ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΙΓΑΙΟΥ

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

Αξιοποίηση παιγνίων σε κινητές συσκευές για την ενίσχυση της ευαισθητοποίησης των μαθητών της πρωτοβάθμιας και πρώιμης δευτεροβάθμιας εκπαίδευσης σε ζητήματα ασφάλειας και ιδιωτικότητας στο Διαδίκτυο.

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για την απόκτηση Διδακτορικού Διπλώματος

στο

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Doctoral Thesis

Raising Internet security and privacy awareness in primary and early secondary education via mobile gamification

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

at the

Laboratory of Information and Communication Systems Security
Department of Information and Communication Systems Engineering
School of engineering
University of the Aegean

Samos, September 2018

Declaration of Authorship

I, Filippos Giannakas, declare that this thesis entitled, "Raising Internet security and privacy awareness in primary and early secondary education via mobile gamification" and the work presented in it are my own. I confirm that:

- This work was done wholly while in candidature for a research degree at this University.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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"Nowadays, due to the increasing internet use and the deployment of the plethora of internet connected devices security and privacy issues are considered fundamental topics in students' education. This becomes more prominent due to the fact that security attacks exploit human's vulnerabilities and the lack of their knowledge rather than exploiting of the system ones."

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Abstract

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Doctor of Philosophy
by Filippos Giannakas

Nowadays, due to the proliferation of the Internet and the increasing deployment of the plethora of internet connected devices, security and privacy issues are considered fundamental topics in students' education. For instance, semantic attacks (also known as social engineering) such as phishing, aim to deceive or lure people into visiting a seemingly legitimate hyperlink in hopes to disclose their personal information. Similar attacks intend to violate computing devices and usurp users' personal information via the use of malware. All these kinds of attacks, exploit human's lack of knowledge rather than the system vulnerabilities. This is quite expected since attacks of this kind are typically unknown to the non-security-savvy individual, while for some others, the knowledge on security protection measures and privacy awareness is mostly classified as a secondary task

Over the last decades, the concept of integrating learning and entertainment appeared in the Information Technology (IT) field and shaped new terms including *learning by playing*, *Educational entertainment (Edutainment)* and *Game-Based Learning (GBL)*. Today, within the context of e-Learning, DGBL generally refers to the deployment of various forms of digital games to support teaching and learning. Such games can be played over the Internet, on personal computers, smartphones, or on specific mobile or traditional game consoles. GBL also pertains to digital board games, card games, and many others that are strategy-intensive. In the literature, DGBL is often referred to as *Digital Game-Based Learning (DGBL)*.

On the other hand, smart mobile devices are considered as context-sensitive and one of the most challenging technological fields in formal or lifelong learning due to their intrinsic characteristics such as portability, connectivity, built-in sensors, etc. Taking advantage of this technological trend, several researchers consider that e-Learning has given birth to an independent type of learning, which is known as mobile-Learning (m-Learning). This transformation supports just-in-time and just-in-place learning capabilities, by allowing learners (and instructors) to have instant access to the learning content and collaborative activities anytime, and from arbitrary device types and platforms. 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). So, the plethora of contextual information that can be detected from a u-Learning environment, led to context-aware learning apps.

In this context, in this PhD thesis, a literature review is conducted in order to identify several aspects of (m)DGBL for improving students' learning experience, spanning a period from 2004 to 2016. This review also contributes to pinpointing the different mobile characteristics and the main trends in mDGBL environments so far. We also paid special attention to whether the existing mobile games substantially utilize the technological affordances of mobile technologies for supporting innovative and pedagogically efficient context-aware learning environments. In this respect, we used a six-dimensional framework for scrutinizing the inherent constituents of the learning games and bring to the foreground important issues pertaining to mobile and context-aware ubiquitous DGBL.

Moreover, this doctoral thesis focuses on the design and development of a novel learning platform that consists of a Learning Content Management System (LCMS) and a mobile DGBL (mDGBL) app for educating and raise users' awareness on basic cybersecurity and privacy issues.

More specifically, the implemented mDGBL app, namely CybeAware, comprises a suit of quick games, that can be played either in a standalone or in a client/server mode, and it is designed to support elementary and early secondary students in formal and informal learning to basic Internet security and privacy issues. Further, the mobile version of CyberAware app can be experienced as a classroom or an outdoor learning activity. Contrary to analogous studies found in the literature so far, during the design phase of the app, our focus was not solely on its technological aspects, but we uniformly paid special attention to the educational factor by applying a specific model of motivation.

Our findings from both the literature review and the evaluation of CyberAware suggest that, in information security and privacy domains, DGBL is rather the most efficient method to be used toward educating young learners. However, additional evaluation efforts are needed to better assess and estimate the positive impacts of this kind of learning for this particular domain.

ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΙΓΑΙΟΥ

Extended Abstract in Greek

(Εκτεταμένη περίληψη)

Τμήμα Μηχανικών Πληροφοριακών & Επικοινωνιακών Συστημάτων
Πολυτεχνική Σχολή
Πανεπιστήμιο Αιγαίου

Διδακτορική διατριβή
του Φίλιππου Γιαννακά

Σήμερα, λόγω της επέκτασης του Διαδικτύου και της αυξανόμενης χρήσης των διαφόρων διασυνδεδεμένων συσκευών στο Διαδίκτυο, τα ζητήματα ασφάλειας και ιδιωτικότητας θεωρούνται θεμελιώδη στην εκπαίδευση των μαθητών. Για παράδειγμα, οι σημασιολογικές επιθέσεις (γνωστές επίσης και ως κοινωνική μηχανική), όπως το ηλεκτρονικό ψάρεμα, στοχεύουν στο να εξαπατήσουν ή να προσελκύσουν τους χρήστες να επισκεφτούν ένα φαινομενικά ακίνδυνο υπερσύνδεσμο, με σκοπό να αποκαλύψουν τα προσωπικά τους δεδομένα. Παρόμοιες επιθέσεις σκοπεύουν στην παραβίαση των υπολογιστικών συσκευών και την υφαρπαγή των προσωπικών πληροφοριών των χρηστών τους μέσω κακόβουλου λογισμικού. Τα συγκεκεριμένα είδη των επιθέσεων εκμεταλλεύονται την άγνοια των ανθρώπων και την έλλειψη γνώσης τους, παρά την ευπάθεια των συστημάτων. Αυτό είναι αρκετά αναμενόμενο, δεδομένου ότι οι απειλές αυτού του είδους είναι συνήθως άγνωστες στους χρήστες που δεν γνωρίζουν θέματα σχετικά με την ασφάλεια, ενώ για κάποιους άλλους τα μέτρα προστασίας για την ασφάλεια, καθώς και η ευαισθητοποίηση σε θέματα προστασίας της ιδιωτικής ζωής τους, ταξινομούνται κατά κύριο λόγο ως δευτερευούσης σημασίας.

Τις τελευταίες δεκαετίες, η σύγκλιση της μάθησης με αυτή της ψυχαγωγίας εμφανίστηκε στον τομέα της Πληροφορικής (IT) και διαμόρφωσε νέους όρους, όπως "μαθαίνω παίζοντας" (learning by playing), εκπαιδευτική διασκέδαση (Edutainment), και εκπαίδευση βασισμένη στο παιχνίδι (GBL). Σήμερα, στο πλαίσιο της ηλεκτρονικής μάθησης, ο τελευταίος όρος αναφέρεται γενικά στην ανάπτυξη διαφόρων μορφών ψηφιακών παιχνιδιών για την υποστήριξη της διδασκαλίας και της μάθησης. Τα συγκεκριμένα παιχνίδια μπορούν να χρησιμοποιηθούν μέσω του Διαδικτύου, σε προσωπικούς υπολογιστές, έξυπνες συσκευές, ή σε κονσόλες παιχνιδιών. Ο όρος GBL αναφέρεται επίσης και σε ψηφιακά επιτραπέζια παιχνίδια, παιχνίδια καρτών και πολλά άλλα που απαιτούν στρατηγική. Στη βιβλιογραφία, το GBL συχνά αναφέρεται και ως ψηφιακή μάθηση με βάση το παιχνίδι (DGBL).

Από την άλλη πλευρά, οι έξυπνες κινητές συσκευές θεωρούνται ότι έχουν υψηλή συσχέτιση με το πλαίσιο στο οποίο κάθε φορά λειτουργούν (Context-sensitive), και αποτελούν τη μεγαλύτερη τεχνολογική πρόκληση στη βασική αλλά και τη δια βίου μάθηση, λόγω των εγγενών χαρακτηριστικών τους, όπως η φορητότητα, η συνδεσιμότητα, οι ενσωματωμένοι αισθητήρες, κλπ. Για τον λόγο αυτόν, πολλοί ερευνητές θεωρούν ότι η ηλεκτρονική μάθηση έχει μετασχηματιστεί σε ένα νέο, ανεξάρτητο τύπο μάθησης, ο οποίος είναι γνωστός ως κινητή μάθηση (m-Learning). Αυτός ο μετασχηματισμός υποστηρίζει τις ικανότητες μάθησης just-in-time και just-on-place, επιτρέποντας στους εκπαιδευόμενους (και εκπαιδευτές) να έχουν άμεση πρόσβαση στο μαθησιακό περιεχόμενο και στις συνεργατικές δραστηριότητες οποτεδήποτε και από οποιαδήποτε τύπο συσκευών ανεξαρτήτου πλατφόρμας. Επιπλέον, οι διαρκείς τεχνολογικές εξελίξεις στον τομέα των κινητών συσκευών, όπως η πληθώρα των αισθητήρων και των ασύρματων διεπαφών που προσφέρουν αυτές οι συσκευές, συμβάλλουν επίσης σε μια νέα μετεξέλιξη της κινητής μάθησης (m-Learning) σε αυτό που είναι γνωστό και ως πανταχού παρούσα μάθηση (u-Learning).

