

Investigating the Coupling of Narrative and Locality in Augmented Reality Educational Activities: Effects on Students' Immersion and Learning Gains

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Abstract: The popularity of Augmented Reality (AR) technologies is on the rise, yet little is known about the design principles which could support immersion and learning in such contexts. This study investigated the hypothesis that greater coupling between the physical space and the narrative of the AR activity leads to enhanced immersion and learning. Forty-five middle school students participated in this study: students in Condition1 ($n=22$) participated in an AR activity with strong coupling between the narrative and the physical space, while students in Condition2 ($n=23$) participated in a loose coupling version of the activity. Data collection included baseline data, questionnaires investigating students' immersion and learning gains, as well as post-activity interviews. Findings showed higher learning gains and increased immersion for the students participating in the strong coupling condition than for the students in the loose coupling condition.

Introduction and theoretical background

Narrative-based AR activities have been argued to be effective in engaging students in science learning due to their immersive affordances (Dunleavy et al. 2009). Conceptualizing immersion as a graduated process of cognitive and emotional involvement, researchers have argued that feelings of *presence* (feeling surrounded by a blended yet realistic physical/virtual environment), and *flow* (being fully absorbed in the activity), are considered as indicators of full immersion and can be powerful contributors to learning (Cheng et al., 2015). Previous studies have provided empirical evidence arguing that such heightened levels of immersion in narrative-based AR activities can increase students' performance and subsequent science learning (e.g., Georgiou & Kyza, 2017a). Despite such reports, little is yet known about design principles which can contribute to more engaging AR learning activities, inducing higher levels of immersion.

Reid, Cater, Fleuriot, and Hull (2005a) were the first ones who argued that the coupling between physical space and narrative may affect the external realism of the narrative resulting in different levels of immersion in mobile-based activities. Reid et al. (2005a) distinguished between three "levels of significance to a place": (a) arbitrary linkage, (b) physicality, and (c) particular location. At the first level, there is no connection between the physical space and the mediated experience. At the *Physicality level* "there are certain features of a place that are significant, but the actual geography is not important", and at the "*Particular location*" level "the actual location and physical artefacts in a place are significant and meaningful" to the experience (p. 28). Based on this distinction, Karapanos Barreto, Nisi, and Niforatos (2012) have proposed that, from a design-based perspective, this may result in (a) mobile-based activities with a strong coupling, as they are enacted at the original location that is directly related to the narrative, and (b) mobile-based activities with a loose coupling, as they are enacted at a location that simply induces the same atmosphere with the narrative.

Existing studies, primarily from the Human-Computer Interaction field, yield inconclusive findings for the coupling phenomenon. Reid, Hull, Cater, and Fleuriot (2005b) investigated users' immersive experiences in "Riot!1831", a situated-based interactive drama employing a location-aware, mobile application. According to their findings, the users' immersion was highly increased during the moments where there was strong coupling between the events in the narrative plot, as it unfolded in the virtual space, and the physical world. According to Reid et al. (2005), during moments of high immersion "the senses are heightened to the coincidence of the event and it feels almost supernatural, as if events in the virtual world have somehow moved across into the physical world" (p. 291). Karapanos et al. (2012) compared the degree of immersion and presence of location-based narratives in different settings and found that the condition with the highest coupling between the place and the narrative resulted in a more immersive experience. However, they did not find statistically significant differences in regard to feelings of presence. Karapanos et al. (2012) explained this latter finding by discussing the limitations of their study, such as the use of a non-standardized scale with a single-item for measuring presence, or the short duration (3 minutes) of the narrative-based activity, which may have contributed to the findings of their study. In a more recent study, Rossitto, Barkhuus and Engström (2016) presented an evaluation of a location-based AR drama activity. Even though the narrative of the activity was loosely-coupled with the physical location where it

unfolded, the users were able to imagine possible ways for interweaving the story with the place. Based on these findings, Rossito et al. (2016) concluded that this process of interpretation and sense-making between the narrative and the space, resulted in a highly immersive experience in this loosely-coupled activity.

