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RESEARCH ARTICLE

A critical review of 13 years of mobile game-based learning

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Abstract With the increasing popularity of smartphones and tablets, game-based learning (GBL) is undergoing a rapid shift to mobile platforms. This transformation is driven by mobility, wireless interfaces, and built-in sensors that these smart devices offer in order to enable blended and context-sensitive mobile learning (m-Learning) activities. Thus, m-Learning is becoming more independent and ubiquitous (u-Learning). In order to identify and analyze the main trends and the future challenging issues involved in designing mGBL learning strategies, as well as to bring to the foreground important issues pertaining to mobile and context-aware ubiquitous GBL, the work at hand conducts a comprehensive survey of this particular area. Specifically, it introduces and applies a six-dimensional framework consisted of Spatio-temporal, Collaboration/Social, Session, Personalization, Data security & privacy, and Pedagogy, with the aim of scrutinizing the contributions in the field of mGBL published from 2004 to 2016. It was found that the transition to mGBL presents several difficulties, and therefore cannot be conceived as a simple and quick modification of existing GBL solutions. In this respect, this work is anticipated to foster the development of well-designed solutions that are intensive not only in their technological aspect, but in pedagogical qualities as well.

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Introduction

Nowadays, smart mobile devices are considered one of the most challenging technological fields in formal or lifelong learning due to their intrinsic features such as portability, connectivity, built-in sensors, etc, as well as due to their context-sensitive characteristics. In the context of e-Learning, the integration of such devices to the learning process gave birth to an independent type of learning known as mobile-Learning (m-Learning). This learning transformation supports just-in-time and just-in-place learning capabilities, allowing learners (and instructors) to have instant access to learning content and collaborative activities anytime, and from arbitrary device types and platforms (Korucu and Alkan 2011). In mobile environments, instructors have the opportunity to interact directly with learners through a synchronous or asynchronous communication channel. Further, several mobile hardware advancements, such as the plethora of sensors and wireless interfaces that these devices offer, have also contributed to a new transformation of m-Learning, which is known as ubiquitous learning (u-Learning). This means that the learning experience has become ubiquitous by situating learners in different learning contexts in physical space. For instance, by utilizing mobile Augmented Reality (AR) technology, learning applications can augment the real-world content via the mobile camera. In the same way, Global Positioning System (GPS) and inertial sensors are used among others in educational applications for positioning and orientation tracking. So, the plethora of contextual information that can be detected from an environment, led to the design of context-aware u-Learning applications. This implies that a digital learning environment detects learners' interaction with the application, senses their behavior in the real world, and accordingly assist them by offering personalized guidance (Hwang et al. 2008).

So far, m-Learning (and in a lower extent u-Learning) have been addressed by several works and from a diversity of perspectives. For instance, Frohberg et al. (2009) conducted a critical analysis of contributions on this particular field that published before the end of 2007. The primary purpose of the authors was to discover common ground and similarities, along with differences, inconsistencies or contradictions within the domain of m-Learning. Other studies examined m-Learning from different perspectives, including (a) users' attitudes specific to the integration of mobile technology within the learning process (Cheon et al. 2012), (b) satisfaction derived from the use of m-Learning systems (Georgieva et al. 2011), (c) course material delivery (Haag 2011), (d) students' collaboration when communicating via texting or multimedia services (Cavus 2011), (e) learners' self-confidence (Attewell 2005), (f) screen size preferences (Alvarez et al. 2011), and (g) learners' behavior and performance (Wang et al. 2009b).

However, while m-Learning has mainly facilitated the embedding of learning in students' natural environment, accessed in their own pace, game-based learning (GBL) aspires to bring the natural human activity of play into the learning process. In this context, GBL is gradually becoming a fundamental term in the mobile arena and an important alternative or fortifier in educative applications (Tsai and Hwang 2013). For example, various studies (Annetta et al. 2009; Tsai et al. 2012; Hwang and Wu 2014; Chen et al. 2015) have indicated that educators' learning achievements, motivation, and interests are augmented and enhanced if game-based activities are blended with Internet tools, mobile environments, and popular communication services. This is because students' motivation is increased in an extrinsic manner (Rau et al. 2008).

Further, various studies have indicated the importance of embedding appropriate learning strategies in GBL activities for improving students' learning performance. In this context, Hwang et al. (2013) argue that when a learning strategy, namely concept mapping, is embedded in a computer game activity, it "can significantly improve the students' learning achievement and decrease their cognitive load". Moreover, they also underlined the importance of supporting educational activities by designing instructional learning strategies, and emphasizing on "the importance and the necessity of effectively integrating learning strategies or tools into the gaming scenarios or gaming objectives". Chen et al. (2015) have also found that both gaming and appropriate (learning) strategies, have significantly positive effects to both students' learning achievements and motivation. These learning strategies integrate digital resources with the aim to support and guide students in real-world scenarios. However, the same authors indicated that "without careful design, adding learning support to a game might have a negative influence on the enjoyment of students while engaged in the gaming process".

So, appropriate learning strategies have to be developed and integrated into mobile/ubiquitous game-based learning environments in order to fulfill their pedagogical potentials. It is to be noted that in the literature GBL is often referred to as digital game-based learning (DGBL). However, for reasons of simplicity, the term GBL will be used hereinafter.

Thus far, in comparison with other GBL-related meta-studies, GBL in the context of e-Learning has been addressed by several works in the literature trying to answer similar research issues, including the embedding of learning theories into GBL applications, the identification of GBL positive impacts, and so forth. Li and Tsai (2013) survey a great mass of empirical research primarily devoted to game-based science learning (GBSL) between 2000 and 2011. This is done by exploring digital games' research purposes and designs (distinguishing technologies, including AR, etc.), as well as their reciprocal linking between basic learning theories and learning outcomes. However, despite that the aforementioned work identifies digital games in science education, it hardly touches upon mobile GBL (mGBL), which is the primary focus of this paper. Another major work in the field of GBL is given by Connolly et al. (2012). There, the authors conduct a systematic review on computer and serious games spanning a period from 2004 to 2009 "in regard to the potential positive impacts of gaming on users aged 14 years or above, especially with respect to learning, skill enhancement and engagement". In this respect, the authors' basic aim is to answer the primary research question of "what empirical evidence is there concerning the positive impacts and outcomes of computer games?". As with Li and Tsai (2013), this contribution does not take into account mGBL works while it considers commercial-off-the-shelf (COTS) games. Both the above mentioned major works answer their research questions by categorizing the various GBL contributions based on specific game characteristics (single/multi-player, digital/non-digital, game genre, etc.). According to Connolly et al. (2012) these characteristics are named as *game variables*.

In addition, as the technology continuously evolves, mobile devices are empowered by new context-based features and characteristics such as the tap-and-go Near Field Communication (NFC tech), location-awareness capabilities (GPS-enabled tech), etc. In this respect, context-awareness is gaining applicability in ubiquitous mobile computing. Meanwhile, mobile computing devices are expected to increase their computational power and wireless capabilities to enable faster services such as multimedia transfers, etc. In this respect, many researchers in the educational technology field have highlighted on the importance of more studies of how to leverage these technologies in order to enhance learning (Heinecke et al. 2001). Further, context-awareness implies gathering, storing and utilizing of the learners' personal information from arbitrary context-based activities. This however may clash with the learner's wish for privacy and particularly anonymity (Kambourakis 2014), and raise the importance of integrating in mGBL environments data encryption and integrity mechanisms. We also identified this necessity for more research work on mGBL in the field of the educational technology. That is, the literature lacks a systematic review of the characteristics of already published mGBL contributions, as well as of the way these characteristics are incorporated in each mGBL implementation.

Based on the above, the paper at hand scrutinizes the mGBL works in the literature spanning a period from 2004 to 2016 with the aim of addressing the following research questions:

RQ1: What are the main learning strategies/educational activities that guide learners in existing mGBL environments?

RQ2: What personalized functionalities for improving learning experience have been applied in existing mGBL environments?

RQ3: What are the end-users' data privacy and security issues in mGBL environments?

RQ4: What are the pedagogical aspects in existing mGBL environments?

- (a) What are the learning theories, the number of players, and the target group that characterize the philosophy and steer the design of mGBL environments?
- (b) What are the educational benefits reported in the mGBL literature? The term *benefits* refers to the techniques that an mGBL application deploys in order to make the learning process attractive and efficient. This is done by enabling various learner's psychological properties such as confidence, satisfaction, and stimulation.
- (c) What are the methodologies adopted in the studied literature for assessing and evaluating the pedagogical efficiency of the mGBL applications?

RQ5: Which mobile characteristics are engaged in mGBL?

RQ6: What are the main trends in mGBL environments?

- (a) What are the learning domains that have been applied in mGBL applications?
- (b) What are the mobile platforms that the mGBL applications are deployed to?
- (c) What type of system architecture is used in mGBL applications?
- (d) What types of learning environment (physical world, virtual world, etc.), have been applied in mGBL applications?
- (e) What are the potentials of emerging technologies in mGBL environments?

RQ7: Do mGBL applications take advantage of the affordances of u-learning environments by utilizing context-aware characteristics?

The rest of the paper is structured as follows. The next section details on the proposed framework and explains our methodology. The classification of mGBL works based on the proposed framework is given in "Context-aware m/u-Learning and mobile games". A discussion of the main trends in mGBL environments is offered in "Trends in mGBL environments". The current and future challenges regarding mGBL are given in "Discussion and future challenges". The last section concludes the paper and provides directions to future work.

Theoretical background and methodology

Theoretical underpinnings

A main question that this research critically discusses is whether the existing mobile games substantially utilize the technological affordances of mobile technologies for supporting innovative and pedagogically efficient learning environments—apart from the apparent anywhere/anytime usage—, or they just superficially reproduce the characteristics of desktop applications on portable devices. To this end, we focus on the ways that existing mGBL applications support certain properties of mobile devices by taking advantage of their technological capabilities (including the various types of hardware sensors and communication capabilities) in order to address unique *educational affordances*, namely portability, social interactivity, context-sensitivity, connectivity, and individuality (Klopfer and Squire 2008).

A relatively recent direction of research that addresses the above issues is the new educational technology paradigm of u-Learning. Actually, u-Learning is considered as an advancement from both e-Learning and m-Learning paradigms (Liu and Hwang 2010). While m-Learning supports portability and limited network availability of educational applications, u-Learning characterizes a new generation of environments, supporting, besides mobility, pervasiveness, context-awareness and adaptability. While, to the best of our knowledge, the term *u-Learning* eludes a certain definition in the literature, various sets of characteristics have been attributed to this learning model, e.g., permanency, accessibility, immediacy, interactivity, and situating of instructional activities accessed in various contexts (Ogata and Yano 2004). According to the same authors, u-Learning is characterized by the combination of pervasiveness, in the sense of the embedding of devices in the environment of the learner, and mobility.

Context-aware ubiquitous learning is a related term widely used in the relative literature. Yang et al. (2008) define context-aware (and) u-Learning as a "computer supported learning paradigm for identifying learners' surrounding context and social situation to provide integrated, interoperable, pervasive, and seamless learning experiences". Hwang et al. (2008) have also stressed on the concept of context-awareness, by proposing certain *situation parameters* of learning activities in a context-aware u-Learning environment:

- Personal contexts, as sensed by the environment: spatial and temporal information, biometrical data.
- Environmental contexts sensed by the environment: information concerning certain sensors of the context-aware system.
- Feedback from the learner through the mobile device.
- Personal data retrieved from databases.
- Environmental data retrieved from databases.

Finally, Wang (2004) in his early work on context-aware m-Learning defines *learning context* as "any information that can be used to characterize the situation of learning entities that are considered relevant to the interactions between a learner and an application". Wang emphasizes on the pedagogic importance of the context in such environments and identifies six dimensions of context that characterize m-Learning:

- *spatio-temporal* referring to space and location awareness and time;
- *identity* referring to the particular roles impersonated by the learner inside an environment;

- *activity* which is related with the actual learning activities that a learner is engaged within a context-aware environment;
- *community* which pertains to the social context and the dynamics of learner groups that are formed inside a context-aware environment;
- *learner* which refers to the psychological implications of learning from the learner's perspective and
- *facility* which is related to the technological facilities that are engaged in a context-aware environment.

