair's immersion affected the learning process, we analyzed the pairs' activity logs, discourse and learning outcomes. 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.

Introduction

Immersion is a widely-used construct in the literature on digital technologies, such as computer and video games, virtual worlds or location-aware augmented reality (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 facilitate science learning (Cheng, She & Annetta, 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 to students' collaboration; this gap is important to be addressed, 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 immersion on students' learning (e.g. Hickey et al., 2009; Ketelhut et al., 2010), other studies found weak or no relation between immersion and learning outcomes (e.g. Cheng et al., 2015; Hsu & Cheng, 2014). 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 7th 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. As in 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 & 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.

Theoretical framework

Location-based augmented reality (AR) settings for science education are assumed to increase students' immersion and impact 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 in science should be structured around authentic but complex real-world problems; for their solution students are often asked to work collaboratively to collect and synthesize relevant data, as they progress through multiple, virtual or real-world 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. Students, who are highly immersed in location-based AR settings, feel surrounded by a blended, yet realistic augmented environment, as being in a unified 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 a lack of studies investigating how the learning process unfolds in such contexts. 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, to investigate: (a) How can we characterize immersion in location-based AR activities, and (b) What is the relation between immersion and learning?

Methodology

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) [names are pseudonyms]. 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.

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 TraceReaders AR app (Georgiou & Kyza, 2013). 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 the 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.

Data collection

To characterize immersion and investigate its relation to learning, data were collected during and after the pairs' AR 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 an integrated recorder from within the AR location-aware app; (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. Each student also participated in a group interview which took place after the learning activity and lasted for 90 minutes; two group interviews were held. The nominal group technique (McPhail, 2001) was used for the post-session

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. As a second step, students were asked to share their ideas with the group; the interviews concluded 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.

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. To characterize students' immersion the views of the four students expressed during the post-session interview were qualitatively analyzed 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* (see Table 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 $\kappa=.816$, $p<.001$ for the pairs' statements and $\kappa=.741$, $p< .001$ for students' discourse.

Table 1: Coding scheme for characterizing students' immersion (based on Scoresby and Shelton, 2011)

Immersive state	**Definition**
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 during the activity, media design (e.g. graphics and sounds), level of difficulty.
Emotion	Students indicate their feelings about the activity, expressing an emotional connection or disconnect with the activity.
Motivation	Students indicate their motivation expressing whether they were looking forward or not to discovering what happens next and accomplishing the learning mission.
Engagement	Students indicate their engagement, or lack of, with the learning process and activities.

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). As part of the audio-taped discussion analysis, an inter-rater process was employed during which two independent researchers coded the 25% of the data corpus. Cohen's kappa 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: Coding students' discourse

Category	**Description**
Obtaining information	Identifying information from the learning environment through reading sources (text, tables, diagrams) or watching videos
Capturing data	Taking photos from the field and keeping notes about them as data

Category	Description
Problem solving	Discussing the content and how to solve the problem
Navigating	Discussing navigation issues related to the augmented reality app or to the hotspots augmenting the physical space
Interacting with other pairs	Discussing application-related issues with other pairs
Interacting with teachers	Receiving feedback from teachers during the learning process
Off-task discussions	Discussing issues irrelevant to the learning environment
Technical issues	Discussing problems with the use of the tablet or the AR app

Findings

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 3 for a summary of the assessment of their immersion experience). 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 of 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 aspect of the activity captured her interest. She provided indications for her motivation since, as she reported that 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 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 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 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 3: Characterizing students' immersion based on the analysis of the post-session interviews

		High immersion pair				**Low immersion pair**			
		Jack		**Susan**		**David**		**Janet**	
		(+)	**(-)**	**(+)**	**(-)**	**(+)**	**(-)**	**(+)**	**(-)**
Immersion State 1: Content		**55.3**	**21.3**	**33.2**	**33.2**	**10**	**76.6**	**14.2**	**71.6**
Interface	User-friendliness	8.5	0	8.3	0	10	0	0	0
	Augmentation of reality	8.5	0	8.3	0	0	0	7.1	0
	Realism, animation and interactivity of graphics	0	4.3	0	0	0	0	0	14.3
	Realism and fidelity of virtual characters	0	2.1	0	8.3	0	10	0	28.8
	Text-based information	0	0	0	0	0	6.7	0	14.3

Narrative	Topic of investigation	14.8	0	8.3	0	0	6.7	0	0
	Level of challenge	0	0	0	0	0	23.2	0	0
	Diversity and usefulness of the data	12.8	0	0	8.3	0	0	0	7.1
	Competition	0	8.5	0	0	0	3.3	0	0
	Agency and first-person perspective	0	8.5	0	8.3	0	0	0	0
	Narrative plot	0	0	0	0	0	13.3	0	0
Locality	Nature-based location	4.3	0	0	0	0	0	7.1	0
	Mobility and location aware nature of the activity	6.4	0	8.3	0	0	6.7	0	7.1
	Balance between the physical and virtual world	0	2.1	0	0	0	0	0	0
	Hotspots' arrangement	0	0	0	8.3	0	6.7	0	0
Immersion State 2: Emotion		**0**	**0**	**25.3**	**0**	**0**	**6.7**	**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	6.7	0	7.1
Immersion State 3: Motivation		**4.3**	**0**	**8.3**	**0**	**6.7**	**0**	**0**	**0**
Continuous Challenge Anticipation	To discover something from your data	4.3	0	0	0	6.7	0	0	0
	To discover new data	0	0	8.3	0	0	0	0	0
Immersion State 4: Engagement		**19.1**	**0**	**0**	**0**	**0**	**0**	**0**	**7.1**
Data collection Reflecting	Collecting data and new information	4.3	0	0	0	0	0	0	0
	Analyzing, interpreting and combining your data	14.8	0	0	0	0	0	0	7.1
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 1). This analysis corroborated students' post-activity statements about their immersion.