Taking into account that existing evidence regarding how coupling influences immersion is inconclusive, the present study compared the effects of two types of coupling (strong/loose) and sought to answer the following research questions: (a) Does the level of semantic coupling influence how students experience immersion? (b) Does the level of semantic coupling have a different impact on what students learn? (c) What are the main factors affecting students' immersion, in terms of flow and presence, for each type of semantic coupling?

Methodology

This study adopted an experimental research design, which included two groups of middle school age students. Each group of students was randomly assigned to one of two semantic coupling conditions: (Condition1: Strongly-coupled AR educational activity, Condition2: Loosely-coupled AR educational activity). A cross-comparison method was employed for investigating students' immersion and learning gains in each condition.

Participants

Fifty-five middle school students, who were enrolled in a summer camp at a public university, participated in this study. Data from ten students were removed from the corpus as the students had missed key activities, resulting to a final sample of forty-five students ($n=45$). Students were randomly assigned to each condition. Condition1 had 22 students (13 boys, 59.1%) and Condition2 had 23 students (12 boys, 52.2%). The mean age in Condition1 was 12.3 years, and the mean age in Condition2 was 11.7 years; there was no statistically significant difference in students' age between the two conditions ($Z=-1.50$, $p=.135$) nor in the baseline assessment (described later).

Intervention

Students in both conditions used the “*Mysterious disease*” marker-based AR activity; the activity was based on Quick Response (QR) codes and took place at one of the university buildings. The AR activity was a narrative-driven investigation running on Android tablets, and its duration was 45 minutes. Students were randomly divided in pairs and were assigned the task to collaboratively investigate a case regarding the outburst of a mysterious disease at the university. The pedagogical goal of the AR activity was to engage students in an explanation-building process about the problem-based case, and support students' understanding of scientific concepts related to the nature of microbes (e.g. types, characteristics, etc.) and the transmission of pathogens. Upon the activation of each QR code, students had access to video-based characters (e.g., university nurse, professor of microbiology, health services agent), who provided them with access to information on different aspects of the learning topic, including relevant evidence. According to the narrative, the mysterious disease was caused by a massive food poisoning due to insufficient adherence to food safety procedures at the university cafeteria. Since the goal of this study was to investigate the impact of loosely-coupled and strongly-coupled AR activities on students' immersion and subsequent learning, two different versions of the “*Mysterious disease*” AR activity were developed: a strongly-coupled version and a loosely-coupled version; students in each condition participated in a different version of the activity.

The strongly-coupled AR activity

The strongly-coupled version of the activity explicitly intended to increase the relation of the content in the mobile environment and the physical space in two ways (Figures 1 and 2).



Figure 1. Students participating in the strongly-coupled activity collect data from a real notepad.



Figure 2. Students participating in the strongly-coupled activity in the kitchen of the cafeteria.

First, the QR codes were placed at specific points of interest that were tightly connected to the narrative (e.g., at the university's medical center, where the nurses recorded the symptoms of the affected students; at the university cafeteria, where the cooks did not follow food safety rules; at a lecture hall, where a professor lectured about microbes, etc.). In this version, the path that students walked along was designed to fit the theme and the narrative structure. Second, the places where the QR codes were activated, were also enriched with physical cues which were also aligned with the narrative (e.g., broken freezer, kitchen disposable gloves, printed posters and diagrams, symptom notebook, fermented food whose production uses microbes such as beer, yogurt, etc.). Such designs of the strongly-coupled activity have been argued to support strong blending between the narrative and the physical space by creating "natural coincidences" between events in the virtual and the physical world (Reid et al., 2005b).

The loosely-coupled AR activity

The loosely-coupled version of the activity took place at the same location (at the university premises) where the narrative unfolded (Figures 3 and 4).



Figure 3. Students participating in the loosely-coupled activity at a QR code.



Figure 4. Students participating in the loosely-coupled activity collecting data from their tablet.