Methodology

In order to systematically answer the research questions concerning gaming characteristics, learning strategies, personalization, pedagogy, and data security and privacy issues in existing mGBL, we propose a six-dimensional framework. This is used for scrutinizing the inherent constituents of the learning games to provide learners a m/u-Learning experience. Based on the above theoretical considerations, the framework consists of the following six dimensions:

- *Spatio-temporal*
- *Collaboration/Social*
- *Session*
- *Personalization*
- *Data security and privacy*
- *Pedagogy*

We consider the above dimensions as an appropriate framework for systematically studying existing mGBL implementations for two reasons:

1. These align with most approaches found in the literature of m/u-Learning, as previously outlined in this section.
2. They are most relevant with the characteristics of mGBL applications found in the literature so far, i.e., challenge, competition and collaboration, role play and identity, and place-based contextual learning (Squire and Jan 2007).

The study of existing mGBL applications and their role in context-aware u-Learning is based on two axes:

1. In the first axis, we have identified specific *mobile game characteristics* of the mGBL applications that were studied in this survey. We have codified these characteristics in the form of *Game Design Patterns* (GDPs) (Borchers 2001; Bjork and Holopainen 2004; Davidsson et al. 2004; Schmitz et al. 2012). A GDP is a method of codifying the knowledge that describes the design of game elements related to interaction. In general, GDPs may describe how the technology could be utilized in different platforms, such as the mGBL ones, within the learning context. For instance, the "player-artifact proximity" GDP is exploited in a learning scenario by triggering a specific event for delivering contextual information to a learner. This event may be triggered when the player is in proximity either with a specific artifact or with another player. Bjork and Holopainen (2004) identified several computer game GDPs and proposed a framework to support game developers during the design, analysis, and comparison phase. Davidsson et al. (2004) were based on the aforementioned work focusing on mobile games, by systematically reviewing mobile GDPs and they

identified 75 new patterns. In the context of the work at hand, we identified a subset of the aforementioned GDPs along with some additional ones in the examined mGBL applications.

2. In the second axis, we have identified those strategies/educational activities that guide learners in a mGBL environment with the aim of addressing context-aware u-Learning experience, as proposed by Hwang et al. (2008).

By using the above framework we do not assume that existing mGBL environments are deliberately designed to address a context-aware u-Learning experience. Rather, we consider the above patterns and strategies for learning activities related to mobile and context-aware u-Learning as a post-hoc framework for the analysis of the most important elements of the existing mGBL applications.

For the survey part of this work, we conducted a review of key literature for identifying relevant contributions published in English. We have only taken into account peer reviewed scientific journal and conference publications pertaining to empirical research and/or evaluation, and solid practice examples published from 2004 onwards. Hence, commercial mGBL products or other non-published efforts remain outside the scope of this paper, and have been intentionally neglected. To identify the relevant works, we searched in a number of major databases, including Web of Science, Scopus, SpringerLink, Wiley Online Library, and IEEE Xplore. The search was performed using appropriate key terms and filters. Specifically, the keyword terms encompassed combinations of: *game-based learning, digital game-based learning, mobile game-based learning, GBL, DGBL, context-awareness, context-based, contextual information, learning strategies, u-learning, sensored-based, gamification, video games, simulation learning games, learning by game, personalization*, and others. Our initial search returned 7340 articles. After the initial screening of articles, first by reading the abstracts and the conclusions, and then by a thorough reading of the most relevant, 339 of them were retrieved. Ultimately, 81 articles were selected for the purposes of the current study. From those, 36 refer to distinct mGBL environments, while the others were utilized for the related work and for supporting our arguments. In this regard, the survey of mGBL works presented in this paper is as far as possible exhaustive, and to the best of our knowledge the sole one in the literature so far.

Context-aware m/u-Learning and mobile games

In this section, we succinctly discuss every work found in the literature regarding the mGBL ecosystem between the specified time frame. Following the discussion of "Methodology", first we identify the mobile GDPs (Davidsson et al. 2004) that a mGBL environment incorporates in its design in order to fulfill its learning strategy. Second, as proposed by Hwang et al. (2008), we identify the strategies/educational activities that the reviewed research works integrate in their learning scenarios in order to deliver to the learners a mobile, ubiquitous, and context-aware learning experience.

Figure 1 categorizes every mGBL work found in the literature. Specifically, in the left part of this figure the classification is done per framework dimension. Each work, where it is applicable, is distinguished to the corresponding dimension and discussed based on the related GDPs and context-aware u-Learning activity strategies. Note however that the classification is rather loose, meaning that the same work may be present in more than one dimensions.

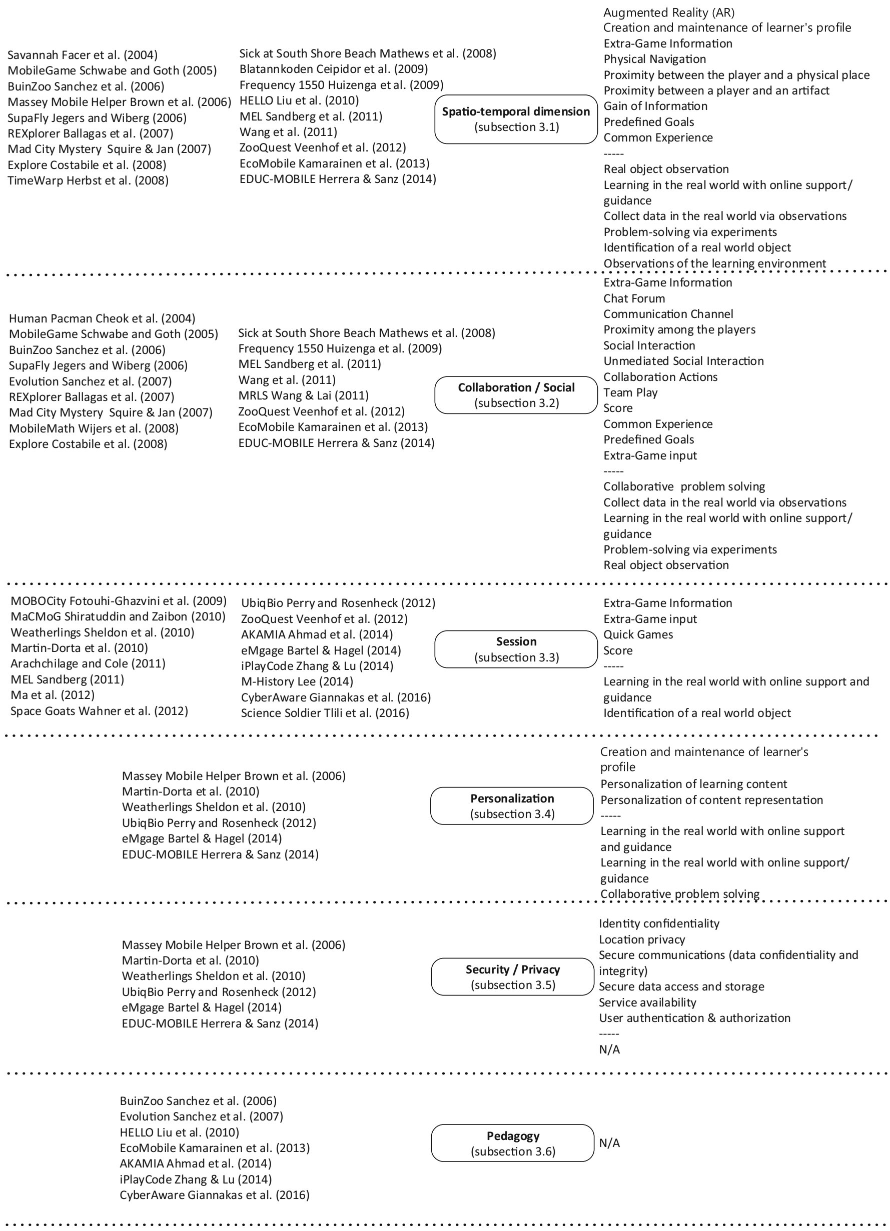

Fig. 1 A loose categorization of works per dimension. The associated with each dimension, learning activity strategies and GDPs (separated by a dotted line) are shown on the upper side of the figure

Spatio-temporal dimension

Portable devices, due to their mobility characteristics, are considered as the most appropriate means of exploiting the spatio-temporal dimension. This dimension encompasses characteristics that have both spatial extension and temporal duration. Modern mobile devices utilize this dimension to deliver learners a meaningful and personalized learning experience, by placing them in an authentic learning context anywhere and anytime. Precisely, learning activities, in the form of games, may exist in a situation-based learning environment where learners gain knowledge in authentic contexts. So, in the situated learning paradigm, learning activities apart from involving the learners in a problem-based and/or a case-based m-Learning experience, can engage them in a context-aware u-Learning activity as well. This dimension may be present in different learning scenarios by triggering specific learning activities, and give learners meaningful feedback.Specifically, this may embrace specific learning tasks in order to: (a) deliver specific learning content, (b) provide the learners with information guidelines, (c) utilize learners' self-assessment activities, (d) support group and collaborative learning, etc. Wang (2004) describes the aforementioned dimension as the information being gathered from the interaction of learners and the application that is related to both place and time.

Learning in physical space by observing a real object (*Real object observation*), is a learning activity strategy that is met in various mGBL applications for addressing mobile and ubiquitous, and/or context-aware learning experiences. An example of this situation was given by Sánchez et al. (2006) who developed a situated mGBL application named *BuinZoo* in order to support learners' navigation in a zoo. The application consists of two games. In the first one, named *At the ZOO*, a virtual map, similar to a real zoo, is displayed on the mobile device screen for providing learners with the necessary information. Specifically, when the learner is in the zoo, she uses the virtual map to move around and receives relevant information about the animals. For instance, she is informed about the physical location of an animal's cage, and answers questions that help her to recognize it.

Blatannkoden Ceipidor et al. (2009) is a mobile game that involves a treasure hunting scenario. It has been designed to assist secondary school students to physically navigate and explore a museum (or any tourist place). In this game, the QR code ubiquitous characteristic is enabled for blending the game learning scenario with the proximity pattern. The players must decode a sequence of riddles by scanning the relevant QR codes scattered around the museum, which in turn lead them to find the exhibited object. Games that engage treasure hunting based on QR codes are also found in the literature in the fields of science and technology with *EDUC-MOBILE* (Herrera and Sanz 2014), and English language learning with *HELLO* (Liu et al. 2010). These two games trigger certain educational activities, such as question answering, upon proximity with certain artifacts tagged with QR labels, while a learner is moving around in a certain physical space. According to the authors, this ilk of games cultivates to learners the feeling of amusement.

Moreover, Jegers and Wiberg (2006) made an attempt to engage learners in daily life activities by playing a 3D pervasive game named *SupaFly* using mobile devices. According to the authors, a game play needs to fulfill the following three goals: *place-independent play, integration between physical and virtual worlds and social interaction* among the players. The game constantly tracks players' geographical location so as to make the necessary connections between the physical and the virtual world. Upon game start, several virtual objects (clothes, shoes, etc) are distributed at various locations in terms of geographical coordinates in the physical environment. Next, the game continuously calculates players' geographical position through GPS or other means of triangulation. These positions are used to enhance the players' awareness about their surroundings and establish potential face-to-face meetings among the participants.

Observations of the learning environment is another context-aware learning activity strategy explored in various mGBL applications. An example of this situation that self-motivates learners by stimulating and instilling environmental awareness is explored in

Savannah (Facer et al. 2004). This game has been designed to teach students about how an animal behaves within its physical environment as well as how it could survive under specific environmental conditions. In this game, the learner senses the feeling of immersion while operating in both a real and virtual world where the animal inhabitants are digitally reproduced. Students send their GPS positioning data in real time, hear specific sounds of wildlife via their headphones, observe still images from animals and the surrounding environment, and "feel" the scents of the current geographical zone through pictures (*player-location proximity* pattern).

