Observation and analysis of a classroom teaching and learning practice based on augmented reality and serious games on mobile platforms

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Abstract

This qualitative research is part of a learning effort to better understand how serious games are exploited in a science education context. The research team examined this issue by focusing on augmented reality as a technological innovation imbedded on a tablet. Given the current state of knowledge related to serious games and augmented reality, and given the fact that its use in the context of teaching/learning is not extended, this paper focuses on an initial exploration of how a new teaching practice involving a serious game based on an interactive augmented reality solution would impact on students in a physics class. A Design Based Research methodology was applied in a real-world context within a college-level physics class. Two conceptual tests containing ten questions on spatial notions regarding electromagnetic fields were administered to two control groups and two groups using the proposed serious game. The latter groups were administrated a game evaluation questionnaire as well. Thematic interpretation of students written responses to the evaluation questionnaire as well as the lessons and observations we derived from the in-class experimentation are provided and discussed in the paper.

Keywords: *augmented reality, design-based research, serious games, mobile learning, physics.*

1. Introduction

Mobile devices such as cellphones, smart phones, laptop computers and tablets are becoming an increasing part of our daily activities and have made their entrance in the world of education [1] According to Uden [2] virtually all students today have cell phones and are “mobile literate”. With increasingly powerful networks, mobile learning is becoming an inescapable reality. There are multiple advantages to the use of portable computers in education; mainly, it allows to improve student motivation, encourage their sense of responsibility, develop their organizational skills, help both individual and group learning and better monitor the students’ progress [3]. These mobile technologies are said to facilitate social interactions and increase the learning motivation by allowing children to move freely [4].

Piette, Pons and Giroux argue that, “today’s youth are the first generation to be immersed from childhood in a World Wide Web [5]. This has to be taken into account and the new media must be integrated into the training of tomorrow’s citizens” [translation added]. Other authors, such as Prensky describe young people born in the 1980s as Digital Natives, and as the Game Generation [6]. Prensky argues that they are able to assimilate information much more quickly than their parents because they have always lived in a world of ubiquitous technologies. Kaplan [7] also examined the characteristics of these young “digital natives” and argued that they are more skilled and able to quickly find answers to their questions by themselves. Despite this situation, most educators have remained skeptical about the relevance of using mobile platforms to facilitate learning [8]. At the present time, the pervasive use of digital technologies as tools of mediation in cultural practices, both in the West and elsewhere in the world, can no longer be ignored. As the Canadian Council on Learning's report on virtual learning stated that Canada's younger generation is primed to exploit the potential of learning technologies. Computers, multimedia programs, chat rooms and other manifestations of the digital age are now common throughout children's developmental years – as almost any parent or educator will attest [9]. The current challenge for educators is to integrate them into their teaching practices [10].

2. Combining serious games and augmented reality on a mobile platform in science teaching

Many educators believe that the use of games has many benefits in the educational context [10]. Serious games is the term used for games whose primary purpose is something other than mere entertainment. They "invite the user to interact with a computer application designed to combine elements of teaching, learning, training, communicating and information processing with playful aspects provided by the video game. Such an association is designed to supplement utilitarian content (serious content) with a videoludic approach (a game)" [translation added] [11, p.11]. They are places for reflexivity, generally virtual, within which learners can develop their own strategies and test their ways of thinking and acting. These practices are well integrated into the practices of today's adolescents. Consequently, they have become a beneficial teaching approach that can be used when students have access to technological tools.

As far as the use of mobile technologies for learning, several studies have been carried out. Among them, Waycott, Jones, and Scanlon concluded that, "like other mobile devices, PDAs (Personal Digital Assistants) have not been designed with learners in mind, yet they offer great potential to support lifelong learning and indeed are being extensively used by learners. Therefore it is important to investigate how learners make use of such devices: what benefits the devices enable and what problems learners face [12 p.126-127]. According to them the use of mobile devices like PDAs can support lifelong learning, and devices bring constraints as well as benefits, which may be important in certain areas of learning, such as sciences. Hennessy demonstrated in his research that "where learners have devices for extended periods, they develop a strong sense of ownership over both devices and the tasks for which they use them" [13, p.127]. In addition, mobile devices offer new learning opportunities related specifically to mobility. Indeed, mobility participates in spatial knowledge acquisition which is needed to build mental representation. Through egocentric or exocentric strategies, involving body movement in specific directions, humans are able to reconstruct a three-dimensional model from the two-dimensional image recorded by the eye [14]. Therefore, the added value does not stem from devices that happen to be mobile platforms. The mobility, movements, displacement enabled by the platform is a component of the learning process.

Beyond the aspect of mobile learning, it seems relevant to reflect on how students appropriate ideas in learning contexts using increasingly powerful technological tools especially when the interface integrates a serious game [15]. The technology used in mobile devices allows for the integration of additional functions when playing a serious game (geolocation, Wi-Fi, email, video, discussion blogs, etc.). Augmented reality (AR) is one of the technological tools recently associated with mobile platforms. AR allows for a fluid, real-time connection between the virtual digital world and the real world. Virtual 3D models can be superimposed on the physical world in such a way that the two seem to coexist in the same environment [16]. With the advent of smart phones and touch tablets, AR has come out of the laboratory and appropriated an increasingly greater place within various consumer markets and industries, particularly in the areas of tourism and marketing. AR has also made a foray into the education field.