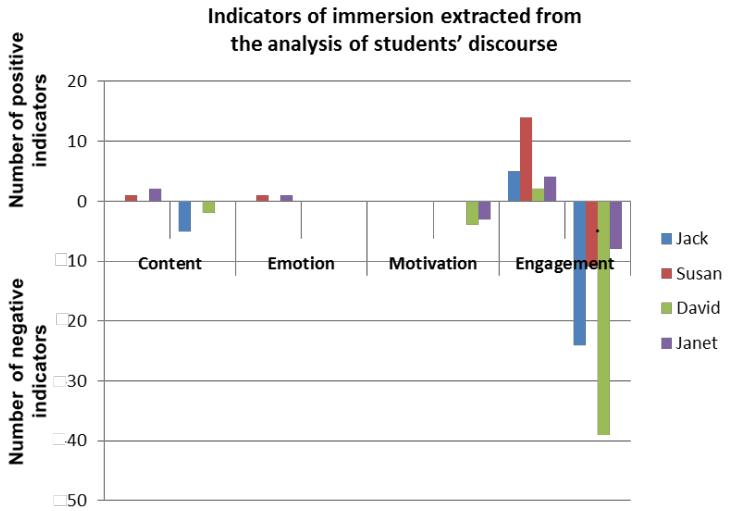

Figure 1. Indicators of immersion extracted from the analysis of students' discourse during the AR activity.

As shown in Figure 1, Pair 1 discourse (Jack and Susan) provided no indications of low motivation while 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.

Does immersion relate to students' learning?

A descriptive analysis of the students' actions, as recorded in the log file of each pair, indicated that both pairs visited all 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 the data sources provided, 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).

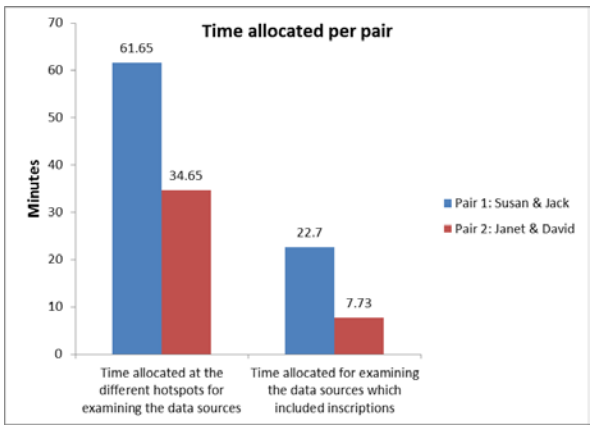

Figure 2. Time allocation per pair at hotspots.

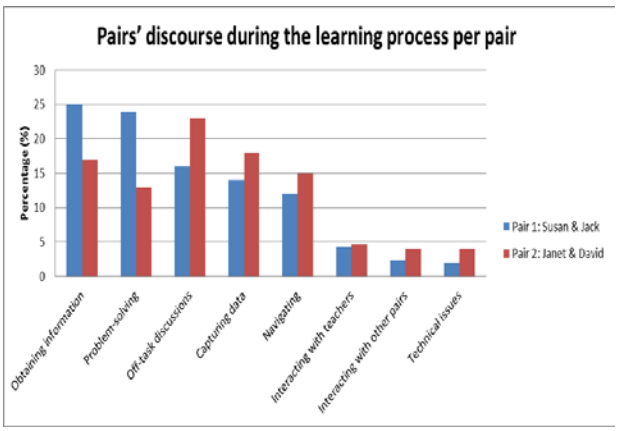

Figure 3. Time allocation per pair at hotspots.

The analysis of each pair's discourse during the learning process indicated that the learning activity of the two pairs also differed: 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 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%). According to students' discourse, the actions of obtaining background information and problem-solving were also much different between 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.

Excerpt 1

Virtual character:	*I have an analysis regarding the water quality for you. 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.

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, blah, blah, blah…. 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 employed 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 an evidence-based decision.

Excerpt 4

Susan: *Yeah… But keep in mind that the cause for the problem is probably one… Now we are divided 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, and collected the same data as quickly as possible, without focusing on analyzing or interpreting the collected data. Hence, while by the end of the investigation, 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.

Discussion and implications

The present study sought to investigate immersion in relation to science learning in a location-based AR activity. In this context, we purposefully focused on 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 indicated 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 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 differentiation between students' 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, motivation, emotion 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 students' behaviors in AR learning, while also extending previous research efforts, from 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 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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