Another context-aware u-Learning activity strategy that is met in various mGBL applications is that of *identification of a real world object*. An example of this situation is *ZooQuest* (Veenhof et al. 2012) used to support the literacy development of English language at primary school level. In the game scenario, students learn English by taking the role of a zoo visitor with the main objective to help the zookeeper track down the allegedly escaped animals. That is, the students move around a virtual zoo to search for an animal. When an animal is found, the student watches a video with the necessary learning information (guided online material). After that, a mini-game starts (e.g., *Jigsaw puzzle, Memory, Multiple choice quiz, Spelling quiz, Yes or No*). In order for a student to catch the animal and return it to its cage, she needs to answer correctly three questions in a row in the English language.

Data collection in the real world via observations learning activity strategy is identified in several mGBL applications. In *REXplorer* (Ballagas et al. 2007) for example, the players are encouraged to take photos and videos from their surroundings and automatically upload them to a blog. Also, in the game by Wang et al. (2011), a group of students contribute a solution to a specific problem along with relevant information material (photos, video, audio clips) and upload them to a server using a wireless data connection.

The role-play environmental learning game *Sick at South Shore Beach* (Mathews et al. 2008) is another example of this situation. Specifically, this game assists students to learn in physical space, while observing, searching it and/or possibly collect real data. That is, the aim of this game is to prompt learners into investigating the bacteria living on sand grains in a sandy beach and conclude on the diseases that these may potentially cause to humans. Thus, the students are equipped with a GPS-enabled device and visit a particular inshore area to collect data (samples) under a specific environmental scenario. After analyzing the data, they arrive at a final decision about the current situation in the beach and the illnesses that may cause to the visitors. The AR technology is used by the application towards providing students with further information regarding the places visited and the current special conditions needed for simulating a hypothetical health crisis. Unfortunately, it is not made clear by the authors if the data collection is done via a wireless sensor or other equipment.

The activity strategy of *Problem-solving via experiments* is also found in a few mGBL environments. For instance, as previously discussed, *EcoMOBILE* (Kamarainen et al. 2013) combines learning in physical space with AR in order to assist middle-aged school students to understand different concepts and perform experiments related to the physical space. This type of activities is sure to be greatly assisted by Internet connectivity because it allows learners to acquire further information and hints about the examined concept. However, in *EcoMOBILE* this is done without using the ease of Internet access. Instead, the experiments are implemented by collecting data and getting familiarized with water quality measurements and common factors between biotic and abiotic at designated AR hotspots.

Learning in the real world with online support and guidance is the last activity strategy that we identified in various mGBL applications. Hwang et al. (2008) argued that in order for a learning environment to provide a context-aware learning experience, it must automatically support learners by utilizing *personal profiles, portfolios and real-world data collected by the sensors*. In this context, Brown et al. (2006) developed *Massey Mobile Helper*, to support learners' navigation during their orientation/exploration days at a university. The application continuously tracks learner's physical position using GPS. When a player is in proximity with a specific location in the University (laboratory, library, etc.), the application delivers her contextual information, say, proposing video lectures, courseware material, laboratory sessions that is relevant to the learner's geographical position and personal profile kept at the server side. A similar mGBL application was developed by Wang et al. (2011) with the aim of supporting self-directed orientation within a university campus. This game can be used as an indoor or outdoor activity in a given physical space. In the outdoor scenario, after logging in the system, the learner's profile and GPS are used for informing the player on how to get to the happening places, or other pre-scheduled activities within the campus.

Another example of this situation is *MobileGame* (Schwabe and Göth 2005). This game supports both individual and team player mode, and triggers specific events when the player is in proximity with a place of interest. In the single player mode, students act individually or cooperate in small groups to get familiar with the university premises. During this orientation rally, there is different contextual information being sent to the students' mobile devices, based on their physical position. Such information pertain to university's daily life, including important places, major events, and so forth.

Also, in *REXplorer* (Ballagas et al. 2007) the player explores sightseeings and places of special historic interest. If an interesting historical place is in proximity, a *heart-beat* appears on the smartphone triggering vibration and an alerting sound. Then, the player holds down a *figure* button and a *tornado* image appears on the touchscreen indicating the preparation progress of a specific gesture. This gesture corresponds to a well-known historical person. When the figure is finalized, it appears on the device screen and talks providing the user with further historical information about that place.

Another example of this situation is *MEL*, developed by Sandberg et al. (2011) to support English language learning. This game tracks learners' physical position via GPS and triggers certain educational activities to an individual or group of learners, including question answering upon proximity with a certain artifact. *Savannah* (Facer et al. 2004) mGBL application also belongs to this category. This game was designed to teach students on how an animal behaves within its physical environment as well as how it could survive under specific environmental conditions. During the game play, the application keeps logs of learner's movement in order to receive supplementary learning material, and therefore enables her to obtain a clearer understanding and develop new strategies on how, for example, a lion could better survive in its physical environment.

A quite similar approach is met in mGBL applications that combine spatio-temporal characteristics with different ubiquitous technologies (including AR) in their game scenarios. The AR technology enables learners to participate in learning activities in the real world by creating a contextualized fictional layer on top of the real world context. While these games provide navigation and hot-spot information, certain AR-driven games combine physical space with virtual space, which augments the former according to specific contexts. Thus, virtual reconstructions of historical/archaeological sites provide a mixed reality setting for games such as the try-catch game *Explore* (Costabile et al. 2008). This is a team-based excursion game called to stimulate and assist middle school students during their visit to an archaeological park. A similar work is called *Frequency 1550* (Huizenga et al. 2009). This game is destined to help learners to navigate in medieval Amsterdam. The *TimeWarp* game (Herbst et al. 2008) is an analogous approach introduced for discovering the history of the city of Cologne in Germany. Other games in this category are *Mad City Mystery* (Squire and Jan 2007) for supporting environmental learning and *EcoMobile* (Kamarainen et al. 2013) for assisting middle-aged school students to understand topics related to the physical ecosystem.

It is to be pointed out that the majority of mGBL applications included in the work at hand combine different learning activity strategies for delivering learners a context-aware u-Learning experience. For instance, *ZooQuest* discussed previously in this section, utilizes both *"learning in the real world with online support and guidance"* and *"identification of a real world object"* learning activity strategies with the aim of guiding the learner to identify an animal in the real world.

Summary of spatio-temporal characteristics and strategies

Based on the list of mobile GDPs proposed by Davidsson et al. (2004), we have identified the following design patterns that actual mGBL environments have incorporated in different learning scenarios:

- *Augmented Reality.*
- *Creation and maintenance of learner's profile.*
- *Extra-Game Information*: These are instructions to the players regarding the game play.
- *Physical Navigation.*
- *Proximity between the player and a physical place (player-location proximity).*
- *Proximity between a player and an artifact (player-artifact proximity).*
- *Gain Information*: Searching information in different places.
- *Predefined Goals.*
- *Common Experience.*

The aforementioned patterns are closely related to the learner's contextual information in the physical space during the time. When implementing an m-Learning or a context-aware u-Learning environment, the functionality of physical navigation and proximity patterns posits that users' context information must be continuously sensed during the learning process. This is practically implemented by utilizing the various ubiquitous computing location-based technologies and devices, e.g. sensors, GPS, SMS, RFID, NFC, or other means of wireless communications.

Moreover, augmenting the physical space and blending it with several ubiquitous technologies, such as the Quick Response (QR), AR, etc, is generally known to give further value to the learning process (Liu et al. 2010; Kamarainen et al. 2013). For instance, an mGBL activity triggers an event when the learner is in proximity either with a specific artifact or with another player by using fiducial markers (*Predefined Goals*), and by elaborating a QR tracking service. These functionalities are considered as added-value techniques that better engage and self-motivate students in the learning process, enhance critical thinking and problem solving skills (Kamarainen et al. 2013), with better results on the learning outcomes.

As previously discussed, there are a variety of mGBL scenarios that utilize the aforementioned GDPs from different perspectives, such as chase and catch, or treasure hunting game scenarios. Thus, we summarize below the learning activity strategies as proposed by

Hwang et al. (2008) that we identified in the discussed mobile game applications. These are associated with:

- *Real object observation.*
- *Learning in the real world with online support/guidance.*
- *Collect data in the real world via observations.*
- *Problem-solving via experiments.*
- *Identification of a real world object.*
- *Observations of the learning environment.*

To sum up, when designing and developing a context-aware mGBL environment, there are various learning activity strategies that are proved to bring along vital motivational qualities from a learner's viewpoint. For instance, in a situation-based mGBL scenario, physical navigation is considered a factor that positively motivates learners (e.g., by enabling confidence, satisfaction, attractiveness). A characteristic example of this situation is *Frequency 1550* (Huizenga et al. 2009.

Another finding that must be discussed is whether or not an mGBL application utilizes the following two characteristics of the spatio-temporal dimension in different learning activity strategies. Based on our analysis, augmenting the space and the time is not always applicable in the learning scenarios. So, we consider that the *spatio-temporal* dimension includes the following distinct extensions:

- *Spatially enhanced* This includes learning environments that place the learner in an authentic learning context in current time and physical space. This is especially applicable to learning domains where only the spatial characteristics (and not the temporal ones) are virtually augmented in the learning scenarios. For instance, in the mathematical domain, *MobileMath* (Wijers et al. 2008), discussed in "Collaboration/social dimension", augments only physical space characteristics for teaching the learners mathematical concepts. This is done by having the players to virtually draw 4 vertex shapes, namely squares, rectangles, and parallelograms.
- *Spatio-temporally enhanced* It includes learning environments that place the learner in a specific authentic learning context in the time, say, a historical place. Consequently, this is applicable to learning environments where both space and time characteristics are augmented in the learning scenarios. For instance, as already pointed out in the current subsection, *Frequency 1550* (Huizenga et al. 2009) augments both spatial and temporal characteristics for assisting the learner to navigate in medieval Amsterdam.

Collaboration/social dimension

Common team experience, collaboration, and communication are considered important ingredients to students' learning development (O'Donnell et al. 2013). These factors may be utilized by a mobile and ubiquitous environment, and specifically by a context-aware intelligent learning one, to enhance students' learning skills, including teamwork, social skills, cooperative skills, and development of critical thinking. Within this context, learning and context awareness in an m/u-Learning environment may be supported when the learners act independently or collaborate in groups in a community, using different mobile technologies and communication facilities.

The interaction and the status among the participants *constitute complex social contexts* in which numerous learning activities may exist (Wang 2004). These activities include learner's attendance and active participation in common learning experiences, peer discussions inside or outside a community, group collaboration, and others. Thus, the introduction of collaborative activities in an mGBL environment is well known to not only enhance knowledge acquisition, but also foster the development of several skills. This is in addition to those discussed above, such as self-direction learning, problem-solving skills, peer assessment, and socializing.

During the aforementioned types of engagement, learners are motivated to participate in skill-based learning activities by using specific communication channels in order to interact with peers. So, in different learning settings, there are various educational activities that an mGBL application may embed so as to deliver learners a context-aware learning experience. For instance, in the constructivist learning paradigm, there are various u-Learning activities in which a student is involved in a collaboration within a community in order to learn by doing and construct knowledge for herself.

Regarding the Collaboration/Social dimension, the first learning activity strategy we identified in the works included in this paper is *Collaborative problem solving*. For instance, Wijers et al. (2008) emphasized on problem solving in the physical space through teamwork. That is, the authors developed a group-based mobile game, namely *MobileMath*, where 8 teams are equipped with a mobile device and scattered to a certain, predetermined physical area. There, each team needs to score as many points, as possible by drawing 4 vertex shapes (squares, rectangles, parallelograms). This is achieved by calculating the proximity between players, using GPS, and by instructing the team's members to walk towards a selected area (*Learning in the real world with online support/guidance* strategy). The completed shapes are shown on the mobile screen for inspecting the final result. If the outcome matches one of the aforementioned vertex shapes, then it is drawn on a virtual map and it is flagged with the specific team's color, so as to be visible to the other teams. Similarly, *BuinZoo* (Sánchez et al. 2006) discussed in "Spatio-temporal dimension", contains a sub-game, named *The evolution game*. In this sub-game, groups of 4 learners must cooperatively solve a problem regarding the colonization of 3 species, among 4 classes (fish, amphibians, reptiles and birds).