AR solutions, applied to the educational context, can be grouped in three categories [17]. 1) They can be used to replace virtual reality, creating interactive virtual objects in a virtual world; the link to the real world is materialized through the use of markers (Kaufmann, 2003) [see Figure 1]. 2) They can be used to enrich actual objects of the real world by providing virtual data, allowing students to interact with the objects [18] [see Figure 2]. 3) They can be used to provide virtual objects that interact with real world properties, such as gravity [19] [see Figure 3].

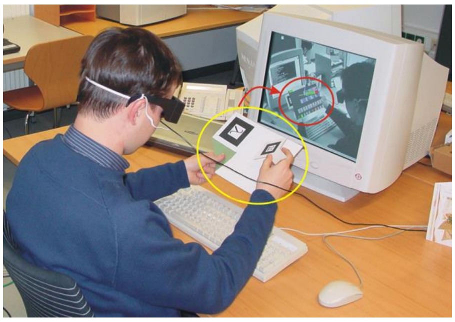


Figure 1. Example of an augmented reality solution involving the manipulation of virtual objects in a virtual world by using markers. (Taken from [20]).

Figure 2. Example of an augmented reality solution with real world objects enriched with virtual information.

Figure 3. Example of a game using augmented reality in which dice and virtual marbles roll and slide as if subjected to gravity (taken from [19]).

With regards to implementation, augmented reality can be used for educational purposes in several ways. Smart phones and touch tablets are among the means to provide mobile AR applications. Given the 3D visualization intrinsic to augmented reality, AR seems suitable for science and technology applications. It allows for the illustration of intangible concepts, for instance the application of forces, such as gravity, on objects. The literature includes several studies on the use of augmented reality to teach mathematics [20], mechanical physics [21], electromagnetism [22] engineering [23] and biomolecular sciences [24]. Research has revealed the conceptual difficulties students face with concepts taught in physics class [25] [26]. Augmented reality could provide a tangible presentation of what are often abstract phenomena and demonstrates spatial and temporal concepts more effectively. Augmented reality also has a positive impact on learners, their connection to the activity, their attention and information retention. It seems to improve understanding in kinesthetic learners. Several studies have demonstrated such key benefits [27]. However, they often consisted in illustrating a phenomenon, involving only visualization without interaction from the students. They did not clearly integrate a serious game context.

Given the current state of knowledge related to serious games and augmented reality, and given the fact that its use in the context of teaching/learning is not extended, this paper focuses on an initial exploration of how a new teaching practice involving a serious game based on an interactive augmented reality solution where a mobile device (i.e., an Apple iPad tablet) is used would impact on students in a physics class. This study documents how the use of a serious game in the form of an innovative teaching strategy contributed to enhance the contextual dimension to learning electromagnetism. It also illustrates how augmented reality acted as a facilitator to allow students, as they moved around the 3-D object during the experiment, to visualize better the variations of magnetic and electric fields under different forces. It is thus a qualitative research, designed not to generalize, but to allow for a close reading of a complex educational problem, and to illustrate how the tool, entitled Parallel, could be promising and significant for students when trying to appropriate difficult concepts [28]. It must be remembered that the degree of appropriation of electromagnetic concepts differs from one student to another [29]. Given the multifaceted of innovation in education and the complexity of investigating the implementation of a new tool in classrooms with students, we have focused on the following question: What is the potential of a new tool that combines augmented reality and a mobile dimension to a serious game scenario on the way students apprehend electromagnetism as a learning object?

3. Methodology

3.1 Parallel

The project, which began in September 2011, was designed to highlight the knowledge acquisition benefits of solutions combining educational entertainment and mobile augmented reality. Based on recommendations made by college teachers, the field of physics, specifically electromagnetism, was chosen for the study. In this field, students often have to visualize an abstract concept involving the three spatial dimensions. When the pedagogical tool used is a book, a projection or a table, the effect of depth is absent. This can complicate understanding of the concept and make its appropriation harder. Parallel is a mobile tablet educational game involving the resolution of a mystery using a simulator showing the true behaviour of charged particles moving in electric and magnetic fields. This is the main learning aim of the game namely understanding the impact of electric and magnetic fields on the trajectory of charged particles. In other words, the game intends to teach students the same notions as the right-hand rule in electromagnetism, which determines the direction of electromagnetic forces. The simulator was specifically designed to provide the student with a new overview of a problem requiring spatial perception. The electric and magnetic fields show themselves as 3D vectors, yielding 3D trajectory for the charged particles. The work brought together many different skill sets and involved the creation of several elements: development of a scenario to establish the game framework, interface design, creation of 3D objects and multimedia elements, modelling of relevant physical phenomena, and the mobile augmented reality component. The project, funded by the university-college collaborative program of the Ministère de l'Éducation, du Loisir et du Sport (MELS), relied on a multidisciplinary team consisting of three professors and a research assistant professional from Laval University, three college teachers and a researcher from a technology transfer centre. This collaboration brought together a variety of skills, covering the fields of computer vision, multimedia communication technologies, GIS, physics and educational sciences.