Στο πλαίσιο της παρούσας διδακτορικής διατριβής, πραγματοποιήθηκε βιβλιογραφική ανασκόπηση από το 2004 έως το 2016, με σκοπό να ανιχνευτούν όλα εκείνα τα στοιχεία που βελτιώνουν τη μαθησιακή εμπειρία των μαθητών με χρήση παιχνιδιών μάθησης. Η μελέτη αυτή συνέβαλε επίσης στο να αναδειχθούν και τα διαφορετικά κινητά χαρακτηριστικά καθώς και οι κύριες τάσεις των εφαρμογών παιγνίων για κινητές συσκευές, μέχρι στιγμής. Επίσης, απαντήσαμε στο ερώτημα εάν τα υφιστάμενα κινητά παιχνίδια μάθησης αξιοποιούν ουσιαστικά τις τεχνολογικές δυνατότητες των κινητών συσκευών για την υποστήριξη καινοτόμων και παιδαγωγικά αποτελεσματικών περιβαλλόντων μάθησης που λαμβάνουν υπόψη τους το πλαίσιο στο οποίο λειτουργεί η κινητή συσκευή. Υπό αυτήν την οπτική, προτείναμε ένα σχήμα έξι διαστάσεων όχι μόνο για τη διερεύνηση των εγγενών συστατικών των παιχνιδιών μάθησης αλλά και για να φέρουμε στην επιφάνεια σημαντικά ζητήματα που σχετίζονται τόσο με τις κινητές συσκευές όσο και με την πανταχού παρούσα μάθηση (u-Learning).

Τέλος, η παρούσα διδακτορική διατριβή επικεντρώνεται στο σχεδιασμό και την ανάπτυξη μιας νέας ηλεκτρονικής πλατφόρμας μάθησης που αποτελείται από την οντότητα διαχείρισης μαθησιακού περιεχομένου (LCMS) και μια εφαρμογή παιγνίου για κινητές συσκευές (mDGBL) για την εκπαίδευση και την ευαισθητοποίηση των χρηστών σε βασικά θέματα ασφάλειας και προστασίας της ιδιωτικής τους ζωής.

Συγκεκριμένα, η εφαρμογή παιγνίου για κινητές συσκευές που αναπτύχθηκε για τον μαθητή, περιλαμβάνει μια σειρά γρήγορων παιχνιδιών, η οποία μπορεί να παιχτεί είτε αυτόνομα, είτε διαδικτυακά. Έχει σχεδιαστεί για μαθητές της πρωτοβάθμιας και των πρώτων τάξεων της δευτεροβάθμιας εκπαίδευσης, της βασικής και μη εκπαίδευσης, και έχει ως στόχο την αύξηση του επιπέδου ευαισθητοποίησης σχετικά με τη Διαδικτυακή ασφάλεια και της ιδιωτικής ζωής. Επιπλέον, λόγω του ότι η εφαρμογή μπορεί να εκτελεστεί τόσο σε διάφορες πλατφόρμες κινητών συσκευών, όσο και σε υπολογιστές, μπορεί να χρησιμοποιηθεί τόσο μέσα στην αίθουσα διδασκαλίας, όσο και ως μια εναλλακτική μαθησιακή δραστηριότητα εκτός αυτής. Σε αντίθεση με ανάλογες μελέτες που έχουν βρεθεί στη βιβλιογραφία μέχρι στιγμής, κατά τη φάση σχεδιασμού της εφαρμογής δεν εστιάσαμε μόνο στα τεχνολογικά χαρακτηριστικά της, αλλά δώσαμε επίσης ιδιαίτερη προσοχή στον μαθησιακό παράγοντα εφαρμόζοντας ένα συγκεκριμένο μοντέλο κινήτρων για τον μαθητή.

Τα ευρήματά τόσο της βιβλιογραφικής ανασκόπησης της εν λόγω ερευνητικής περιοχής όσο και της αξιολόγησης της εφαρμογής, μας παρείχαν ισχυρές ενδείξεις ότι, για τον τομέα της ασφάλειας των πληροφοριών, η ψηφιακή μάθηση με χρήση ψηφιακών παιχνιδιών έχει ιδιαίτερα υψηλές πιθανότητες επιτυχίας και οι μαθητές μικρής ηλικίας έχουν περισσότερες πιθανότητες να μάθουν και να διατηρήσουν τις αποκτηθείσες γνώσεις. Ωστόσο, απαιτούνται πρόσθετες προσπάθειες αξιολόγησης για την καλύτερη αποτίμηση και εκτίμηση των θετικών επιπτώσεων αυτού του είδους μάθησης σε αυτό το συγκεκριμένο πεδίο.

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Contents

List of Figures

List of Tables

Abbreviations

2D	Two Dimensions
3D	Three Dimensions
3G	Third Generation cellular network
4G	Fourth Generation cellular network
5G	Fifth Generation cellular network
ADL	Advanced Distributed Learning
API	Application Programming Interface
Appx	Appendix
AR	Augmented Reality
ARCS	Attention, Relevance, Confidence, and Satisfaction
BB	Board-based
BYOD	Bring Your Own Device
COTS	commercial-off-the-shelf
CPU	Central Processing Unit
CR	Chat Room
DC	Digital Cards
DGBL	Digital Game-Based Learning
DM	Digital Maps
GB	Group-based
GBL	Game-Based Learning
GBSL	Game-Based Science Learning
GDP	Game Design Patterns
GPRS	General packet radio service
GPS	Global Positioning System
GSM	Global System for Mobile