MobileGame (Schwabe and Göth 2005) also falls under the umbrella of the Collaboration/Social dimension. Recall from "Spatio-temporal dimension" that this game supports both individual and team players mode. In the latter mode, students (or even teachers) cooperate in small separate groups in order to exchange information and get familiar with the university premises. Also, the *proximity among the players* pattern is a decisive factor for the social interaction achieved through the game and specifically for the implementation of a chase and catch type of sub-game based on specific hunting rules. That is, the players intend to reach and catch other group players in the physical area, while simultaneously being hunted by others. The same observations stand true for the team-based excursion games designed by Costabile et al. (2008) and Huizenga et al. (2009). The learners are collaborating in teams, and play these games with the aim of acquiring common knowledge about a historical place.

Also, in the mGBL application introduced by Wang et al. (2011), the students are informed for nearby players in order to meet with others and get socialized. The game offers various communication channels such as a chat room and memo book for supporting students' discussion with peers, to schedule activities, and collaborate with other players. A similar approach is followed by *EDUC-MOBILE* (Herrera and Sanz 2014). This game enables inter-team communication via SMS or phone calls aiming at exchanging pieces of data that will help them accomplish a task.

Squire and Jan (2007) proposed a group-based game named *Mad City Mystery* in which players are encouraged to exchange and share information, synthesize, and communicate for the purpose of debating about a scientific topic with other group members. According to the authors, this enables learners to *develop scientific argumentation skills*. *Human Pacman* Cheok et al. (2004), *BuinZoo* (Sánchez et al. 2006), *Evolution* (Sánchez et al. 2007), *MobileMath* (Wijers et al. 2008), *MEL* (Sandberg et al. 2011), Wang and Lai (2011), and *ZooQuest* (Veenhof et al. 2012) are very similar mGBL applications correspondingly in the fields of technology, mathematics, biology, music, place exploration, and English language.

The use of communication channels is also explored in *Mobile Rhythm Learning System (MRLS)* music game (Wang and Lai 2011). This game supports single or two-player gaming experience with the aim of assisting elementary school students in acquiring rhythm skills, which are considered a fundamental task at the first stages of learning music. In the two-player game mode, the players connect with peers through a Bluetooth communication channel and collaborate in order to assemble a given song.

Unmediated social interaction describes any type of communication that takes place among players, without the (m)GBL application to restrict the content being exchanged. In this kind of communication, several actions may happen between the learners, such as the publishing of informational material during or after their engagement with the application. For instance, *REXplorer* (Ballagas et al. 2007) offers a communication channel for an unmediated social interaction among the learners. Specifically, players are being socialized while using a blog that enables them to indicate their location on Google maps. After observing an interesting place, the players can publish to the blog relevant material such as photos and videos being collected during their exploration.

Similarly, *SupaFly* (Jegers and Wiberg 2006) enables players to send SMS commands for establishing or maintaining a relationship with others. This interaction allows them to gain game points and improve their social status. To succeed such a connection, a custom SMS LOOK command is being executed when a player wishes to find another one to interact with. Then, as a feedback, the game provides a list of nearby players. The aim of the game is for the players to achieve the highest level of social status within the community and ultimately become a *"SupaFly"*.

Situated learning activities that take advantage of the environment observation (*real object observation*) and data collection u-Learning activity strategy through collaboration (*Collect data and Problem-solving via experiments in the real world*) are also explored by mGBL applications. For instance, the works *Sick at South Shore Beach* (Mathews et al. 2008) and *EcoMobile* Kamarainen et al. (2013) enable collaboration among the players in order for them to co-work and be engaged in problem solving activities in the environmental field. The students learn in physical space, while observing, searching and collecting real data.

Summary of collaboration/social characteristics and strategies

Depending on the usage of the *communication channel* (as a GDP) and the way it is embodied in each mGBL application, the channel could be described as independent or relevant to the game states or instances (Davidsson et al. 2004). Based on this work, we identified the following GDPs that the discussed mGBL environments may possess with the aim of realizing different learning scenarios.

– *Chat forum* It corresponds to a communication channel which is independent of the game rules.

- *Communication channel* It describes a relevant to the game rules channel, which for example may be used to provide the learner with *indirect information* regarding the current game state.
- *Extra-game information* These are instructions to the players regarding the game play.
- *Proximity among the players (player-player proximity).*
- *Social interaction* The player can meet face-to-face with their co-players in order to communicate and accomplish a learning task.
- *Unmediated social interaction* It describes the communication between peers, via external channels controlled by the game rules. This could be for example a website, a blog, etc.
- *Collaboration Actions.*
- *Team Play.*
- *Common Experience.*
- *Predefined Goals.*

As previously discussed, there are a variety of mGBL scenarios that utilize the aforementioned GDPs from different perspectives. Thus, we summarize below the learning activity strategies as proposed by Hwang et al. (2008) that we identified in the discussed mobile game applications. These are associated with:

- *Collaborative problem solving.*
- *Collect data in the real world via observations.*
- *Learning in the real world with online support/guidance.*
- *Problem-solving via experiments.*
- *Real object observation.*

Concluding, there are various means with which an mGBL application may deliver mobile and context-aware u-Learning experiences to the learners. This is usually done by motivating players to use a communication medium in order to interact with peers and get socialized through different strategies, such as the chase and catch type of games. Also, in many cases, mGBL applications combine collaboration and group formation with spatio-temporal activities as presented in this subsection. Finally, our analysis shows that from the total of 36 surveyed games, 12 of them elaborate collaboration activities in their learning strategy.

Session dimension

A GDP that is definitely well-suited in mGBL applications is that of *Quick Games*. This GDP is considered to provide strong motivational characteristics to the learners (Jonker et al. 2009). In the literature, quick games are used to deliver *burst-knowledge experience* to the students (Giannakas et al. 2016). This kind of games are also known as casual or mini-games and combine characteristics including short and flexible time duration (quick session), easy access through quick screens, and others. For example, pop-quizzes, simulations, and puzzles are types of quick games that are considered in mGBL scenarios with the aim of making the learning process more attractive from a learner's viewpoint.

As already discussed in "Spatio-temporal dimension" and "Collaboration/social dimension", this GDP is incorporated in *MEL* (Sandberg et al. 2011). This game is destined to the field of foreign language learning and utilizes quick-session games, such as quizzes, puzzles, and questions (with a yes or no answer) in order to assist learners in doing various activities.

Several other works utilize the aforementioned GDP for delivering m-Learning without incorporating any context-aware learning activity strategy. In the subject of chemistry education, Ahmad et al. (2014) designed an adventure mGBL application for high school students named *AKAMIA*. This game focuses on calculation-based chemistry covering fundamental topics such as Formula and Chemical Equation, Periodic Table of Elements, Electrochemistry Acids, and others. In the game, the student moves a virtual hero in a labyrinth full of monsters. When the player attacks on a monster she must answer a number of chemistry pop-quiz questions based on the above mentioned topics. Another example in this category is the *CyberAware* (Giannakas et al. 2015, 2016). This game is devoted to cybersecurity education and awareness and consists of three mini-games for the sake of familiarizing students with fundamental issues regarding cybersecurity technologies. In the first two, the student must gain knowledge about the right use of cybersecurity technologies matching the given technology with its correct usage. The third one is an action game in which learners are challenged to score as many points as they can. The goal of this mini-game is to interlink the knowledge the students acquired after playing the first two mini-games with real-life cyberattack incidents and information security issues. A quite similar approach is followed by *MOBOCity* (Fotouhi-Ghazvini et al. 2009), *MaCMoG* (Shiratuddin and Zaibon 2010), (Martin-Dorta et al. 2010), (Arachchilage and Cole 2011), *SpaceGoats* (Wahner et al. 2012), (Ma et al. 2012), *ZooQuest* (Veenhof et al. 2012), *eMgage* (Bartel and Hagel 2014), *iPlayCode* (Zhang and Lu 2014), *M-History* (Lee et al. 2014), and *Science Soldier* (Tlili et al. 2016) correspondingly for the domains of computer science, environmental learning, history, place exploration, and foreign language learning.

Quick session activities are also witnessed in the so-called Ubiquitous Games for learning (UbiqGames) genre (Klopfer et al. 2012). These are browser-based, casual (simple/quick) games, mostly custom-tailored to the curriculum with the intention to be played occasionally and outside of class time. Perry and Rosenheck (2012) designed a mobile game named *UbiqBio* that comprises a suite of four simple/quick mobile games for teaching biology. This game has been designed to assist high school introductory biology students in understanding rudimentary biology concepts that normally are cumbersome to grasp.

A similar approach is also explored for climate and weather forecasts in *Weatherlings* (Sheldon et al. 2010). This game simulates specific weather conditions. Precisely, the authentic weather data being collected from various cities in the recent past are preloaded in the system. These data are utilized during a battle specially designed for the purpose of the game, where the weather conditions change based on the weather pre-recorded data. As a result, for winning the battle, the players must make weather predictions and change their strategy accordingly.

Summary of session characteristics and strategies

Based on the list of mobile GDPs proposed by Davidsson et al. (2004), we have identified the next design patterns that the discussed mGBL environments have incorporated in different learning scenarios:

- *Extra-game information* These are instructions to the players regarding the game play.
- *Extra-game input* Apart from player's input, the game state also relies on external input.
- *Quick games* Short session games.
- *Score*.

The aforementioned GDPs can be utilized in a variety of mGBL scenarios from different perspectives. Following the methodology of the previous subsections, we identified below the learning activity strategies that each of the examined mGBL applications elaborates with reference to this dimension (Hwang et al. 2008):

– *Identification of a real world object.*
– *Learning in the real world with online support and guidance.*

Following the above analysis, we can safely argue that despite the fact that much effort has been put in addressing m-Learning in various learning domains, context-aware u-Learning activity strategies are not well-explored in session-based mGBL applications.

Personalization dimension

Few will argue that personalization, including online guidance and support, is a crucial adaptation strategy for virtually any learning environment (Cordova and Lepper 1996). Both these sub-issues are useful when the learning environment needs to provide support and feedback to the learner so as to deliver a customized learning experience that will be tailored to their own knowledge, preferences, and goals.

Personalization strategies

In general, a learning environment and specifically an mGBL one, may include one or both of the following personalization strategies:

– *Personalization of learning content that is based on learner's educational background, experience, and preferences.*
– *Personalization of content representation that is based on learner's needs as well as on specific adaptive techniques of the learning objects such as those to overcome limitations of mobile screens, data storage, platforms, etc.*

These two strategies may rely on the following approaches.

– *Controlled by the learner* The learner directly varies the learning content and appearance based on her desires, needs, and preferences.
– *Profile-driven* The learning environment alters the learning content and appearance by utilizing learner's personal data, which are already stored in her profile.

Personalization is becoming more challenging when being applied in a context-aware u-Learning environment. This is because the pieces of data stemming from mobile sensors need to be combined with the learners' profile in order to offer a more personalized learning experience. In this sense, *personalization in context* for addressing customized learning experience also utilizes the data that are relevant to the states of the physical environment, and in general to the context of use (Zimmermann et al. 2005).

The *Massey Mobile Helper* game (Brown et al. 2006) constantly records learner's physical location and other information for creating and updating her profile. After that, based on the personal information gathered, a server delivers to the student personalized contextual data to ameliorate the game experience.

In the literature there are also a variety of mGBL applications that support learners and track their learning curve, by recording quantitative information, say, how much time a learner spent in a task, or whether the learner accomplished it successfully or not, with the aim of providing them customized support. This is mostly done in games that are being played in virtual space, such as in *Weatherlings* (Sheldon et al. 2010) and *UbiqBio* (Perry and Rosenheck 2012). In these games, the players are able to check their personal information, including win-loss record, review results from previous tasks, and so on, while the teachers can track student progress by reviewing the corresponding information collected by the data-logging system. A similar approach is followed by mGBL applications given in Martin-Dorta et al. (2010), *eMgage* (Bartel and Hagel 2014), and *EDUC-MOBILE* (Herrera and Sanz 2014), where the players log in the system for retrieving specific learning material, view their score, control the time spent playing, etc. Also, the work in (Martin-Dorta et al. 2010) provides a front-end that enables the teacher to add or modify the database containing the relevant educational content or the exercises needed for checking students' prior knowledge among others. In the domain of English language learning, *MEL* (Sandberg et al. 2011) builds learners' personal profile in order to support them with custom-tailored learning content.