Parallel is based on an exploration in which the player progresses in a mysterious environment. There is no character to control and the order of progress is not well-defined. When the student starts Parallel, a storyboard briefly explaining the scenario appears (see Figure 4). Students discover that a sealed chest inscribed with Sumerian writings has been recovered from a northern sea. This discovery coincides strangely with the excavation of three tablets with Sumerian inscriptions corresponding to those of the chest. Inspections reveal that weak electromagnetic fields emanate from three separate locations on the sides of the chest. The tablets suggest that symbols are hidden in corresponding places inside the chest. These symbols turn out to comprise the secret combination to open a door in a huge stone arch.

Figure 4. Start screen of the *Parallel* game that presents the opening of the storyboard describing the game context.

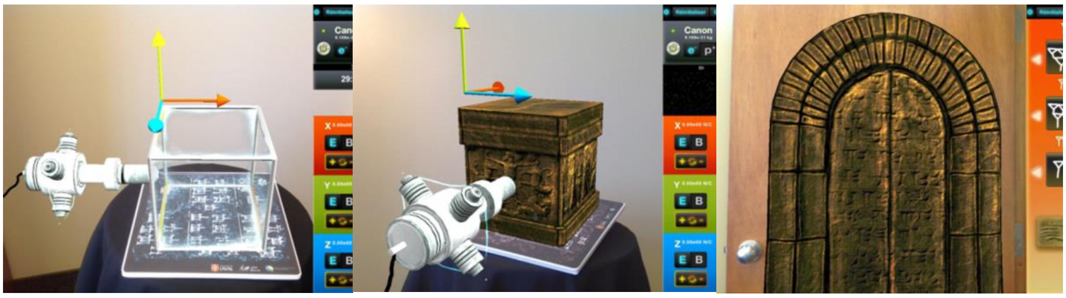
The objective of the game is to discover the three symbols that will open the door. To uncover the symbols, the player has a digital tablet and three steles, and markers bearing different inscriptions (see Figure 5). The three markers represent the three steles mentioned in the scenario described above. They come into play to trigger the apparition of the augmented reality elements.

(a) (b) (c)

Figure 5. The three *Parallel* game markers trigger the apparition of (a) a glass cube, (b) a mysterious chest and (c) a door.

In the game's scenario, each marker identifies a particular scene allowing actions needed to complete the game. The first scene (see Figure 6-a) shows a transparent glass cube. The interface allows the player to activate a particle gun, which projects a particle beam in the cube. By using the interface to adjust the electromagnetic fields, the player can change the beam trajectory, which will be affected by the field forces. The second scene shows a sealed chest (see Figure 6-b). Hidden inside the chest are three symbols used to complete the game. The last scene shows a sealed door, linked to a lock containing three inscriptions (Figure 6-c).

The game was designed for the Apple iOS platform and runs on the iPad tablet. The display creates the illusion that the virtual element truly is part of the scene: the element is rendered in a way adapted to the player's point of view. Players can move around the marker and observe the cube or the chest as if they were really placed on the marker.



(a) (b) (c)

Figure 6. The *Parallel* game is composed of three scenes. (a) The first scene shows a glass cube, which allows configuration and observation of the particle beam. This is the practice cube; (b) the second scene shows a chest which contains the three fundamental clues needed to win the game; (c) the third scene displays a sealed door which can be opened by using the three symbols found in the chest, in scene (b).

3.2 The Design-Based Research approach

The qualitative research methodology called Design-Based Research (DBR) proposed in this article was applied in a real-world context within a college-level physics class. DBR was developed by researchers in the field of education to address the gap between basic and applied research practices [30]. It is aimed at investigating innovative teaching and learning interventions by combining multiple approaches as the research unfolds [31]. DBR allows researchers and designers to understand the contextual demands placed on designs and on adopters of designs when experimenting in the real world. As maintained by the Design-Based Research Collective group of authors [30], it has been often noted that education research does not take into account the complex problems of daily life which are relevant for young people. By targeting a situated learning study [32], the Parallel multidisciplinary research team modelled, produced and tested a promising tool for the implementation of an innovative learning environment. Even though this paper addressed the issue of learning in the field of what is usually called 'hard science', our research challenges the positivist approach in the field of physics learning and opted for a DBR qualitative enquiry with its strengths and limitations. In the footsteps of Kincheloe and Berry [33], we believe that using only a one standardized testing procedure, the research does not appreciate the complex dynamics, beyond pedagogical intervention, that mediate school performance.