GUI	Graphical User Interface
IDM	Instructional Design Model
IT	Information Technology
JSON	JavaScript Object Notation
LCMS	Learning Content Management System
LO	Learning Object
MB	Maze-based
mDGBL	mobile Digital Game-Based Learning
MOOC	Massively Open Online Courses
MP	Multiplayer
MR	Mixed Reality
NFC	Near Field Communication
MVC	Model View Controller
OS	Operating Systems
PDA	Personal Digital Assistants
PHP	Hypertext Preprocessor
QR	Quick Response
QB	Question-based
REST	Representational State Transfer
PC	Personal Computer
RP	Role Play
RFID	Radio Frequency Identification
RPG	Role-Playing Game
SB	Story-based
SCORM	Shareable Content Object Reference
SD	Standard Deviation
SDK	Software Development Kit
SMS	Short Messaging Service
SP	Single Player
SUS	System Usability Scale
TB	Terminal-based
TP	Two-Player
UI	User Interface

u-Learning	ubiquitous Learning
VC	Video Call
VO	Virtual Objects
VR	Virtual Reality
WB	Web-based

Chapter 1

Introduction

Over the last decades, the concept of integrating learning and entertainment appeared in the Information Technology (IT) field and shaped new terms including *learning by playing*, *Educational entertainment (Edutainment)* and *Digital Game Based Learning (DGBL)*. Today, the latter term generally refers to the use of digital games to support teaching and learning. Such games can be played over the Internet, on personal computers, smartphones, or on specific mobile or traditional game consoles. From the time of legacy edutainment software being designed to serve educational purposes back in 1990s to modern educational game software, many researchers agreed on the value of DGBL to the learning process (Malone, 1981, Lepper and Malone, 1987, Burguillo, 2010, Yang, 2012, Woo, 2014).

Nowadays, smart mobile devices have established themselves as one of the most developing markets worldwide. These devices are considered as context-sensitive and one of the most challenging technological fields in formal or lifelong learning due to their independent characteristics such as portability, connectivity, etc. Taking advantage of this technological trend, several researchers consider that e-Learning (Kambourakis et al., 2004) has given birth to an independent type of learning, known as mobile-Learning (m-Learning). Due to the undisputed mobility characteristics, this learning transformation supports just-in-time and just-in-place learning capabilities by allowing learners (and instructors) to have instant access to the learning content and course materials, as well as to collaborative activities anytime, and from arbitrary device types and platforms (Korucu and Alkan, 2011, Gikas and Grant, 2013). Also, these environments 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, the learning app augments 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 apps for positioning and orientation tracking. So, the plethora of contextual information that can be detected from a u-Learning environment, led to context-aware learning apps. This means that a digital learning environment detects learners' interaction with the app, senses their behavior in the real world, and accordingly assist them by offering personalized guidance (Hwang et al., 2008).

However, while m-Learning has mainly facilitated the embedding of learning in students' natural environment, accessed in their own pace, Digital Game-based Learning (DGBL) aspires to bring the natural human activity of play into the learning process. In this context, DGBL is gradually becoming a fundamental term in the mobile arena and an important alternative or fortifier in educative apps (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. Thus, blending m-Learning with games, becomes gradually a disciplinary challenge, since this type of learning combines mobile characteristics and the human activity of play for motivating learners (Rau et al., 2008).

Moreover, the proliferation of Internet-connected devices along with the rise of social networking has revolutionized the way we communicate with our peers, do business, and manage our online daily activities. However, this ubiquitous connectivity is associated with various delinquent behaviors pertaining to a great variety of cyber crimes and frauds. For instance, semantic attacks (also known as social engineering) such as phishing, aim to deceive or lure people into, say, visiting a seemingly legitimate hyperlink in hopes to disclose their personal information. Similar attacks intend to violate computing devices and usurp users' personal information via the use of malware. Ordinary users are also prone to identity theft and fraud when they use weak passwords to access their accounts over the Web. Mostly, the aforementioned attacks aim to exploit humans' weaknesses and the lack of knowledge about security and privacy, rather than taking advantage of vulnerabilities found in operating systems, communication protocols, and so forth. This is quite expected since threats of this kind are typically unknown to the non-security-savvy individual, while for some others, the knowledge on security protection measures and privacy awareness is mostly classified as a secondary task (Kambourakis, 2014).

1.1 Motivation and Objectives

Given the above, pervasiveness and, subsequently, ubiquitousness are considered growing trends in mobile computing. In this context, various digital services into everyday objects are easily accessed from the Web, thus rendering user security and privacy increasingly important. Motivating from the aforementioned issues, it is imperative to educate and raise users' awareness on fundamental cybersecurity and privacy issues. This becomes even more prominent among school-aged learners. Especially for elementary and secondary school age students (K-12), security and privacy education is anticipated to be joyful when the knowledge is delivered in the form of a digital game-based learning activity.

According to (Giannakas et al., 2015), the particular learning task has greater chances to succeed if it is delivered via the use of DGBL. If so, the learning experience turns out to be more attractive and personalized, especially for the young learners (Komalawardhana and Panjaburee, 2018). Also, given that the great majority of children and teenagers use the Internet via mobile devices, the positive outcomes of DGBL can be further enhanced if the learning content is delivered via the use of a mobile app. In fact, this form of learning has been applied to diverse scientific fields and curricula, and more lately to cybersecurity education (Giannakas et al., 2018), which is the topic of this PhD research work.