Summary of personalization characteristics and strategies

As previously discussed, in a context-aware u-Learning environment, data collection from mobile sensors is considered vital for supporting the learning process in a more personalized way. This requires that the application constantly tracks learners so as to capture and record all the exchanged information, update their personal learning profiles, and manage their identity. In this mindset, we identified the next GDPs that should be addressed by an mGBL application:

– *Creation and maintenance of learner's profile.*
– *Personalization of learning content.*
– *Personalization of content representation.* This is a favorable quality to be met by any mGBL application due to certain hardware limitations, including the smaller screen size.

Following the discussion of the existing mGBL works, we summarize below the learning activity strategies that an mGBL application elaborates with reference to the personalization dimension (Hwang et al. 2008):

– *Real object observation.*
– *Learning in the real world with online support/guidance.*
– *Collaborative problem solving.*

To sum up, personalization is a quality that greatly contributes to the effectiveness of any mGBL application, but only a handful of the reviewed works incorporate this characteristic into their design. However, this demands the creation of a learner's profile with data collected during her engagement with the application and contextual data sensed from the physical environment via the appropriate sensors. Wang (2004) identified a dimension named *identity* to describe "context in m-Learning". In this dimension, the learner's profile must be firstly accessed (by means of an authentication method) so as the system to deliver them personalized learning content depending on the particular context.

Data security and privacy dimension

Excluding player authentication and authorization issues, the constant engagement of the mGBL application with the learner generates a variety of personal sensitive data, including the places the player has visited in the past and how long she stayed in each place. So, from a privacy point of view, each mGBL implementation must provide ways of protecting these personal data from unauthorized third parties. That is, gathering, storing and utilizing this information may clash with the learner's wish for privacy and particularly anonymity. In this respect, mGBL applications should include privacy policies that clearly inform the learners about sensitive data collection and usage, and request their explicit consent on it. This necessity becomes more obvious when a learner participates in group-based activities (chat-rooms, blogs, etc) where she may wish to retain her anonymity (Kambourakis 2014).

The utilization of data encryption and integrity mechanisms is also deemed important for any mGBL application. This is mainly due to two reasons. First, to protect any communication against passive monitoring or active kind of attacks, and secondly to safeguard the player's (and sometimes the educator's) personal data stored in databases against unauthorized access. For instance, (Wang et al. 2009a) identified the need of a secured mechanism for sharing information in collaborative environments. Also, the potential interaction of the mGBL application with resources stored in the cloud gives rise to greater worries regarding this dimension.

Further, in modern online game architectures (and especially in massive multiplayer ones) the designers need to take game service availability under serious consideration. That is, outages due to cyber-attacks or other random reasons may bring the game platform to its knees, causing dissatisfaction to the players (refer for example to the PlayStation Network outage issues in 2011).

From our survey, we realized that only a handful of mGBL applications deploy special security and/or privacy-preserving measures. In fact, none of the surveyed works takes into serious consideration all the aforementioned characteristics, except from the user *authentication/authorization* one. The *Massey Mobile Helper* (Brown et al. 2006) uses password-based authentication in order for the learners to log into the system. Similarly, *UbiqBio* (Perry and Rosenheck 2012), and *Weatherlings* (Sheldon et al. 2010) collect students' relevant data to a Web server (*Teacher portal*) for the teachers to overview the student's learning curve. Password-based authentication is also supported in mGBL applications developed by Martin-Dorta et al. (2010), *eMgage* (Bartel and Hagel 2014), and *EDUC-MOBILE* (Herrera and Sanz 2014). That is, both learners and educators are able to log into the system so as to retrieve specific learning material, see their score, and observe other parameters like the time spent during playing, and others.

However, although all the previous games continuously track learners' geographical position and collect data about their learning curve and player-to-player or player-to-game interactions they neglect to cope with user privacy. So, the players are left defenseless, say, against eavesdroppers who possibly track their position, sniff their personal data, and ultimately profile them in the mid or long-run.

Summary of data security and privacy characteristics

Considering the above observations, we propose the following security and privacy characteristics that should be addressed by an mGBL application. Note that here we use the term characteristics instead of GDP because these qualities are neither defined as such in the related literature nor included in the majority of the mGBL applications under study.

- *Identity confidentiality.*
- *Location privacy.*
- *Secure communications (data confidentiality and integrity).*
- *Secure data access and storage.*

– *Service availability.*
– *User authentication/authorization.*

It is to be underlined that while the great mass of applications collect a diversity of private information from the learners, e.g., positioning data, personal preferences, etc., none of them puts forth or even touches upon security or privacy measures. However, nowadays, this dimension is becoming a sine qua non and must not be neglected by any mGBL implementation. Namely, the developers owe to be occupied with issues regarding end-user security and privacy when designing and implementing a context-sensitive mGBL application, especially when this is destined to non security-savvy users. Putting it another way, the users of any mGBL environment should have absolute control over their contextual information and to choose who, when, and for how long will have access to their personal data. This important requirement is further discussed in "Discussion and future challenges".

Pedagogy dimension

Sometimes, within the context of mGBL, there is an obvious rush to implement games for educational purposes. However, in several cases, this haste ends up in poor learning content and goals. More specifically, in respect to the already examined works, we coincide with the opinion of Gunter et al. (2008) that a great mass of game designers simply believe that players/learners are motivated only by the housing of the learning content inside a game. Nevertheless, the educational benefits can be enhanced if the learning environment takes into account several extrinsic, intrinsic, and psychological learner's aspects that arise during the learning process. These can be cognitive aspects, comprising the performance and the history of the learners' behavior, but may also include, in the case of context-aware environments, the "emotional state, focus of attention, and background" of the player (Wang 2004). Therefore, the discussion of the analytical and methodological tools engaged by the designers of the environments under consideration, pertains to the evaluation phase in the life cycle of these games, and not to the utilization of the psychological state as an aspect of the learning context, as conceived by Wang (2004).

Additionally, designers should also consider some other aspects that also influence and steer the design of mGBL environments. These include the age, cultural background and needs, educational level, socio-economic background, learning styles and preferences, etc. This is crucial for the success of the mGBL application, since each participant, depending on the target group that belongs to, has different learning characteristics, styles, and learning preferences. This influences the learning strategy that should be followed, and the level of the selected learning content.

Another important factor that a designer should take into account is the number of the players. Namely, independently of the purpose a game is designed for, it can be very different in its single and multiplayer versions. For instance, a multiplayer game could promote team's collaborative skills given that learners work together to reach a final result. On the other hand, a single player game is considered to promote player's individual skills and increase their self-confidence.

Thus, this last dimension deals with the various pedagogical aspects identified in the surveyed mGBL applications. These aspects can be summarized as follows:

– The educational benefits derived from each mGBL application.
– The methodologies adopted from the authors for assessing and evaluating the pedagogical efficiency of the mGBL applications.

– The learning theories, the number of players, and the target group that characterize the philosophy and steer the design of the game.

Educational benefits and evaluation methodologies

In the literature there exist various research works that focus on different educational benefits that are based on the assessment of various learner's psychological properties such as confidence, satisfaction, stimulation, and attractiveness. Researchers tend to conduct evaluation using methods such as pre/post-questionnaires, interviews, or data collection. Especially the latter method aims at gathering pieces of data relevant to how much time a learner spent in a learning activity, if the given learning task is accomplished or not, measuring performance, and other information for creating the learner's portfolio. After that, research typical conducts in-process evaluations for concluding to certain educational benefits. For instance, *iPlayCode* (Zhang and Lu 2014) aims at teaching the principles of C++ programming language to students of higher education. Within the limited time given, the player should participate in short quizzes, and answer a series of questions regarding the correct syntax of short programming statements. Depending on her answer, the player is being rewarded with points or being penalized with a negative score if the answer is incorrect. The aforementioned results are stored in a database that the teacher may review afterwards so as to conclude to certain educational benefits. Bar chart (A) in Fig. 2 summarizes the evaluation methods used in mGBL works under the umbrella of the survey at hand. Additionally, Table 3 shows each evaluation method used by the various mGBL works.

We have also identified the educational benefits for each reviewed paper, as reported by the corresponding authors. The results are summarized in Table 1. As observed from the table, main educational gains from mGBL applications comprise increasing motivation, self-directedness and self-efficacy, and social and inquiry skills.

Learning theories, target group, and number of players

The creation or amendment of a pedagogical approach by elaborating specific learning theories is the key element for building truly effective mGBL context-aware educational games that focus on specific learning goals. The goal is not only to embed educational content in a game "as is", but also to choose the appropriate underlying learning theories in a way that learners are positively influenced and gain tailored learning experience during their gaming. For instance, the design and implementation of *CyberAware* (Giannakas et al. 2015, 2016) was based on the Attention, Relevance, Confidence, and Satisfaction (ARCS) (Keller 1987) motivational model.

Bar chart (D) in Fig. 2 illustrates the learning theories that drove the design in the mGBL environments under study. In addition, Table 2 summarizes the learning theories for each mGBL, as implicitly or explicitly stated by the authors of each surveyed paper. As seen in the figure and in the table, a variety of learning theories are involved. Unsurprisingly, situated learning provides the theoretical background in the majority of works. This fact aligns with other findings concerning the transition from mobile to context-aware ubiquitous learning (Ogata and Yano 2004; Liu and Hwang 2010). However, constructivism is also applied, as well as behavioristic theories.

Moreover, the definition of the target group is another important pedagogical factor that should be considered when designing a mGBL environment. This is because learners are

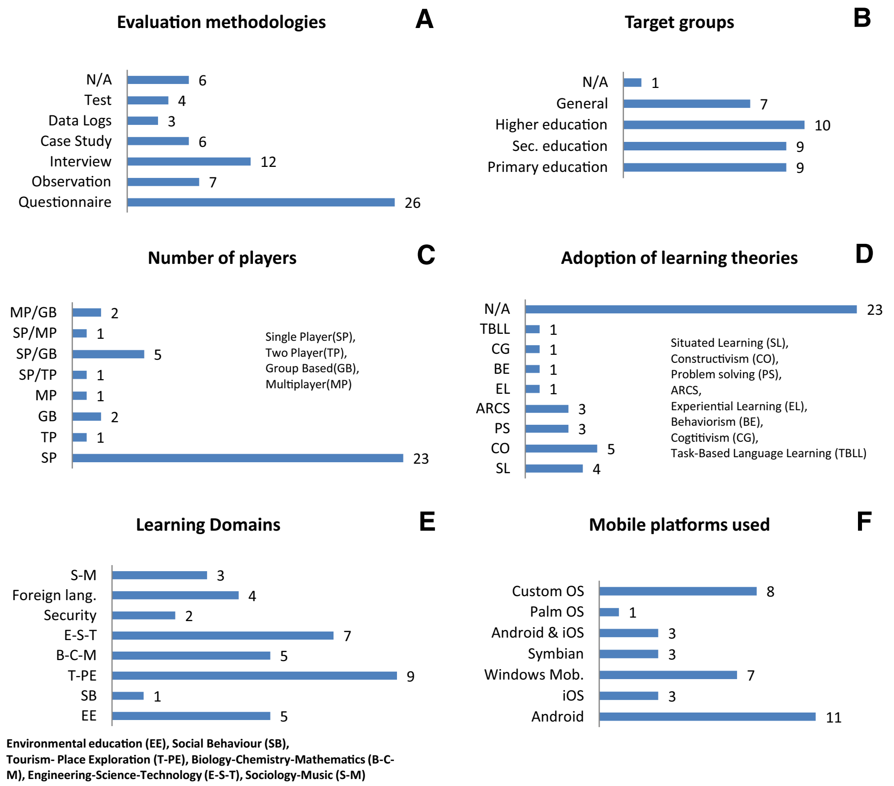

Fig. 2 Key demographics of mGBL apps included in this survey

motivated in different ways. Therefore, to stimulate learners, the learning content should be organized and presented to them in different ways, based on their special characteristics. Bart chart (B) in Fig. 2 illustrates the mGBL applications' target group, based on learners' educational level. These findings show that 9 games are destined to primary education, 9 to secondary education, 10 to higher education, 7 to general education, and 1 is unclear.