In this way, the location induced the same ambience (e.g., same building, physical conditions) as the narrative plot. However, there were no further relations between the AR activity narrative and the physical place. The QR codes were placed randomly within the building and were not meaningfully related to the narrative. In addition, the location was not enriched with any physical cues or real objects. As a result, the relation of the narrative to the location was weaker, which according to Rossito et al. (2016) could allow students to imagine their own connections between the story and the physical space.

Data collection and analysis

This study employed a mixed methods approach. The collected data included baseline data, questionnaires investigating students' immersion and learning gains, as well as post-activity interviews with 14 students from Condition1 (63.6%) and 14 students from Condition2 (60.9%).

Baseline data

We collected baseline data using a survey, aiming at creating a profile for the students and establishing the equivalency of the two conditions. The survey had two main parts: *Interest in science* and *Students' attitudes towards tablets*. *Interest in science* was measured using a Likert scale with 10 items derived from the Test of Science-Related Attitudes (Fraser, 1981), as this was adapted and validated in the study of Bressler and Bodzin (2013). The Cronbach's α for the adapted instrument was 0.90. *Students' attitudes towards tablets* was assessed using the Computer Attitude Measure for Young Students (CAMYS, Teo & Noyes, 2008), which was composed of 12 items, using a five-point Likert scale. The CAMYS is considered a valid instrument and has a documented reliability alpha coefficient of .85. Differences between the two conditions were examined using the Mann-Whitney U test, given the small sample size of each condition and the lack of normal distribution in the data.

Immersion and conceptual gains questionnaires

After the implementation of the "Mysterious disease" AR activity, the students in each condition completed the *Augmented Reality Immersion (ARI)* questionnaire (Georgiou & Kyza, 2017b), which measured their experienced immersion, and a conceptual assessment test to investigate learning gains. First, the students were asked to complete the *Total Immersion* scale, which is comprised of two subscales with a total of seven items: *Flow* (3 items) and *Presence* (4 items). The Cronbach's α for the *Total Immersion* scale has a documented reliability alpha

coefficient of 0.82, while the Cronbach's α for the *Flow* and the *Presence* subscales are .87 and .80 correspondingly. Second, a conceptual understanding test was administered to assess the differences in students' conceptual learning about the scientific concepts related to topic of the AR investigation. The conceptual understanding test was composed of ten multiple-choice items and five open-ended questions. The aim of the multiple-choice items was to evaluate students' factual knowledge, while the aim of the open-ended questions was to evaluate students' reasoning about microbes and the transmission of pathogens. A Mann-Whitney U test was used to investigate the differences between the two conditions, given the small sample size of each condition and the lack of normal distribution in the data.

Post-activity interviews

Fourteen students from each condition participated in semi-structured individual interviews, which took place after the intervention. The average time of the interviews was 19:09mins (SD=4:34mins). Students were initially asked to report feelings associated with their experience during the immersive AR activity, and then were probed to discuss feelings of presence (e.g., *To what extent did you experience this problem-based investigation as a fictional case? Did you perceive the narrative-based storyline as a real one or not?*), their feelings of flow (e.g., *How focused did you feel during the problem-based investigation? To what degree did this investigation manage to capture all of your senses?*), as well as the factors which had affected these feelings positively or negatively (e.g., *What were the main factors affecting your feelings? How did these factors affect your feelings?*).

All interviews were transcribed and qualitatively analyzed using a thematic analysis approach (Attride-Stirling, 2001), to investigate the factors students reported as affecting their feelings of presence and flow. This analysis led to the identification of basic thematic categories, and factors discussed within each thematic category which were hypothesized to influence the feelings of presence and flow during the AR activity in each condition. Each unique factor was counted once for each student (absence/presence) and was coded as negative or positive, thus providing a more nuanced indication of how each factor affected students' immersion.

Findings

Setting the baseline

A Mann-Whitney U test was used to identify any potential differences between students in the two conditions, in terms of their prior interest toward learning science and attitudes towards tablets use. As shown in Table 1, there were no statistical differences between the students in both conditions.