One of the major challenges in BBR comes from the fact that new learning methods must be conceived in a way that is coherent with a knowledge creation vision of learning, and not knowledge acquisition [30] [34] In conformity with the principles put forward by Anderson and Shattuck [35], [30] and the Design-Based Research Collective [32], our research team:

(1) took into account the teaching context in an electromagnetic physics course in order to understand the difficulties facing two groups of college-level students in Quebec;
(2) paid particular attention, in each stage of prototype conception, to the concerns of all members of the team (practising teachers, researchers, programmers and IT specialists) as they sought ways to enrich the learning environment related to the appropriation of electromagnetic concepts. "Thus, a partnership is developed that negotiates the study from initial problem identification, through literature review, to intervention design and construction, implementation, assessment, and to the creation and publication of theoretical and design principles." [35, p. 17];
(3) carried out several iterations and adjustments needed to harmonize the more technical elements with the conceptual elements, in relation to the tasks required of students by teachers;
(4) took into account the choice of methodological tools (closed and open questionnaires, participatory observation, video recordings), which allowed not only for the documentation of the success or failure of the tool trial, but also illustrated the interactions between students and their teachers, as well as those with the tool itself;

(5) has, in light of this initial exploration, guided the pursuit of the research and the underlying principles in the design of a new classroom intervention. This step is akin to the principles of grounded theory adopted as an analytical method [36].

3.3 Investigation context and data collected

Adopting a DBR-type methodology has consequences on the game design process and the verification of the iterative steps. We follow the ideas of Sanchez, Ney and Labat [37], who stated that the search for equilibrium between the play aspect and learning in a serious game is a complex task. Moving away from a type of teaching termed “traditional” to lead the student to resolve complex problems in real time is a challenge. Adopting an iterative research approach also has an impact on the data selection and the analytical approach to take. This section presents a narrative of the investigation context and justifies the type of data collected and the analytical approach taken.

The intervention in the classroom began just after formal teaching of the section covering electric fields was finished, and at the very beginning of the part of the course devoted to magnetism. It extended over two classes lasting one hour each. The investigation was carried out with 4 class groups, that is 2 control groups (CG1 and CG2) and 2 groups using the Parallel game (PG1 and PG2). As well, 2 college physics professors (called Teacher A and Teacher M from here on) were involved, as were 160 students registered in the Electricity and Magnetism course taught in the winter 2012 semester. Each professor had 2 groups (one CG group and one PG group). The PG group of teacher A, which used the Parallel game, is labelled A in the rest of the article, while teacher M’s PG group is identified as M.

Figure 7 below provides a synthesis of the investigation process that began about two-thirds through the semester and continued over a three-week period (i.e., weeks 9, 11 and 12).

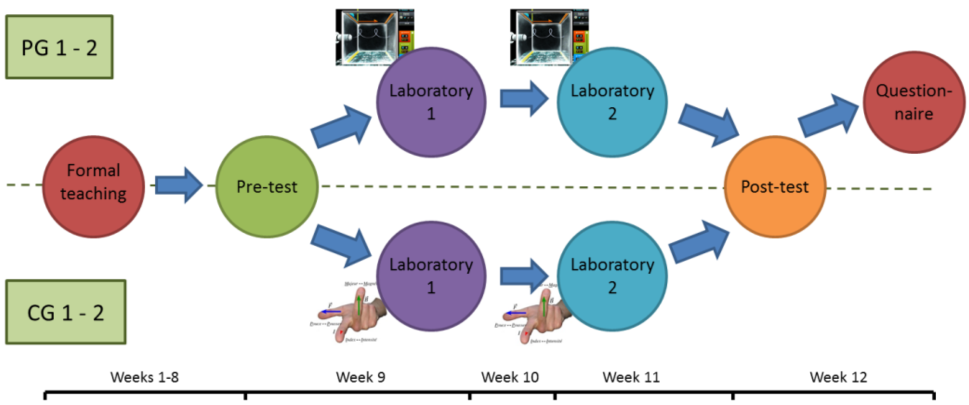


Figure 7. Diagram of the investigation process.

Two conceptual tests containing ten questions on spatial notions regarding electromagnetic fields were administered to the two control groups and the two groups using the Parallel game. The first test is labelled pre-test and the second, post-test. The two conceptual tests (pre-test and post-test) are criteria-referenced and are related to the following competency: application of the laws of electricity and magnetism. They include the recognition of laws, concepts and principles related to a situation involving electromagnetism in order to determine the nature of a problem, and the mapping of a physical situation. Two evaluations were conducted in four classes. The conceptual pre-test was conducted April 17th in both groups. Afterwards, the Parallel group had two gaming sessions as the Control group used only the right hand traditional method to experiment electromagnetism during the same amount of time. Then both performed a conceptual post-test. By comparing the average results of the two groups for Tests A and B, we noticed a larger increase in the group that worked with Parallel. Indeed, that latter group obtained an average increase of 1.3, compared to an average increase of 0.88 for the control group. The tests did not contain True/False questions, but only multiple-choice questions. This means that the effects of chance were reduced. Questions were somewhat different in the two tests (changes to the charge signs, order of choices, question order). This was done to prevent a student from completing the second test while relying only on memory.