Finally, considering the number of the players, bar chart (C) in Fig. 2 illustrates that from the total of 36 mGBLs apps, 23 are single player, 1 multiplayer, 5 are designed as single player and group-based, 2 are multiplayer and group-based, 2 are group-based, 1 two-player, and 1 single player and multiplayer. Also, *MRLS* (Wang and Lai 2011) described in "Collaboration/social dimension", supports both single and two-player gaming.

Summary of pedagogy characteristics

Summarising the educational gains of mGBL, as reported mainly by the authors of the environments that were reviewed in this paper, we see that the main benefits lie in the affective domain. More work needs to be done for investigating potential cognitive gains from mobile games and context-awareness. Moving learning in new contexts implies the creation of specific learning activity strategies that will incorporate learners' contextual information and produce new knowledge towards improving their learning outcomes. In

Table 1 mGBL GDPs and educational benefits

GDP def.	App. name	Educational benefit(s)
Physical navigation (To successfully play the game, the player needs to roam in the physical space)	Blatannkoden	Participants are engaged and "feel amused" during museum exploration
	BuinZoo	Learners are motivated by participating in "playful activities", in order to simulate specific biological conditions through the discovery of species' evolution at a zoo
	EDUC-MOBILE	Learners are motivated by feeling satisfaction after collaboratively solve problems on specific science and technology topics.
	Explore	Participants are stimulated and engaged in acquiring historical knowledge for an archaeological park in an exciting and efficient way
	Frequency 1550	Learners are engaged and feel amused when acquire historical knowledge
	HELLO	Players feel excited when participate in a campus tour game and learn about it
	Human Pacman	Participants are "socialized" when they actively participate in physical action game (tap on other participants' shoulder)
	Massey Mobile Helper	Participants feel "confidence, satisfaction and attractiveness" when exploring daily university life
	MEL	Learning become more "effective and efficient" since the participants learn the English language when exploring the animals at a zoo
	MobileGame	Participants feel fun when exploring daily university life
	MobileMath	Learners move in the physical space and shape 4 vertex shapes in order to be engaged and learn about mathematics
	N/A (Wang et al. 2011)	Participants learn how to be "shelf-directed" in and around the university premises
	REXplorer	Participants are engaged in a place exploration in order to learn about its history
	SupaFly	Players develop social skills
	TimeWarp	Participants gain historical knowledge about a city

Table 1 continued

GDP def.	App. name	Educational benefit(s)
	Savannah	Learners are motivated when learning about animals' behavior, and their survival in specific environmental conditions
	Sick at South Shore Beach one	Participants are motivated by the "mystery nature" of the game, and "feel like working in an authentic case" while examining the bacteria living on sand grains
Player-location proximity (The geographical distance between the player and a certain physical location is an aspect which can affect gameplay and trigger further events in the game)	Human Pacman	Players pick up a treasure box located somewhere in the physical space
	MEL	Students locate the places where the cages of the various animals are in order to play a mini-game or answer a series of questions
	REXplorer	When a learner is in proximity with a historical site of interest, then further historical information is displayed on the mobile screen
	Explore	When learners is in proximity with a historical site of interest, they receive guided information that helps them to acquire historical knowledge
	Frequency 1550	When a learner is in proximity with a historical site of interest, she receives and watches pre-recorded video messages figuring medieval characters. Then, she prepares and sends back answers to certain assignments
	Savannah	Students hear specific sounds of wildlife via their headphones, see still images of animals and the surrounding environment, and smell the "scents" of the current geographical zone via pictures
	Sick at South Shore Beach	Learners investigate the bacteria living on sand grains after visiting a particular inshore area to collect data samples
	TimeWarp	When a learner is in proximity with a place of interest, she receives historical information about it
Player-player proximity (The geographical distance between two players is a factor which can affect the gameplay and trigger further events in the game).	Human Pacman	The player physically taps on enemy's shoulder to obtain virtual objects

Table 1 continued

GDP def.	App. name	Educational benefit(s)
	MobileGame	Learners get informed about nearby players in order to meet each other, cooperate and/or exchange information. Additionally, learners participate in a chase and catch type of game based on specific hunting rules
	N/A (Wang et al. 2011)	Players are informed about nearby students
	SupaFly	Players establish face-to-face meetings with others in order to develop social skills
Player-artifact proximity (The geographical distance between the player and a certain artifact is a factor which can affect gameplay and trigger further events in the game)	Blatannkoden	Players scans QR codes to locate and explore a museum
	EDUC-MOBILE	Learners scan QR codes which correspond to certain questions that need to be answered
	HELLO	Learners use their mobile devices to read the corresponding QR tags
	Mad City Mystery	Learners develop investigation and inquiry skills
	Massey Mobile Helper	Learner's current geo-position is tracked within the university premises and contextual information is displayed to her
	MobileMath	Learners draw 4 vertex shapes ("squares", "rectangles", or "parallelograms")
	N/A (Wang et al. 2011)	Learners schedule activities within the university campus
	Savannah	Students are able to receive supplementary learning material for obtaining a clearer understanding about animal behavior
	SupaFly	Players increase their awareness about their surroundings
Augmented reality (The player's perception of the game world is created by augmenting the player's perception of the real world)	EcoMOBILE	Learners are engaged in field trip experiences and cultivate skills such as self-directed learning, independency, and self-efficacy
	HELLO	When approaching a physical place, players receive contextual information
	Sick at South Shore Beach	Biology-focused. Learners investigate the bacteria living on sand grains after visiting a particular inshore area to collect data samples

Table 1 continued

GDP def.	App. name	Educational benefit(s)
	TimeWarp	Learners receive augmented information about the visited place
Communication channels (Using mobile devices, learners may find alternative communication channels with which can communicate the status of the game state instead of just using the game device. Also, such communication channels may provide players with indirect information about the game state)	Mobile Rhythm Learning System (MRLS)	Students connect with others via Bluetooth in order to collaborate on music projects
	TimeWarp	The player uses a wireless connection for retrieving the necessary information from an online server, including guidelines, game's remaining time, and other digital tools. This material will help the players to complete their learning tasks
Chat forum (A communication channel independent of game instances where players can talk to each other about the game)	EDUC-MOBILE	Players communicate with each other to exchange any information that will help them to answer a given question pertaining to a science and technology topic
	N/A (Wang et al. 2011)	The player communicates with others to accomplish a given task
Unmediated social interaction (The game allows players to communicate outside the channels controlled by game rules)	REXplorer	Players collaboratively involved in social activities and publish information to a blog
Quick games (Games that are short, concise and typically fun. They are a good fit for mobile games given that the latter are played casually and on-the-go)	AKAMIA	Chemistry-focused. The learners must answer short pop-quiz questions
	CyberAware	Data security and privacy oriented. The goal is to familiarize the students with cybersecurity issues and raise their security awareness
	eMgage	Learners are engaged in quick game activities and are motivated to learn about software engineering topics
	iPlayCode	Learners are engaged and motivated to learn about software engineering topics
	MaCMoG	Learners are engaged in quick games activities related to social behavior and the environment
	MEL	Learners are motivated to practice English language
	M-History	Learners learn history after playing 5 mini-games and answering a quiz
	MOBOCity	Learners are engaged in a short session adventure game to learn about engineering concepts

Table 1 continued

GDP def.	App. name	Educational benefit(s)
	Mobile Rhythm Learning System (MRLS)	Students are engaged in short session games to learn about music topics
	N/A (Arachchilage and Cole 2011)	Learners develop critical thinking about information security and awareness
	N/A (Ma et al. 2012)	Learners practice and test their knowledge in English language
	N/A (Martin-Dorta et al. 2010)	Learners are engaged in game activities and get familiarized with engineering topics for developing "spatial-skills"
	Science Soldier	Computer architecture focused. Learners feel satisfied and being motivated to learn computer architecture
	Space Goats	Software engineering focused. Learners are engaged in short session game activities
	UbiqBio	Biology-focused. Players are engaged in short session game activities
	Weatherlings	Players are engaged in short session game activities in order to learn about environmental concepts
	ZooQuest	English language oriented. The learners are engaged in short session games
Collaboration (Some goals can only be reached though a collaboration action executed by two or more of the players. Collaboration forces players of a mobile game to co-work in order to make progress in the game. This allows people who have never met before to cooperate on shared objectives. This includes but is not limited to the action of simply being at the same location at the same time or attacking a target simultaneously)	Explore and Frequency 1550	Learners cooperate in teams in order to gain historical knowledge
	BuinZoo	Biology-focused. The students develop problem solving skills
	EcoMOBILE	Learners in pairs are engaged to problem solving activities pertaining to environmental education
	EDUC-MOBILE	Learners are engaged in learning science and technology activities
	Evolution	Biology-focused. Learners are involved in problem-solving activities
	Human Pacman	Players are engaged in physical activities and develop social skills

Table 1 continued

GDP def.	App. name	Educational benefit(s)
	Mad City Mystery	Learners develop scientific argumentation skills
	MEL	Learners are engaged in practicing the English language
	MobileGame	Players meet each other, exchange information and get familiar with university premises. Also, groups of players cooperate in a chase and catch type of game based on specific hunting rules
	MobileMath	Learners are engaged in learning mathematics
	Mobile Rhythm Learning System (MRLS)	Students develop social skills while interacting with music projects
	Sick at South Shore Beach	Payers are engaged in hypothetical environmental scenarios

this section, we have identified how such strategies are implemented by existing mGBL applications by utilizing mobile games characteristics and GDPs. The systematization of such strategies would possibly require "new modes of learning which in turn involve new pedagogies" (Hwang et al. 2008).

Trends in mGBL environments

In this section, we discuss RQ6 that deals with several aspects of the mGBL environments, intending to synthesize and present the different trends in this evolving area.

Learning domains and technological characteristics

The characteristics of the mGBL applications that address RQ6 (a), (b), (c), (d), and (e) can be summarized as follows:

- The learning domains that have been applied in the surveyed mGBL games.
- The mobile platforms in which mGBL applications are deployed to.
- The type of system architecture (ad hoc or client/server) that is used in the surveyed mGBL games.
- The type of the learning environment (physical world, virtual world, etc.), that have been applied in the surveyed mGBL games.

The mGBL systems that were analysed in this study address a variety of learning domains. More specifically, bar chart (E) in Fig. 2 illustrates that 5 games are destined to environmental learning, 9 to tourism and place exploration, 5 to biology/chemistry and mathematics, 7 to engineering, 2 to information security, 4 to foreign language, 3 to sociology/music, and 1 to social behavior. It can be said that while there is not a great

Table 2 mGBL applications according to their main characteristics

App. name	Players	Services, technologies, content	Learning theory	Collaborative—cooperative
AKAMIA	SP	VO, QB, UB	Behaviorism, Cognitivism, Constructivism	No
Blatannkoden	SP	QR, Bluetooth	N/A	No
BuinZoo	SP, GB	DM, QB	Problem solving, Constructivism	Yes
Blind for review	SP	MG, QB	ARCS motivational theory, Problem solving	No
EcoMOBILE	TP	GPS, AR, DM	Situated learning	Yes
EDUC-MOBILE	MP	GPS, QR, SMS, VC, CR, MR, QB	N/A	Yes
Evolution	SP	Simulation, VO	Constructivism, Problem solving	Yes
eMgage	SP	QB, UB	N/A	No
Explore	MP, GB	GPS, DM	N/A	Yes
Frequency 1550	MP, GB	GPS, C, VC, DM	N/A	Yes
HELLO	SP	C, QR, AR, WiFi, DM, WB	ARCS motivational theory, Task-Based Language Learning (TBLL)	No
Human Pacman	SP	GPS, Bluetooth, VC, WiFi, DM, VO	N/A	Yes
iPlayCode	SP	VO, QB	Experiential learning	No
MaCMoG	SP	VO, WB, ST	N/A	No
Mad City Mystery	GB	AR, VO, RP	N/A	Yes
Massey Mobile Helper	SP	GPS, Bluetooth, DM	N/A	No
MEL	SP, GB	GPS, VO, MR, MG	N/A	Yes
M-History	SP	VO, MG, RP, ST, QB, UB	Constructivism	No
MobileGame	SP, GB	GPS, C, AR, WiFi, DM	N/A	Yes
MobileMath	GB	GPS, DM, VO	Situated learning	Yes
MOBOCity	SP	Simulation, VO	N/A	No
MRLS	SP, TP	VO	N/A	No
REXplorer	SP	GPS, C, VO, DB, ST	N/A	No
Savannah	SP	GPS, C, VO, MR	N/A	No
Science Soldier	SP	MG, QB	N/A	No
Sick at South Shore Beach	SP	GPS, AR, DM	Situated learning	Yes
Space Goats	SP	Simulation, VO	N/A	No
SupaFly	SP, GB	SMS, GPS, VO	N/A	No
TimeWarp	SP, MP	GPS, AR, Bluetooth, MR, DM	N/A	No

Table 2 continued

App. name	Players	Services, technologies, content	Learning theory	Collaborative—cooperative
UbiqBio	SP	Simulation, VO, WB	N/A	No
Weatherlings	SP	Simulation, VO, WB	N/A	No
ZooQuest	SP	RP, Video, MG, QB	Constructivism	No
Arachchilage and Cole (2011)	SP	Simulation, VO	N/A	No
Ma et al. (2012)	SP	VO, Cards	N/A	No
Martin-Dorta et al. (2010)	SP	VO (2D, 3D Objects)	N/A	No
Wang et al. (2011)	SP, GB	3G, GPS, DM, CR, MB, VO, MR, WiFi	Situated Learning	No

VO virtual objects, *DM* digital maps, *VC* video call, *QR* quick response code, *AR* augmented reality, *SP* single player, *GB* group-based, *MP* multiplayer, *TP* two-player, *C* camera, *WB* web-based, *DB* discussion blog, *ST* storytelling, *MG* mini-games, *RP* role play, *CR* chat room, *MB* memo book, *MR* mixed reality, *VC* voice call, *QB* question-based, *UB* quiz-based, *3G* third generation of mobile telephony

number of works for this year span, the interest in this area is constant and is anticipated to grow as mobile technology evolves.