Table 1: Baseline assessment of students' interest in science and attitudes towards tablets in each condition

	Condition 1		Condition 2		Z
	Strongly-coupled AR		Loosely-coupled AR		
	Mean	SD	Mean	SD	
Interest in Science	3.90	0.88	3.48	1.02	-1.52
Attitudes towards tablets	4.47	0.57	4.51	.44	-0.69

Note. * $p \leq .05$, ** $p \leq .01$. *** $p \leq .001$

Total immersion: Experienced feelings of presence and flow

A Mann-Whitney U test indicated statically significant differences in students' total immersion in both conditions, after the intervention (Table 2). In particular, the students who participated in the strongly-coupled version of the activity outperformed their counterparts, who participated in the loosely-coupled version of the activity, in terms of their reported sense of presence. No differences were detected in terms of flow.

Table 2: Comparison of the two conditions in terms of flow and presence during the educational AR activity

	Condition 1		Condition 2		Z
	Strongly-coupled AR		Loosely-coupled AR		
	Mean	SD	Mean	SD	
Total immersion	5.40	1.41	4.53	1.22	-2.54**
Flow	5.65	1.50	5.39	.99	-1.52
Presence	5.20	1.57	3.89	1.74	-2.65**

Note. * $p \leq .05$, ** $p \leq .01$. *** $p \leq .001$

Learning gains: Factual knowledge and reasoning

A Mann-Whitney U test indicated statically significant differences between the students' learning gains in the two conditions after the intervention (Table 3). In particular, the students who participated in the strongly-coupled version of the educational activity outperformed their counterparts, who participated in the loosely-coupled version of the activity, in their ability to explain their reasoning but not in terms of their factual knowledge.

Table 3: Comparison of learning gains for the two conditions

	Condition 1		Condition 2		Z
	Strongly-coupled AR		Loosely-coupled AR		
	Mean	SD	Mean	SD	
Total score	11.77	2.52	10.75	1.98	-1.67
Factual knowledge	7.77	1.45	7.43	1.20	-.97
Reasoning	4.00	1.27	3.31	1.30	-1.96*

Note. * $p \leq .05$, ** $p \leq .01$. *** $p \leq .001$

Immersive factors: What has contributed to flow and presence?

The factors identified as having affected the students' sense of flow were classified in two basic themes: (a) Focus, expressing students' attention during the activity, and (b) Level of challenge, expressing the level of perceived difficulty for the students. The factors identified as affecting students' sense of presence were classified in two different basic themes: (a) Realism, expressing the extent of the activity's fidelity for the students, and (b) Agency, expressing students' perceived sense of control and volitional involvement in the activity. These factors are presented in Table 4 and discussed in the following subsections in relation to the two students' conditions.

Table 4: Categorization of factors reported as affecting feelings of flow and presence in each condition

Organizing themes	Basic themes & Factors discussed	Condition 1		Condition 2	
		+	-	+	-
1. Sense of flow	1.1 Focus	33	5	21	10
	1.1.1 Augmentation of reality	5	0	1	0
	1.1.2 Problem-solving process	14	0	13	0
	1.1.3 Narrative plot	10	1	6	3
	1.1.4 Navigation and orientation	1	2	1	2
	1.1.5 Collaboration	3	0	0	2
	1.1.6 Technology hardware	0	0	0	3
	1.1.7 External interruptions	0	2	0	0
	1.2 Level of challenge	1	4	3	5
	1.2.1 Problem-solving process	1	2	3	5
	1.2.3 Artifacts and real props	0	2	0	0
2. Sense of presence	2.1 Realism	27	4	13	6
	2.1.1 Augmentation of reality	0	2	2	2
	2.1.2 Video-based characters	2	0	2	1
	2.1.3 Multimedia material	3	0	1	1
	2.1.4 Narrative plot	6	1	8	2
	2.1.5 Artifacts and real props	9	1	0	0
	2.1.6 QR codes arrangement	7	0	0	0
	2.2 Agency	14	0	2	3
	2.2.1 Problem-solving process	3	0	0	0
	2.2.2 Narrative plot	5	0	2	0
	2.2.3 Artifacts and real props	6	0	0	3

Note. The (+) and (-) signs indicate whether a factor was positively or negatively evaluated by the students

Focus

Students in both conditions indicated that their feelings of flow depended on their focus during the activity, and mentioned the following seven factors as attracting or distracting their focus during the learning process: (a) the augmentation of reality, (b) the problem-solving process, (c) the narrative plot, (d) navigation in real space, (e) collaboration, (f) the technological hardware and (g) external interruptions (from other student pairs). The most

frequently reported factor was the problem-solving process, which was equally present and positively evaluated in both conditions. As students mentioned, the problem-solving process increased their focus and attention. E.g.