However, changes to questions were minor and did not affect the level of difficulty. The tests' measurement qualities were not compromised. They remained valid and reliable[1].

Table 1: Conceptual pre-test and post-test results (4 classes)

	Results average for Pre-test /10	Results average for Post-test /10	Delta
Control group	5,08	5,95	0,88
Parallel group	4,90	6,20	1,30

Even if there is an increase in term of average results with the Parallel group, in the context of this paper, we focus on another investigating tool that was part of the research i.e. a game evaluation questionnaire that in addition to the conceptual tests, was administered to the two groups that used Parallel. Regarding the game evaluation questionnaire administered to the two groups that had used Parallel, 68 forms in total were filled out and subjected to thematic qualitative analysis [36]. The full version of the questionnaire is annexed at the end of the paper. Questions primarily addressed the students' appreciation of the gaming experience in class, the utility of the game for visualizing electromagnetic concepts as well as students' opinion on the relevance of the use of the simulator in a science course. The questionnaire also evaluated the students' initial interest in video games. As a result, we were able to collect information regarding the comprehension of the intuitive functioning of the application, as well as the game's originality (introduction, graphics, augmented reality) and its level of difficulty. Added to this were the video recordings of classes during which the simulator was used by students. The videos allowed for real-time observation of students' reactions. Moreover, a participant-observer produced a report. Not all registered students completed the pre-test, post-test and the questionnaire (some students were not present when a test was administered, others did not continue attending the course through the end of the semester).

Since this paper focuses on the exploration of the impact of augmented reality and the addition of mobility in the context of a serious game in a physics class and is not aiming at generalizing, we focused on the thematic interpretation of students written responses to the evaluation questionnaire. All the responses were transcribed and we engaged in a multilevel thematic analysis leading to emerging open-ended categories [36]. Triangulation of the qualitative analysis was done as different members of the research team discussed their characteristics to minimize the subjective impact of qualitative interpretation. The team also triangulated its interpretation with the ethnographic observation notes that were taken during the observation in the physic's classes.

Table 2 indicates the exact number of participants for each interrogation stage of the investigation. This contribution is focused on the evaluation questionnaire.

Table 2. Student groups involved in the investigation

	Teacher M	Teacher A	Total
Pre-test			
Control group - CG	41	35	76
Groups using *Parallel* - PG	37	37	74
Total	***78***	***72***	***150***
Post-test			
Control group - CG	41	31	72
Groups using *Parallel* - PG	36	32	68
Total	***77***	***63***	***140***
Game evaluation questionnaire			
Groups using *Parallel* - PG	35	33	68

[1]Our pre- and post-test were created by selecting questions from the Conceptual Survey in Electricity and Magnetism form (CSEM) developed by Maloney, O'Kuma *et al*. [38], and from the Brief Electricity and Magnetism Assessment test (BEMA) developed by Ding, Chabay and Sherwood [39].

Table 3 is a complement to figure 7, providing details about the objectives for each stage of the investigation and the types of data collected. Implementation planning to meet project objectives was based on a rigorous, DBR approach structured in five successive work blocks spanning over a nine-month period.

Table 3: Objectives and types of data collected in the investigation stages (N/A = not applicable)

Weeks	Groups involved	Stages	Objectives	Types of data collected
1 to 8	CG and PG	Formal teaching of concepts of electricity	Rigorous application of the laws of electricity	N/A
9	CG and PG	Pre-test	Measurement of the degree of retention of notions regarding electromagnetism covered in high school	Multiple-choice questionnaire: 10 multiple-choice questions
	CG and PG	Continuation of formal teaching: beginning of electromagnetism	Rigorous application of the laws of electricity and magnetism	N/A
	CG	Laboratory without the use of the game	Rigorous use of electromagnetic concepts, laws and principles at the experimental level	N/A
	PG	First game session filmed during a laboratory session		Video recording Participatory observation Observation notes
11	CG and PG	All material on magnetic fields has been seen in class		N/A
	CG	Laboratory without the use of the game	Linking theory to practice	N/A
	PG	Second game session filmed during a laboratory session		Video recording Participatory observation Observation notes
12	CG and PG	Post-test	Measurement of the degree of appropriation of electromagnetic concepts	Multiple-choice questionnaire: 10 multiple-choice questions
	PG	Game evaluation questionnaire		Questionnaire: 12 open-ended questions

4. Results and discussion

4.1 Augmented reality

The primary advantage of augmented reality is that it significantly helps students see and visualize the physical situation and trajectory in 3D (35 answers), for all field configurations, which facilitates their understanding (11 answers). Augmented reality also helps students by providing a visual representation (glass cube) of an abstract situation that is not otherwise easily accessible. They can “see instead of imagining” and link the theory to its physical manifestation. Students can think about what they are seeing instead of starting with their mental representation of the situation. For some students, this facilitates the adoption of a mental representation of the situation. We noticed that the glass cube scene became a reference during discussions between some students. Moreover, when they tried to limit the time spent with the glass cube to practice on the fields and direct the particle beams to a specific site, they used the cube as a reference, and drew it on a sheet of paper. Some used the cube scene without starting the particle gun, or the beam (meaning no time countdown) to discuss their field configuration.