However, various studies have indicated the importance of embedding appropriate learning strategies in DGBL 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 by 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 aforementioned 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".

Given the above, we consider that in science education in general, and in cybersecurity and privacy in particular, the design and implementation of an effective DGBL platform is a multidisciplinary challenge. This stands true for a number of reasons. First, human learning particularities must be taken into account along with the inherent technological characteristics and the advances of mobile technology. Second, special attention should be paid on how a learning theory and an appropriate instructional design model are embedded in the development of the (serious) game in order to maximize its learning outcomes. Third, due to the plethora of Internet connected devices and the efforts in coding new apps, there is a need of deploying the DGBL app in arbitrary mobile devices. In this respect, DGBL platform independence becomes an important issue not only because it overcomes the different mobile peculiarities, but it is also expected to augment the learning experience and make it available anywhere, and anytime. The latter point can be also examined in conjunction with the Bring Your Own Device (BYOD) policy, since it is anticipated to increase learners' satisfaction when they use their own devices, and to extend the app's dissemination prospects (Vieira and Coutinho, 2017).

(Obj. 1) The main goal of this PhD thesis is the design and implementation of a learning platform that consists of a Learning Content Management System (LCMS)

and an mDGBL app towards educating and raising awareness among learners to basic security and privacy issues.

(Obj. 2) Towards the previous objective, we scrutinized the inherent constituents of the learning games to provide learners a mobile/ubiquitous-Learning (m/u-Learning) experience. This is fulfilled by using a six-dimensional framework. This framework also helps addressing our analysis on the main trends and the future challenging issues as well as bringing to the foreground important issues pertaining to context-aware learning strategies that are deployed in an ubiquitous mDGBL environment.

(Obj. 3) The last objective of this thesis is to foster the development of well-designed solutions that are intensive not only in the technological aspect, but in pedagogical qualities as well. In fact, the current objective capitalizes on the knowledge gained after exploring the *obj. 2*.

1.2 Methodology and Milestones

So far, m-Learning (and in a lower extent u-Learning) have been addressed by several works and from a diversity of perspectives. A critical analysis of contributions published before the end of 2007 on this particular field was made by Frohberg et al. (2009). The primary purpose of these 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., 2009).

On the other hand, in comparison with other meta-studies, DGBL has also been addressed by several works in the literature trying to answer similar research issues, including the embedding of learning theories into DGBL apps, the identification of DGBL positive impacts, and so forth. Actually, the work by Li and Tsai (2013) surveys a significant 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 as well as digital games, reciprocal linking between basic learning theories and learning outcomes. However, despite that the aforementioned work identifies digital games in science education that were developed in conjunction with distinguishing technologies, including AR, it hardly touches upon mobile DGBL (mDGBL), which is the primary focus of this research.

Another major work in the field of DGBL 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 mDGBL works, but interestingly it considers commercial-off-the-shelf (COTS) games. It is also worth mentioning that both the above major works answer their research questions by categorizing the various DGBL contributions based on specific game characteristics (single/multi-player, digital/non-digital, Game genre, etc.), named by Connolly et al. (2012) as *Game variables.*

In addition, as the technology continuously evolves, mobile devices will be empowered with 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 will increase their computational power, wireless capabilities for providing faster services such as multimedia transfers, etc. In this respect, many researchers in the educational technology field have highlighted the importance for more studies examining how these technologies leverage for enhanced learning (Heinecke et al., 2001). Further, context-awareness implies gathering, storing and utilizing of the learners' personal information from arbitrary context-based mobile features and characteristics. Therefore, this may clash with the learner's wish for privacy and particularly anonymity (Kambourakis, 2014), and arise the importance of integrating to mDGBL environments data encryption and integrity mechanisms.

Having the above into mind, we identified this necessity for more research work on mDGBL in the field of the educational technology. That is, the literature lacks a systematic review of the characteristics of already published mDGBL contributions, as well as the way these characteristics are incorporated in each mDGBL implementation.

Thus, in order to fulfill the 3 objectives of subsection 1.1, the current PhD study was divided into the following six distinct milestones:

I. A thorough study of the DGBL ecosystem. This milestone is to be satisfied by conducting literature review.

II. A comprehensive literature review for scrutinizing the mDGBL works in the literature spanning a period of 12 years, that is, from 2004 to 2016. This is also done in order to assess the solutions proposed by other researchers so far.

III. Detect the mobile characteristics and main trends that have been used in mDGBL environments as summarized below.

    (a) The learning domains addressed by mDGBL applications.
    (b) The mobile platforms that the mDGBL applications are deployed to.
    (c) The system architectures exploited by mDGBL applications.
    (d) The types of learning environment (physical world, virtual world, etc.), that have been applied in mDGBL applications.
    (e) The use of emerging technologies in mDGBL environments.

IV. Definition of a six-dimensional framework for scrutinizing the inherent constituents of the learning games to provide learners a mobile/ubiquitous-Learning (m/u-Learning). Being in line with obj. 2 given in subsection 1.1, this milestone is mainly theoretical and is intended to incorporate all knowledge gained from the previous ones to form the current framework for addressing the following issues. However, its findings is envisioned to be materialized in future works.