I was focused during the activity... As we had to look for evidence, organize them, and then find out the answer. (I was concentrated) as we had to reach a conclusion. From all the available data, we had to reach an outcome. From the first, second, third... From all the data anyway. From all the data you should find a basic... You should combine everything.

[#13, Girl, Loosely-coupled activity]

Also, in most of the cases students in both conditions emphasized how the narrative plot captured their focus. E.g.

At the beginning, we felt anxiety. What will we find out? ... What is the case about?... And because of the continuous action you feel impatient, to see what is going on until the end.

[#24, Girl, Strongly-coupled activity]

Level of challenge

Students in both conditions suggested that their feelings of flow depended on their perceived level of challenge. Students discussed two factors defining the level of difficulty they had experienced: (a) the problem-solving process, (d) the integration of artifacts and real props (only mentioned in the case of the strongly-coupled activity), as in two cases students reported that they had difficulty to understand how the artifacts and real props were related with the case that they had to investigate as well as with the rest of the data that they had already collected. The most positively and negatively evaluated factor in both conditions was the problem-solving process. According to the positive evaluations, the level of the problem-solving was challenging but yet satisfactory. E.g.

It was difficult but interesting. It was complicated... It was difficult as you had to had to gather many data. During the activity, time flew. It was really nice."

[#2, Boy, Loosely-coupled activity]

In contrast, according to the negative evaluations, the problem-solving process seemed very easy or very difficult for other students. E.g.

We were investigating the case.... However, the solution was obvious... It was all about food poisoning. We had no purpose to search anymore for something that was already obvious.

[#26, Girl, Strongly-coupled activity]

Realism

Students reported that their feelings of presence depended on the perceived level of realism of the activity. Students in both conditions discussed four factors as positively or negatively contributing to the realism of the activity: (a) the augmentation of reality, (b) the video-based characters, which were activated at each QR code, (c) the multimedia material (e.g., videos, photos, etc.) which were provided during the activity, and (d) the narrative plot. The most positively evaluated factor by students in both conditions was the narrative plot which provided an authentic case for investigation. E.g.

Generally, it was quite a true story. For instance, it was not about a dragon, which killed the students and then disappeared. It was not very fictional. It was making sense.

[#16, Boy, Strongly-coupled activity]

A difference between the conditions was that realism was reported as more increased for the students who participated in the strongly-coupled activity due to two additional factors: (a) the artifacts and the real props, as well as (b) the QR codes' purposeful placement in the physical space. According to the students, the artifacts and real props allowed the collection of "realistic" evidence and made the investigation more "alive". E.g.

When we found the notepad, I was carried away as it did not seem as something fake. [...] I thought that it was real, as there were also (handwritten) notes inside.

[#20, Boy, Strongly-coupled activity]

Students also reported that the QR codes' purposeful placement in the physical space allowed a more heightened relation between the narrative plot and the real space. E.g.

For instance, when we visited the cafeteria, it was a real cafeteria! It was not something that I would have just seen through the tablet.

[#25, Boy, Strongly-coupled activity]

Both of these factors, which emerged as positive factors only in the case of the strongly-coupled activity, appeared to be also as the most influencing ones for students' experienced sense of presence.

Agency

Students reported that their feelings of presence also depended on their perceived level of agency. Students in both conditions discussed three main factors as positively and negatively contributing to their sense of agency: (a) the problem-solving process, (b) the narrative plot, and (c) the artifacts and real props. According to students in both conditions, the narrative plot positively contributed to their sense of agency as they felt a personal involvement with the case. E.g.