Another benefit of augmented reality is that it provides an experience, an interaction with a virtual setting that would not otherwise be accessible. Students can try their field configurations, concretely see in real-time the effect on the particle beam and validate their understanding. In other words, the tool provided a certain sensory experience of the situation. In addition, augmented reality provides for greater interactivity between the student and the virtual setting than the real display usually available (electron beam in a bulb and Helmholtz coils to create a magnetic field) allows. This comment also applies to the accessibility of the real display (i.e., number of display vs. number of students) and to the limited number of manipulations and configurations possible regarding electromagnetic fields. Table 3, below, details the elements related to augmented reality.

Table 3. Augmented reality elements acting as supports or obstacles to the learning of electromagnetic concepts

Evaluation	Type of support or obstacle	Observation and comments
Strong point	Significant support of 3D visualization of phenomena	- The 3D is the main element of the game that allowed me to properly visualize things, as did the colour of the different virtual elements. (M79) - The game allowed me to see in 3D situations that were too complicated to explain on paper or orally. (A19) - I have problems with 3D and the *Parallel* experiment helped me improve my understanding. (M63) - It helped me work on my 3D perception while assimilating elements of physics. (A40) - “The user can understand particle trajectory by seeing it.” (A5) - “A very good visual aid to understand fields and their properties.” (A17) - “It allowed me to better understand the notions seen in class, since I am more of a visual person.” (A3) - Yes, it clearly helped me a lot, especially with regards to understanding the E and B fields.(A12) - I think the game allowed me to concretely see particle movements which I didn’t know existed. (M76)

Strong point	Virtual availability of a visual representation of an abstract situation which is not easily accessible	- It helps visualize trajectories better, instead of imagining them [...] something that doesn't really exist. (A28) - It is much easier for me now to imagine the trajectory of the different particles. (M79) - Now I can visualize the elements without having to use my right hand. (M44) - It is much more interesting to see it for real. (A9) - Understand the influence of magnetic and electrical fields on particles in three dimensions. (M77) - The fact that we saw the trajectory taken by the particles in various and mixed fields made us understand in a concrete way, as opposed to something from our imagination or to a 2D design on a white board. (A39)
Strong point	Availability of realistic experimentation methods in real time	- Practical use (M58), improve one's understanding (M43), see our level of understanding. (M70) - The game allowed me to better understand the subject at hand, to a point where I was able to play with the elements. (A12) - Having to move the beam on different sides of the cube made us take into account the different magnetic and electric fields, and understand their impacts on the particles. (A27)
Weak point	Configuration of the implementation of augmented reality	- Nineteen students mentioned having a hard time, at one point or another, making the augmented reality images appear or stay visible. This situation mostly occurred when the markers were placed on relatively high counters, or when the students involved weren't tall enough. These problems were quickly resolved by telling students that the angle of their tablet's camera should not be too low with relation to the marker's surface.

In light of the experiments and the results of the evaluation questionnaire, it seems that student perception of the relevance of using augmented reality is positive. In fact, all responses regarding the usefulness of augmented reality in science courses were positive (58/58), with two students not replying. Among students who provided a positive answer, two deemed it important to specify that the game as a tool was "useful and interesting, but not necessary for the purpose of understanding" (A19) and that the game alone "could not replace a class" (M55).

Interpretation of experimental results regarding augmented reality is consistent with the suggestions of Dilenbourg and Jermann [18] regarding the added value of the technology in terms of the enrichment of knowledge regarding real-world objects and interactivity. We noted that students appreciated the simplicity of using augmented reality. In their opinion, it promoted contextual learning and autonomy. They believed that augmented reality, linked to a serious game on a mobile technology platform (e.g., touch tablet), facilitated the understanding of the concepts of electromagnetism, since it allows for a direct contact with a tangible reality. The virtual object thus becomes a mediation artefact. It provides new meaning to the mobilization of resources (theoretical knowledge) in context, creates an interaction zone and generates an attraction effect triggered by immersion.

4.2 Mobile serious games

Students appreciated the “way that the game provided a perspective, a different way to teach physics in comparison with what is normally a lecture course” (M71). The game provided a “different way to put into practice concepts seen in class, to understand them” (M61). It offered an “interesting context” (M64) that triggered motivation and was “much more fun and stimulating” that the traditional methods used to learn certain concepts of physics. Even if this paper focuses on the evaluation questionnaire, the research team’s observation notes described how the fact that students were able to move around the appearing 3-D box was essential in helping them to better visualize and look at the cube or the doors from different angles. The tablet, acting as an extension of their body, allow them to personalize each of their hypothesis when it came to predict the direction of the beam going under different forces in each of the 3-D vertical axes.