    - Identify the main learning strategies/educational activities that guide learners in existing mDGBL environments.
    - Identify the personalized functionalities that have been applied in existing mDGBL environments for improving learning experience.

- Identify the end-users' data privacy and security issues in mDGBL environments.
- Document the pedagogical aspects in existing mDGBL environments by identifying:
  (a) The learning theories, the number of players, and the target group that characterize the philosophy that steer the design of mDGBL environments.
  (b) The educational benefits reported in the mDGBL literature. The term *benefits* refers to the techniques that an mDGBL 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) The methodologies adopted by the various contributors for assessing and evaluating the pedagogical efficiency of their mDGBL applications.

V. Design and implementation of a learning platform for educating and raising awareness among learners to basic security and privacy issues. This milestone builds upon the insight of the previous ones. Specifically, being in line with obj. 1 in subsection 1.1, this milestone involve the development of a web-based learning content repository and a mDGBL client application especially for the Android platform. The latter application can also be deployed on desktop computers.

VI. Evaluation of the mDGBL application under different prisms, including app's effectiveness, usability, and students' attitude (satisfaction and expectations).

1.3 Contributions

As already pointed out, the main ambition of this PhD work is the development of a full-fledged learning platform for raising awareness among learners to basic cybersecurity and privacy issues. This ambition is in line with obj. 1 as described in subsection 1.1. However, the fulfilment of the aforementioned objective requires the completion of the next two. So, the contributions of this thesis are in full accordance with objectives 2 and 3, and also introduce a novel learning proposal that significantly adds to the results

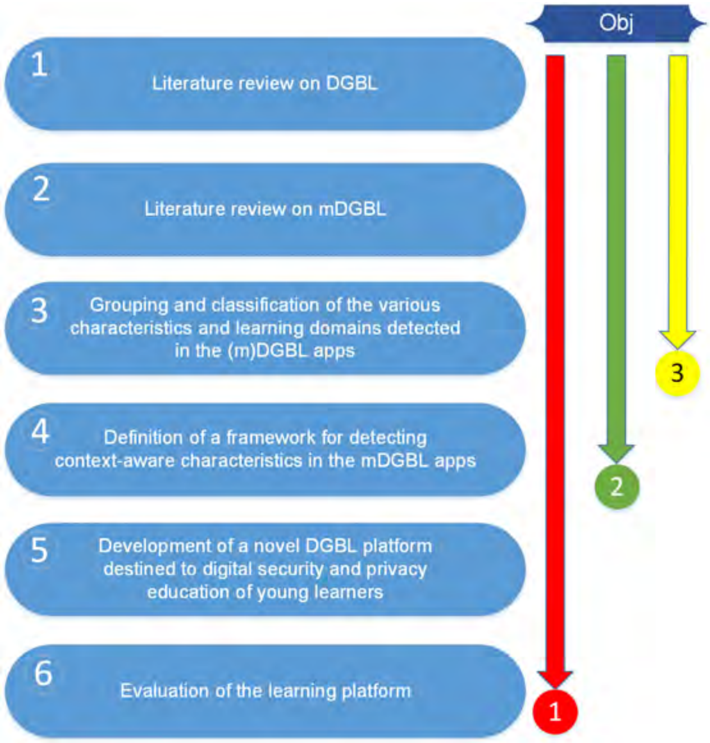

FIGURE 1.1: Research milestones with reference to objectives

presented so far in the literature of mDGBL in the information security and privacy domain.

More precisely, to address obj. 3 and, as a result, milestones I to III, we conducted a literature review in order to identify the solutions proposed by other researchers in the (m)DGBL field, spanning a period from 2004 to 2016. This also contributes to pinpointing the different mobile characteristics and the main trends in mDGBL environments so far. As further detailed in Chapter 2, the aforementioned objective also unveils several other difficulties pertaining to the transition from DGBL to mDGBL suggesting that a mDGBL cannot be conceived as a simple and quick modification of an existing DGBL solution.

Another major contribution in the context of this PhD thesis is to identify personalized functionalities and pedagogical issues concerning motivation and learning strategies that have been applied in existing mDGBL applications for improving students' learning experience. In this respect, we paid special attention on whether the existing mobile games substantially utilize the technological affordances of mobile technologies for supporting innovative and pedagogically efficient context-aware learning environments.

Thus, we focus on the ways that existing mDGBL applications support certain capabilities of handheld computers that take advantage of the technological properties of the synchronous mobile devices (including the various context-based hardware sensors and communication capabilities).

Further, due to the context-aware characteristics that the mDGBL environments incorporate in the learning process, an important part of this doctoral thesis is also to shed light on end-users' data privacy and security issues that come up in such environments. This is because a great mass of applications collect a significant amount of private information from the learners, e.g., positioning data, personal preferences, etc.

In order to address the aforementioned issues that fulfill obj. 2 and as a result milestone IV, we proposed a six-dimensional framework for scrutinizing the inherent constituents of the learning games and bring to the foreground important issues pertaining to mobile and context-aware ubiquitous DGBL. All the aforementioned contributions are explained further in Chapter 3.