It was really nice. It felt like that you were "inside", as you were making the activity. [...] It felt like you were a detective and you were looking to find the truth that was hidden in the mystery.

[#10, Girl, Loosely-coupled activity]

However, an emerging difference between the conditions was that the sense of agency was more heightened for the students who employed the strongly-coupled activity, due to the artifacts and real props, which allowed students to interact with "realistic" evidence and collect data through a more interactive process. E.g.

It was different, because in the tablet there were only some images. However, when there were props it was different. You could hold the evidence, you could see it, you could study it better...

[#24, Girl, Strongly-coupled activity]

In contrast, the lack of artifacts and real props was a negatively evaluated factor for the students who participated in the loosely-coupled activity. Some of these students suggested the integration of real props which could provide more interactivity to the investigation process, even though they were not prompted on this topic. E.g.

There were no real clues, we were just scanning the QR codes with the tablet. [...] I would prefer the QR codes to be smaller or even hidden to search for them... as well as to provide us with real clues as evidence, and not only the website-based ones.

[#8, Boy, Loosely-coupled activity]

Overall, the use of artifacts and real props emerged as the most positively influencing factor for the condition with the strongly-coupled version of the AR activity, while their absence emerged as the most negatively influencing factor for the condition with the loosely-coupled version of the activity.

Discussion and implications

The present study sought to investigate the hypothesis that the greatest the coupling between the physical space and the narrative of an AR activity is, the greater will students' immersion and subsequent learning be. In this context, we purposefully compared two conditions; Students in Condition1 participated in an AR activity with strong coupling between its narrative and the physical space, while students in Condition2 participated in a loosely-coupled version of the activity.

The findings from the analysis of the data from the two conditions indicated several differences. Students who participated in the strongly-coupled version of the AR activity had no statistically significant difference in their experienced flow when compared to the students who participated in the loosely-coupled version of the activity. However, students in the strongly-coupled version outperformed their counterparts, in terms of the experienced sense of presence. This finding is aligned with the study of Reid et al. (2005), who argued that presence is increased when the virtual world of the activity matches with some artifact of the surrounding physical environment. In contrast, this result contradicts the position of Rossito et al. (2016), who argued in favour of loosely-coupled AR activities.

The analysis of students' post-activity interviews shed light to our findings in terms of the experienced sense of flow and presence between the two conditions. In particular, the integration of real props as well as the purposeful placement of the QR codes in the physical space did not seem to affect students' focus as well as their perceived level of challenge; as such, this could explain the lack of statistical difference between the experienced flow among both conditions. On the other hand, the integration of real props as well as the QR codes' purposeful

placement in the physical space had a significant positive impact on students' perceived realism, as well as on their perceived sense of agency, which appeared as the most positively influencing factors for presence. As such, this could explain why the students who participated at the strongly-coupled version of the activity outperformed their counterparts, in terms of their experienced feelings of presence. These findings are aligned with prior arguments claiming that place-dependent learning experiences, such as those provided by strongly-coupled educational AR activities, may provide a "narrative" hook as well as an increased sense of agency or sense of control during the activity (Squire et al., 2007). In contrast, a place-independent educational AR activity, even though increasing the portability of the activity, may decrease the amount of authentic interaction with the environment (Klopfer & Sheldon, 2010). Our findings provide empirical support, while they also extend these arguments, as we have found that a strongly-coupled activity can heighten the feelings of presence.

The differences between students' learning in the two conditions could be attributed to the differences in students' perceived immersion. According to our findings, the students who employed the strongly-coupled version of the AR activity and experienced higher levels of presence also had higher learning gains, as they were able to explain their reasoning better. These findings provide empirical support for Cheng and Tsai's (2013) assumption that "perceptions of presence are expected to relate to learners' behaviors in AR-related learning" (p. 459), thus defining also their subsequent learning gains. Aiming to investigate this argument further, our future work will analyze the learning process of the students who participated in each condition. A better understanding of how learning occurs in informal AR learning contexts can support the creation of hybrid spaces for learning, and the development of more immersive and effective AR learning environments.

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