Students appreciated the fact that the game allowed them to verify or “confirm their understanding” (M53), as was underlined in the previous section with regard to augmented reality. The students brought attention to this contribution of the simulator and to the serious game design. They emphasized the interactive character of the application and the real-time response of the simulator. They appreciated being able to configure the fields as they wished, “to see in an ongoing fashion the effect” of the modifications (five comments), i.e. to have “a [transparent] box for testing purposes”. (M56).

Regarding support for the understanding of electromagnetic concepts, in general, students appreciated the Parallel application because it used “notions directly linked to the content” of the Electricity and Magnetism college course (8 comments). Students mentioned that the game helped them better see, understand and become aware of several specific aspects, such as the difference between the effects of electrical and magnetic fields, the way in which field polarity is expressed and the effect on trajectory of a field polarity reversal, the effect of charge for each of the different fields, the effect of field size variation, as well as the effect of the simultaneous presence of electric and magnetic fields.

Regarding the game’s design, the originality of the game, the level of difficulty of the tasks to accomplish, and the nature of the challenge to be met were generally seen as positive by students and helpful in terms of involvement. The game was seen by some, to be “difficult but accessible”, while two students stated the game’s level was “too difficult.” Three students indicated that, once they were able to understand it, the game seemed “easy” to them. When asked about their view on the challenge presented by the game, 37 students answered in the affirmative to the question “Did you like the proposed challenge?” Among the least appreciated elements of the game were the repetitions of the tasks to be completed, criticized by several students. The majority of students were also disappointed by the rewards gained in the different phases of the game and at completion; they felt they did not match the level of effort devoted to the game. Table 4, below, lists the elements related to the serious game, its classroom use and the support needed for its use.

Table 4. Elements of the mobile serious game acting as support or obstacle to the learning of electromagnetic concepts

Evaluation	Type of support or obstacle	Observation and comments
Strong point	Contextual dimension of learning	– Using concepts learned in class (E and B) to attain a concrete objective was motivating. (A1) – Finally, it offered a “less theoretical, more practical” teaching method (M81), a context to “compare theory [and] practice” (A6), or to “apply theory and put it into practice” (A40). – The game teaches us how to make links and connections. (M44)
Strong point	Supports the understanding of electromagnetic concepts	– The effect of magnetic fields on particles is a bit difficult to understand and visualize in our head. It’s good to see their impact on particles. (A4)

		– [The game] allowed better visualization of the magnetic field and its effects on particles, even if I had already understood the material. (A36, A40) – The game only helped me understand magnetic fields; electrical fields are much more intuitive and I already understood them. (M57) – The game mostly helped me understand magnetism when there are several components. (M57)
Strong point	Supports real-time self-verification of what has been learned	– I predicted movements and the game allowed me to correct myself. (M70) – We were able to make a hypothesis with the right-hand [rule], and verify it after. (M81) (numerous references) – I have to say that trying different configurations after having made predictions was good! (A1)
Strong point	Game originality	– Among the 32 people giving an opinion, 14 evaluated it as “original” and 17 (out of 32) judged it “very original”. Only one (1/32) student judged it “not very original”.
Strong point	Difficulty level	– Pretty hard, but just enough. (M55, M65) – Adapted to [our level]. (M56) – Difficult and stimulating; it pushed us to work and succeed. (M61) – The challenge is at the right level to allow us to see if we understood. (M70) – Not that difficult if you understand the impact of various fields on particles. (A4)
Strong point	Challenge to meet	– Difficult and stimulating challenge; it pushed us to work and succeed. (M61) – I found it interesting even it I wasn’t able to complete the game. (M62). – The principle of the puzzle and the door to open made us want to play. (M68) – Creating some rivalry was fun and encouraged us to understand the physical phenomena. (M81) – It develops logic and its gratifying to succeed. (A22)
Weak point	Intuitiveness and advance information required	– In terms of the intuitiveness of the solution, 7 out of 68 students reported having been able to understand the game at least by the end of the first session, “to know what to do” (A19) and to “understand how it worked” (A5), and that the environment was “clear” and intuitively understandable. – Only one student mentioned that he “found it rather difficult to mix all the concepts in just one game” (A33); – one student criticized the game for not “using formulas” (M55);
Weak point	Time spent playing the game in class	– We only used it twice, and the first time we played the game somewhat randomly. (M51) – We didn’t have enough time to take notes and understand the concepts sufficiently. (A9)
Weak point	Repetitiveness of the tasks	– The game isn’t very long once you have understood the electric and magnetic concepts.

		– It is a bit repetitive, in that you had to always think in the same way. (M58, M46, M64) – We looked for the same thing three times. (M46, M60)
Weak point	Rewards and incentives	– No comments.