Finally, the ultimate contribution of this PhD work is the design and implementation of a learning platform, called CyberAware, that addresses obj. 1 and as a result fulfills milestones V and VI. The platform comprise a web-based custom LCMS and a novel client mDGBL application that is destined to introduce the learners to basic cybersecurity and privacy issues. The client application can support either or both formal or informal learning and can be experienced as an outdoor or classroom activity. This contribution is explained further in chapter 4.

Fig. 1.1 summarizes the major research achievements been accomplished in the context of this PhD thesis. Also, the contribution of this thesis with reference to publications in refereed scientific journals and conference proceedings is as follows:

- A comprehensive review[1] on the field to fulfill obj 2 and 3.
- The development and evaluation of a client-server DGBL platform, namely Cyber-Aware, that can be used to raise user awareness about cybersecurity and privacy

[1] Giannakas, F., Kambourakis, G., Papasalouros, A., & Gritzalis, S. (2018). A critical review of 13 years of mobile game-based learning. Educational Technology Research and Development, 66(2), 341-384.

issues to fulfill obj 1. Cyberaware is destined to primary and early secondary education students[2,3,4].

1.4 Thesis Structure

The next chapter starts by identifying, analyzing, and categorising, non-mobile educational games developed for educating users in various fields, including Security, Medicine, Tourism and Place exploration, Engineering, Music, etc. This is succeeded by identifying specific criteria from these research works, such as game's characteristics, pedagogical approaches, learning theories, target group, research method, and type of publication. This chapter is in accordance with milestone 1 in Fig. 1.1.

Chapter 3 starts by identifying the mobile Game Design Patterns (GDPs) (Davidsson et al., 2004) that a mDGBL environment incorporates in its design in order to accomplish its learning strategy. Secondly, 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 mobile, ubiquitous, and context-aware learning experience. Finally, we discuss other related issues concerning mDGBL enviroments, such as usability constraints, visualization technologies, and content delivery methods. This chapter accomplishes milestones 2, 3, 4 in Fig. 1.1.

The fourth chapter details on the CyberAware learning platform, which accomplices milestones 5 and 6 in Fig. 1.1, and thus is the most important contribution of this thesis. The last chapter concludes this PhD thesis by summarising the results of the current PhD thesis. It also, gives some directions and thoughts for future work.

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[2] Giannakas, F., Kambourakis, G., & Gritzalis, S. (2015, November). Cyberaware: A mobile game-based app for cybersecurity education and awareness. In Interactive Mobile Communication Technologies and Learning (IMCL), 2015 International Conference on (pp. 54-58). IEEE.

[3] Giannakas, F., Kambourakis, G., Papasalouros, A., & Gritzalis, S. (2016). Security education and awareness for k-6 going mobile. International Journal of Interactive Mobile Technologies (iJIM), 10(2), 41-48.

[4] Giannakas, F., Papasalouros, A., Kambourakis, G., & Gritzalis, S. (2018): A comprehensive cybersecurity learning platform destined to elementary education, International Journal of Learning Technologies (iJLT), XX(X), XXX-XXX.

Chapter 2

Digital Game Based Learning

2.1 DGBL environments

Admittedly, DGBL can be used to mitigate, if not eliminate, boredom and add life to learning. In fact, so far, many works in the literature speak in favor of bringing games to learning. For instance, the work by Rogers and Sawyers (1988) underlines that games have the characteristic of play, an activity that among others allows children to extend their skills of communication, give free run to their imagination, promote their physical and healthy development, demonstrate their knowledge, and represent their experience.

However, for orderly reach milestones 2 and 3, one needs to first study the transition from DGBL to mDGBL and review the existing non-mobile apps for identifying their special characteristics. More specifically, within the next subsections, we identify and categorise, non-mobile educational games developed per field of interest, including Information Security, Medicine, Tourism and Place exploration, Engineering, Music, etc. Tables 2.1 and 2.2 summarize these works for each science learning domain based on several criteria, such as specific games' characteristics, learning theories, target group, research method, and type of publication. In more detail, we identify the number of players, the type of the game, the visualization techniques, the underlying learning theories as well as if these games establish collaboration activities, where available. Also, the last two columns of table 2.2 contain basic information about the assessment or description of students' learning process or outcomes after using the corresponding game. That is, how many participants were involved in the evaluation process as well as the research method used. In fact, the comparison of the various works per 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).

2.1.1 DGBL in information security

Protection and security awareness are considered as a fundamental topic in the digital world. In this context, digital games may be proved valuable for teaching security issues more effectively (Kumaraguru et al., 2010), and in a more personalised way towards cultivating a robust security culture. In fact, several implementations have been proposed for teaching security and privacy related terminology, including Phishing, PKI, Firewall etc. In the following, we detail on works devoted to this field covering specific security issues.

The work in *PhishGuru* (Kumaraguru et al., 2010) is a story-based anti-Phishing educational standalone software that aims at alerting learners about email phishing attacks. Also, *Anti-Phishing Phil* (Sheng et al., 2007) complements (Kumaraguru et al., 2010) for the purpose of teaching users how to properly use cues in Uniform Resource Locator (URL) in order to protect themselves against phishing attacks. That is, the authors' main goal is to familiarize users with ways of identifying if a cue that appears in the web browser's address bar correspond to a malicious site. In this respect, Anti-Phishing Phil provides an entertaining platform for teaching more difficult anti-phishing tactics which are not addressed by PhishGuru. Both the aforementioned games are based on certain learning theories, namely Conceptual knowledge (Star and Stylianides, 2013) and Reflection (Boud et al., 2015) respectively. From the results in (Kumaraguru et al., 2010), it seems that the individuals who played the aforementioned games were more skilful in identifying fraudulent websites and phishing-account emails, when the training material is integrated with simulation activities into everyday tasks.