Regarding application porting in different platforms, bar chart (F) in Fig. 2, illustrates that 11 games are ported to Android OS, 3 to iOS, 7 to Windows mobile OS, 3 to Symbian OS, 1 to Palm OS, 8 to Custom OS, and 3 to both Android and iOS. It is also to be noted that none but one of these mGBL applications has been ported to newer or diverse versions of mobile platforms. This is however quite expected having in mind that the porting of, say, an iOS application to Android is not straightforward and requires a great deal of effort devoted to both coding implementation and testing. In this direction, cross-platform implementation as that in *CyberAware* (Giannakas et al. 2015, 2016), will assist the building of applications that will be suitable for running on different platforms and it is sure that it will extend the game's life span. This fact alone underpins the need for developing standards and common frameworks for use in this particular area. "Discussion and future challenges" details on this last point.

Finally, regarding the type of architecture and the learning environment that have been applied in mGBL environments, 19 games are build on ad hoc philosophy, and 17 on client/server. Considering the type of the environment of the learning application, 15 games use mixed reality, meaning that combine physical and virtual world elements, 15 virtual world, and 6 amalgamate virtual worlds and simulation activities.

Potentials of emerging technologies

Another factor that enhances learning experience, increases motivation, and spurs the design of context-based mGBL applications, is that of emerging technologies, including Cloud Computing, Mobile AR, QR codes, etc.

From a quantitative point of view, only a handful of the surveyed works use emerging technologies. Specifically, from a total of 36 mGBL applications, 3 of them incorporate QR technology, and 6 AR. Nevertheless, as further discussed in "Discussion and future challenges", the potential of exploring emerging technologies should be highlighted as an important factor for future mGBL implementations.

Summarizing the trends in mGBL applications

Figure 3, gathers in chronological order all the works included in "Spatio-temporal dimension" to "Data security and privacy dimension". The same figure offers a triple classification of the works according to the field they address, the type of publication, and their technological nature. As observed, from a qualitative point of view, from a total of 36 mGBL applications, 16 of them have been published in journals and 20 in conferences (Fig. 3).

Also, Table 1 summarizes all the works included in "Spatio-temporal dimension" to "Data security and privacy dimension" based on the GDPs. Recall from "Introduction" that the term *benefits* refers to the techniques that an mGBL application deploys in order to spur learners' confidence, satisfaction, and stimulation. Also, Tables 2 and 3 outline all the works included in the aforementioned subsections for each science learning domain based on several criteria, including specific game's characteristics, learning theories, target group, research method used, and type of publication. In more detail, in these two tables we identify the number of players, the type of the game, the services and educational content being deployed, the underlying learning theories as well as the support of collaboration activities, where available. Also, the last two columns of Table 3 contain basic information about the assessment or description of students learning process or outcomes after using the corresponding game. That is, it depicts, how many participants were involved in the evaluation process as well as the research method being used by their authors. The comparison of the various works per learning field is limited to the aforementioned parameters in an effort to find a common ground of discussion (and sometimes due to lack of further information in several of them).

Discussion and future challenges

Designing a game for learning purposes is a cumbersome and challenging task since there are a lot of both technological and human factors that need to be considered. This is especially true if the game under development is destined to modern mobile platforms. This is because there exist a considerable number of already identified technological restrictions mainly germane to mobile hardware and platforms as well as issues that are often associated with the pedagogical usage of the learning application. Additionally, in the interactive ubiquitous gaming paradigm, context-awareness is gaining more attention and applicability in a variety of learning environments. So, this situation demands a context management procedure to be applied on the data collected from various mobile hardware or software sensors during the (mobile device-player) interaction. This may be implicitly utilized by the learning application for the sake of actively guiding and affecting its behavior, i.e., towards addressing a more contextualized and personalized learning experience.

In this section, we discuss the findings of the work at hand, mainly concentrating on the mGBL characteristics, expressed as GDPs, and the learning activity strategies that an mGBL environment incorporates in its learning scenarios. Finally, we identify potential

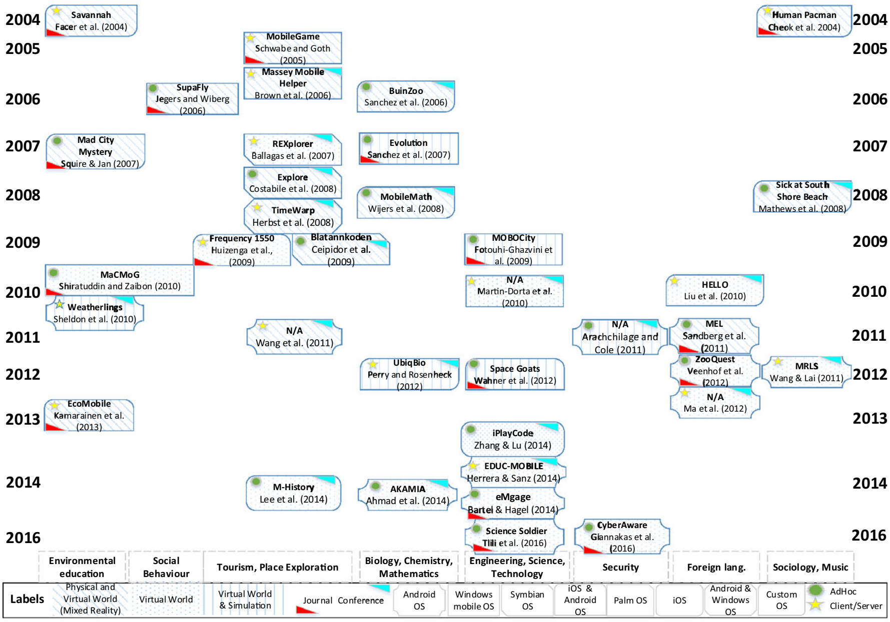

Fig. 3 mGBL applications in chronological order, grouped by field, type of publication, game type, and mobile platform

literature gaps and other interesting issues that seem to have great potential for future research in the mGBL ecosystem.

u-Learning and context-awareness

Based on our analysis, GBL and context-aware u-Learning experience currently mainly fit on mobile-empowered applications that encompass spatio-temporal characteristics, placed in a situated learning environment. This includes mGBL applications destined to place exploration, and/or incorporate collaborative activities in their learning plot. Therefore, our analysis shows that augmenting space and time simultaneously is not always applicable in the mGBL learning scenarios. This is the reason why in "Summary of spatio-temporal characteristics and strategies" we have identified two distinct extensions of spatio-temporal dimension, namely a) *Spatially enhanced*, and b) *Spatio-temporally enhanced*.

Further, our analysis shows that there are various mGBL applications that do not take advantage of the affordances of the ubiquitous environment via the utilization of context-aware characteristics. This is mainly associated with session-based activities as discussed in "Session dimension". Instead, these applications usually employ different *edutainment* characteristics, such as puzzles, pop-quizzes, etc, for delivering learning experience in diverse learning domains and curricula, including engineering, science, technology, security education, and so forth.

There are two possible views to converge to the aforementioned observation. The first is that not all games fit this mold. The other is associated with the complexity of designing and implementing mGBL context-aware activities for different curricula.

Table 3 mGBL applications according to target group and evaluation method

App. name	Target group	Participants	Research method
AKAMIA	Sec. education	46 (groups of 40 and 6)	Questionnaire
Blatannkoden	Sec. education	N/A	N/A
BuinZoo	Sec. education	25	Questionnaire, observation, interview
Blind for review	Primary education	43	Questionnaire
EcoMOBILE	Sec. education	30	Questionnaire, case study, interview
EDUC-MOBILE	Higher education	13 (groups of 9 and 4)	Questionnaire
Evolution	Sec. education	101 (groups of 25 and 76)	Questionnaire, observation
eMgage	Higher education	N/A	N/A
Explore	Sec. education	66 (groups of 24 and 42)	Questionnaire, observation, interview, multiple choice tests, post-experience elicitation techniques (drawings and essays)
Frequency 1550	Sec. education	232	Questionnaire, observation
HELLO	Higher education	20	Questionnaire, Interview
Human Pacman	General	N/A	Questionnaire
iPlayCode	Higher education	36	Questionnaire
MaCMoG	Primary education	102	Informal interview, observation
Mad City Mystery	General	34 (groups of 18, 3, 7, 6)	Questionnaire, interview
Massey Mobile Helper	Higher education	7 (groups of 3 and 4)	Screening questions, questionnaire, case study
MEL	Primary education	43	Questionnaire
M-History	General	13	Questionnaire, semi-structured interview
MobileGame	Higher education	22 (groups of 13 and 9)	Case study, questionnaire
MobileMath	Sec. education	60	Interview, questionnaire
MOBOCity	Higher education	15 (groups of 5)	Case study, observation
MRLS	Primary education	22	Questionnaire
REXplorer	General	N/A	N/A
Savannah	Primary education	10 (groups of 5 and 5)	Case study, interview, observation
Science Soldier	Higher education	27	Questionnaire

Table 3 continued

App. name	Target group	Participants	Research method
Sick at South Shore Beach	Primary education	N/A (groups of five schools)	Case study, interview
Space Goats	N/A	N/A	N/A
SupaFly	General	58 (groups of 16 and 42)	Interview, questionnaire, data logs
TimeWarp	General	24	Questionnaire
UbiqBio	Sec. education	156	Questionnaire, interview
Weatherlings	Primary education	20	Questionnaire, data logs, interview
ZooQuest	Primary education	43	Questionnaire, tests
Arachchilage and Cole (2011)	General	N/A	N/A
Ma et al. (2012)	Primary education	N/A	N/A
Martin-Dorta et al. (2010)	Higher education	16 (groups of 8 and 8)	Questionnaire, data logs, tests
Wang et al. (2011)	Higher education	39	Questionnaire

Adaptivity

Another key issue that needs to be tackled within the mGBL field is the flexibility and adaptivity of the learning content, so as the gaming environment to be able to extend and enrich its learning features (including its plot, challenges, knowledge base, etc.) whenever such a need arises. This functionality becomes even more essential in context-aware u-Learning gaming environments, where the game strategy and the associated learning content may need to be changed based on the player's geographical location and the way they interact with the physical environment. As already pointed out in "Personalization dimension", this functionality deems to be necessary for a number of learning activity strategies in order to fulfil specific learning goals that are tailored to the learner's needs. Unfortunately, our findings indicate that the great mass of mGBL applications are based on predetermined and static learning content. *MOBOCity, Savannah, and MaCMoG* discussed in "Context-aware m/u-Learning and mobile games" are characteristic examples of this situation. As a rule of thumb, the game architecture should be guided by an approach for providing the educator, and sometimes the students, with the necessary tools to enhance, optimize and alter the behavior of the (m)GBL application. As discussed in "Personalization dimension", the game designed by Martin-Dorta et al. (2010) satisfies these qualities and can be characterized as adaptive. Specifically, this game provides a front-end that enables the teacher, among others, to add or modify the database containing the relevant educational content or the exercises needed for checking students' prior knowledge. Another example to this point is *Massey Mobile Helper* discussed in "Spatio-temporal dimension". In any case, one can argue that a high degree of adaptivity and flexibility of the learning content is sure to extend the game's life span.