Results regarding the elements of the serious mobile game and its use as a support or obstacle to learning electromagnetic concepts lead to the emergence of two dimensions proposed by Yin, Ogata and Yano regarding the possible convergence of said technologies and learning methods: learning in context and learner-centred learning [40]. The learner can physically appropriate Parallel, and move with it around the markers in order to become involved in the learning process. These results are in line with the observations of Alvarez who stated that serious games provide a considerable benefit in allowing us to find "memory" [41]. Another point greatly revealed is the support of real-time self-verification of learning. Given that, this is the first verification of the tool through an exploration process and at this point we cannot presuppose the representation of electromagnetic concepts. This is a non-conventional experimental framework, given the multiplicity of the parameters involved in student learning, including the mobile technology tool, the serious game, and augmented reality. In the problem-solving context of the Parallel game, students each had a degree of freedom regarding the use they could make of space and the application of the theoretical concepts involved. Consequently, in a group context, the researcher is faced with a multitude of strategies. Mobile technology, through the possibilities it offers, provides learners with immediate verification of their strategy choices.

5. Conclusion

The results of this first iteration of the Parallel game illustrate our interpretation of the first stage of Design-Based Research approach, as adopted. As we discussed, the lessons and observations we derived from the in-class experimentation, and especially on the thematic analysis of the student's evaluation of the game, are in accordance with the ideas of several authors addressing the targeted problems. Augmented reality significantly helps students see and visualize the physical phenomenon in 3D. This innovative technology provides a visual representation of an abstract situation that is not otherwise easily accessible. Students can "see instead of imagining" and link the theory to its physical manifestation. Another benefit of augmented reality is that it provides an experience, an interaction with a virtual setting that would not otherwise be accessible. Students can validate immediately their understanding. Thus the game supports real-time self-verification of learning. From the serious game standpoint, students appreciated its originality, the level of difficulty of the tasks to accomplish, and the nature of the challenge to be met. They contributed to their involvement, among others by offering different way to put into practice concepts seen in class in a much more fun and stimulating fashion. The experiments in class underlined the benefits of mobility inherent to the proposed serious games. Indeed, the research team's observation notes described how the fact that students were able to move around the appearing 3-D box was essential in helping them to better visualize and look at the cube and chest from different angles, increasing the feeling of presence of the virtual objects. Further efforts should be invested in specifying the components involved in such findings in order to better understand the learning method and envision a design strategy for such teaching practice.

Even within the context of an exploratory effort, we noted that learning, supported by a mobile platform, offered several usage contexts; the student is required to take into account the following parameters: movement in space, appropriation of the virtual interface, active involvement while interacting in a space provided by the augmented reality, and retention of disciplinary knowledge to resolve the serious game puzzle. These findings constitute the basis on which the next iterations will be built and are coherent with the definition of mobile learning we have adopted.

Parallel was appreciated by physics students. This indicates that it fits within the social practice of mobile technology use with which they are comfortable. By accepting to avoid guiding the students too much in their experimentation with the Parallel game in the classroom, professors, although not deprecating a more traditional teaching/learning method, modified the use of teaching space, the division of tasks among themselves and between their students, as well as the usual classroom rules. We also observed a strong convergence of mobile technology and two learning aspects, i.e., learner-based learning and contextual learning [42]. These conclusions lead toward new possibilities in science teaching and provide an incentive to become involved in additional work while aiming for a more collaborative aspect via a network connection.

Consequently, we are already exploring a second project phase, during which classroom time allocated to handling the Parallel game will be increased. The immersivity of augmented reality and the mobile aspect of the game will be reinforced by offering a unique, class-scale augmented reality, simultaneously shared by several students. This type of configuration will promote interaction and collaboration among players, and will make observed phenomena more tangible and reality-based.

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Annexe 1

Student evaluation questionnaire: Parallel

Physics-Electricity Designated number: ___________________________

Date: ________________ Sex: M F Group: __________

General questions

Q1 If you had to summarize your gaming experience with the tablet, what would say was interesting or less interesting in the context of a physics class?

Interesting	Less interesting

Q2. Provide your appreciation of each of the 2 gaming experiences with Parallel.
1.____
1.____
____
____
____

2____
____
____
____

Physics concepts

Q3 Did Parallel help you visualize the behaviour of charged particules as they moved in an electric or magnetic field? Did it help you better link the theoretical elements that had been presented during the class?

a) If yes, describe with specific concepts the game helped you visualize or understand. (E, B)

b) If not, what were the obstacles to your comprehension or visualization?

a____

b____

Q4 After two game sessions, do you think it is easier for you to anticipate the trajectory of the electric particles and the effects of the different fields on the particules? (E, B) Give some detailed comments whether you find it helpful or not.

Game elements

Q5 Describe your own interest with videogames and your experience as a gamer.

Q6 What do you think about the introduction?

Q7 In your opinion, what are the aspects of *Parallel* that would make you better understand the way the game is played intuitively? Tell us what remained not understood at the end of the first gaming session.

Q8 Did you enjoy the challenge that was proposed to you? Give your impression (level of difficulties, originality, etc.)

Q9 What do you think of the objects that appear with the help of AR?

Future

Q10 How do you think *Parallel* could be improved? (challenges, scenario, ending, etc.)

Q11 In your opinion, is AR useful in the context of a science class? If so, provide concrete examples. If not, justify.

Q12 Any other comments?