Personalization

The ability of the mGBL application to motivate and retain learners in learning track is necessary for improving the learning outcomes and augmenting the game's life span (Hwang et al. 2012). This is typically achieved by delivering to the learners meaningful, targeted, and tailored learning experience that best fits their current knowledge. Yet, our findings indicate that the great mass of mGBL applications do not offer any kind of personalized learning experience. Instead, few games track learners' curve in order to provide them access in quantitative learning information, such as access to win-loss records, results from previous tasks, etc. As detailed in "Spatio-temporal dimension", the *Massey Mobile Helper* Brown et al. (2006) partially addresses this issue by collecting learner's data for the purpose of delivering them personalized contextual information.

In the literature, there exist several mGBL environments that are destined to support learners in a more personalized way. This imposes the extraction of new knowledge derived after processing the collected contextual information. Nevertheless, this functionality is not simple because, among others, it usually demands the use of data mining and machine learning techniques. This is considered necessary in order to give a meaning to the collected information and extract useful inferences for the learner's progress during the learning process. In this regard, Fuzzy Item Response Theory (FIRT) was utilized by Chen et al. (2005) for implementing a personalized web-based tutoring system that delivers targeted learning material to the learners. Another characteristic example is Fuzzy Weighted Average (FWA) theory introduced by Huang et al. (2008). That is, the authors aimed at implementing a context-awareness synchronous learning system to deliver formulated learning contents that fit on diverse learning devices, and thus address the personalization of the learning experience. In this regard, personalization is not implemented by any mGBL application discussed in the current review. For this reason, we consider that several issues must be addressed in this specific field. Specifically, personalization functionality must be extended not only to take into account learners' characteristics such as their desires, needs, and data produced by their engagement with the application, but also those characteristics that derive from their current emotional and psychological conditions, during the learning process. Further, producing a meaningful learning experience and targeted feedback is another important aspect, which nevertheless imposes the utilization of specific data mining algorithms for extracting knowledge from the collected data.

Data security and privacy

As already discussed in the previous sections, continuously tracking players during their context-aware u-Learning activities may raise serious concerns regarding their right to privacy. That is, it is a common ground for context-aware mGBL applications to collect a sizable amount of sensitive personal information with the intend to enhance learners experience and/or provide personalized learning guidance. The works in *SupaFly* (Jegers and Wiberg 2006), *REXplorer* (Ballagas et al. 2007), *Explore* (Costabile et al. 2008), *HELLO* (Liu et al. 2010), *UbiqBio* (Perry and Rosenheck 2012), and *eMgage* (Bartel and Hagel 2014) are only some examples of mGBL applications that indirectly leak sensitive information without taking any measures toward preserving player's privacy. Further, when learners participate in group-based activities, they may wish to keep their anonymity.

Nevertheless, not even one of the mGBL applications included in the current survey makes any provision to preserve this quality. Communication among the players and the application also calls for empowering end-user privacy. This also appears when the mGBL application integrates with cloud-based services.

All the aforementioned requirements are correctly identified in (Kambourakis 2013), focusing on m/u-Learning security and privacy. Specifically, the author underlines the fact that private information stemming from learners' interaction with the mobile device, including their geographical location and preferences, inevitably leak out. According to the author, the same issue is envisioned for context-aware u-Learning. In fact, the emergence of, say, NFC-, RFID-powered applications for the m-Learning realm and inevitably for mGBL is already a reality. For instance, we have already witnessed prototypes and other more mature products (see Google Glass and smartwatches) of highly portable devices which combine a camera, a plethora of sensors, and wireless connectivity to offer contextual information to users about places, experiences, and activities. In the mid or long run, such devices may even replace smartphones, at least to some extent. As already pointed out, such technologies are destined to enhance the learning experience by putting users in position to learn via their interaction with smart objects scattered in the environment. This enables the system to actively provide personalized and contextual services to the learners. A typical example of this case is a museum where each exhibit has been labelled with an RFID tag.

Motivation/engagement and technological trends

Overall, the main question of what forces or encourages students to prefer an educational game as a supplementary (or core) process in their learning activity can be answered within their personal behavioral characteristics. Many students prefer to learn in their own pace, do things without continuous supervision, and act in the way they prefer under specific circumstances. This can happen in a way that is most familiar to them, i.e., through gaming. More importantly, the interaction of the learners with the learning material can take place anytime, anywhere in diverse learning contexts. On the other hand, teachers choose to use (m)GBL in their curriculum to introduce a new learning topic for a number of reasons. This for example may happen towards finding a more friendly and delightful way of teaching difficult scientific concepts to their audience. Additionally, a game could be introduced as an outdoor or (less often) classroom activity for several other reasons. These include the opportunity to increase the motivation of learners, to keep them in learning track, and to offer them an alternative, more attractive way of interaction and communication (Pivec 2007). If the above requirements are met, then (m)GBL is anticipated to enhance learning throughout experience by augmenting the physical world and giving the learners the freedom to vividly participate in their learning process.

In this direction, (Eseryel et al. 2014) investigate the interrelationships between motivation and engagement within a GBL environment. More specifically, the authors identify a literature shortcoming in this area and underline the need for designing instructional frameworks that will *leverage the affordance of game-based learning to design effective situated learning environments*. According to the same authors, this is deemed necessary for supporting learners' cognitive developments throughout their continued engagement with the GBL environment. Most would agree that this observation stands true for any mGBL environment as well. Taking into account the above analysis, learning theories are a key element for building truly effective educational games. From our analysis and following the discussion of "Pedagogy dimension", we concluded that only few mGBL applications encapsulate a specific learning theory in their design.

In the quest for more motivating and context-based learning environments, another challenging issue is that of mGBL integration with emerging technologies, including Cloud Computing, Mobile AR, QR codes, etc. These technologies are generally considered to have the potential to enhance the learning experience within the Technology Enhanced Learning (TEL) ecosystem (de-la Fuente-Valentín et al. 2013). The incomparable success of Pokemon GO is self-evident in this respect. This is because when utilized with mobile devices, these technologies have the potential of delivering rich and more personalized contextual information to the learners (Liu et al. 2010). The works *Blatannkoden* (Ceipidor et al. 2009), *HELLO* (Liu et al. 2010), and *EDUC-MOBILE* (Herrera and Sanz 2014) are characteristic examples of such a situation that agglomerates this couple of technologies into an mGBL application. Also, the works *MobileGame* (Schwabe and Göth 2005), *Mad City Mystery* (Squire and Jan 2007), *Sick at South Shore Beach* (Mathews et al. 2008), *TimeWarp* (Herbst et al. 2008), and *EcoMobile* (Kamarainen et al. 2013) are some other examples of games that use mobile AR technology.

Furthermore, cloud computing, for instance, is envisioned to introduce cloud-based learning as a potent and supportive dimension within the (m)GBL arena. This is not so much for overcoming mobile hardware constraints—besides, smartphones and tablets are gradually becoming more potent making it feasible to implement as much functionality as possible in the client side—but for building powerful mobile game cloud-based back-ends that will allow one to augment the overall experience for the end-user, render the game more immersive and alluring, offer personalized and enhanced functionality, and create context-based communication beyond the confines of just a client application itself.

Indeed, today, several popular mobile games use mobile back-ends as that of Google's cloud platform and others to (a) ease multiplayer games, (b) deliver dynamic game content, such as matching players, (c) conserve smartphone memory and increase the amount of space available for saving information, including the scores achieved in the previous plays and/or the last completed level, and (d) coordinate push notifications. This research trend is expected to ramp up in the coming years mainly due to the virtually endless possibilities in terms of resource availability and design flexibility that cloud computing can offer (Abiresearch 2011).

Although these technologies already support ubiquitous environments in general and e/m-Learning in particular, only some preliminary steps are made toward importing and capitalizing their learning capabilities into the (m)GBL arena. So, an interesting research trend is that of exploring further the potentials stemming from the use of such emerging technologies toward maximizing their benefits for learners.

Lastly, especially for mGBL, a research timeline has to be updated over the years in order to preserve the ability of observing the development of mobile trends in this field. This will facilitate researchers to trigger a quicker and more effective decision making process regarding mGBL design and implementation.

To sum up, currently, the most challenging issues for an (m)GBL designer to deal with are:

– Embed adaptivity and flexibility capabilities for enhancing and varying the educational content and extending the game's life span.
– Embed personalized functionalities for enhancing the learning characteristics of the environment and improve the learning outcomes.

- Find the golden mean between the optimal combination of delightful play and the achievement of the learning goals with reference to specific learning theories.
- Provision of security, and privacy measures in a manner that will be both user-friendly and security/privacy-preserving. A failure to do so would implicitly subvert the learning experience.
- Capitalize on the potentials of emerging technologies (including cloud computing, graphical game engine development, advanced wireless infrastructures and services) by adopting and combining them with others with the aim of adding flexibility, adaptivity and easy access to the educational content and increasing the efficiency of the learning experience.
- Examine the potentials of creating new context-based learning activity strategies towards assisting developers to put emphasis on context-awareness, and extend it to cover new learning domains.
- Develop standards and common interoperability frameworks for facilitating and instrumenting code porting processes to newer versions or different mobile platforms. This is rather imperative as the open nature of some mobile platforms, as the Google's Android one, allows smartphone manufacturers to design their own custom Application Programming Interfaces (APIs) to meet their specific needs. So, say, even after an OS update, it is probable for the application to require certain amendments to its software code. Integration with new peripherals and emerging input methods like Leap Motion, Oculus Rift, and Google Glasses is also a very interesting trend worthy of investigation.

Conclusions

Today, due to the proliferation of mobile technologies and cloud computing amongst others, we are witnessing a radical change in several aspects of our everyday life. This includes ubiquitous networking, communication, collaboration and social interaction with others, and sharing of information. In this setting, traditional GBL undergoes a rapid shift to mobile platforms with the aim not only to move learning outside the classroom and take advantage of the anywhere, and anytime experience, but also to transform radical the learning experience. This shift is also anticipated to move learning experience in learner's everyday context, and make it more situated and contextual.

Motivated by this fact, the paper at hand offers a comprehensive analysis of the major works in the field of mGBL proposed in the literature from 2004 to 2016. We only address scientific journal and conference publications leaving out commercial products and any other unpublished work. With the help of a multidimensional framework, we categorize each mGBL application by analyzing its features in terms of learning activity strategies and GDPs. In addition, we conduct an extensive discussion on future trends and challenges in this particular area, which may be of great aid to anyone interested in mGBL.

It was concluded that research on this topic is at a rather budding stage, as the transition to mGBL presents several difficulties (mainly due to the inherent limitations already pointed out in "Personalization dimension"), and therefore cannot be conceived as a simple and quick modification of an existing GBL solution. From analyzing the existing literature it has emerged that the most noteworthy issues for future mGBL designs to cope with are: (a) finding the *juste milieu* between delightful play and learning outcomes with reference to learning theories, (b) embed adaptivity and flexibility capabilities for improving and varying the educational content and extending the game's life span,

(c) embed personalized functionalities for enhancing the learning characteristics of the environment and ameliorating the learning outcomes, (d) considering end-users' security and privacy misgivings to an acceptable point, (e) taking advantage of emerging technologies and software frameworks (including cloud computing, game engines, advanced wireless infrastructures and services) to add flexibility, adaptivity and easy access to the educational content, (f) examine the potentials of creating new context-based learning activity strategies to assist developers to enrich context awareness, and (g) develop standards and common interoperability frameworks for facilitating and instrumenting code porting processes to a newer or different mobile platform.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest, and fully comply with ETRD declaration of ethical responsibilities.

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