As discussed further in section 2.2, both the aforementioned games are based on learning theories such as the Conceptual knowledge and Reflection. According to the authors in Kumaraguru et al. (2010), participants who played the aforementioned games were more skilful in identifying fraudulent websites and phishing-account emails compared to others. Specifically, their evaluation for Anti-Phishing Phil was organized in three groups of participants according to their pre-test scores: a) "novice", b) "intermediate", and

c) “expert”. The participants had to identify legitimated websites that wrongly characterized as phishing ones (false positives) and phishing website that incorrectly judged to be a legitimate (false negatives). The results showed that the greatest improvement succeeded by novice and partially intermediate users, while no statistically significant betterment was perceived for expert ones. They also evaluate learners’ knowledge acquisition, retention, and transfer following a scheduled training with PhishGuru. Their findings enforce the previous observations obtained with Anti-Phishing Phil for the same groups of users.

SecurityCartoons (Srikwan and Jakobsson, 2008) is another online web-based game that simply embeds the graphical concept of cartoons as its main media type. This game is designed to increase users’ security awareness against security threats as well as to advise them on how to protect themselves against major Internet attacks, including identity theft, phishing, and others. The work by (Dasgupta et al., 2013) is a puzzle-based interactive learning environment for teaching basic cybersecurity issues. They elaborate on the possible ways a network protocol and inbound/outbound communications in general can affect system security. The authors focus on sensitive data breaches and their implications to individuals.

Be Internet Awesome (Google, 2017) is an online web-based game that introduces topics related to phishing attacks, Internet harassment, password security, and other networking safety issues. The game comprises four learning sections in regards to the sharing of personal information online, avoiding phishing attacks or falling for scams, guidelines for creating strong passwords, and rules for avoiding negative online behavior. Each section comprises one web-based game and a number of offline activities.

A last entry to this category is called *CyberProtect* (IASE, 2014). This is an interactive online web-based game for information assurance that composes the Information Assurance Support Environment (IASE), sponsored by DISA. CyberProtect revolves around topics such as: a) Cyber Awareness Challenge, b) Phishing, c) Public Key Infrastructure, d) Smartphones and tablets. Each topic provides professional educators with the relevant knowledge for conducting a successful security awareness training method.

2.1.2 DGBL in medicine

A major obstacle in teaching medical content is that of the huge quantity of knowledge students have to acquire in a limited amount of time. Understanding and memorizing medical facts is fundamental in the clinical practice as well. In this direction, medical curricula have been enriched and some times modified in order to overcome such problems by incorporating advanced forms of teaching including DGBL. In this section we examine non-digital as well digital DGBL works made in medical training.

Non-digital game based approaches for teaching antimicrobial agents and microbial resistance or other medicine contexts are examined in the work of Bochennek et al. (2007). Specifically, Card and Board games are audited for medical education purpose, and in particular those played with dice and pawns.

An interesting web-based interactive digital game for individual learning is the *MEDGAME* (Wyckoff, 2002) one that teaches pediatrics to medical students. *The pediatric board game* (Ogershok and Cottrell, 2004) is another web-based pediatric board-based game that teaches medical students throughout questions. All questions are written and presented in the form of digital cards, thus enabling easy interaction with the theory and the various pediatric terms.

Another work in this category is *Total Knee Arthroplasty (TKA)* serious game developed by Sabri et al. (2010). This is a 3D multiplayer game based on Experiential learning theory (see section 2.2) that was designed primarily to teach surgical residents about the procedures of orthopedic surgical, and to evaluate if this type of training could enhance skill acquisition in such a complex field. Note that a game is characterized as *"Serious"* when its main purpose is not entertainment but training, advertising, simulation, or education (Zyda, 2005).

2.1.3 DGBL in tourism and place exploration

Exploring a place in two dimensions (2D) or three-dimensions (3D), is also a field where learning by gaming approach has been utilized. For instance, games for exploring a museum, a zoo or even a historical place is considered to add value in the learning process.

For example, *Ways of Knowing Trail* examined in (Schaller et al., 2002) is a web-based Role-Playing Game (RPG) developed by the Brookfield Zoo & Chicago Zoological Society (Society, 2010). By choosing their own adventure with a focus on science and geography skills, students enjoy a virtual trip to a rainforest in the village of Epulu in Central Africa. The *Be a Patron of the Art* (Din, 2006) is another web-based game that uses RPG elements. It offers its users the opportunity to experience a virtual travel 500 years into the past. The game scenario makes possible to discover several Renaissance innovations exhibited via the Allentown Art Museums collection of European art.

Games could also play a significant role when utilized in tourism, say, by introducing travellers or tourists to cultures and local traditions before they visit a place or during their stay. In the following, we detail on a work that capitalizes on DGBL in the context of cultural heritage and tourism respectively.

Travel in Europe (TiE) (Bellotti et al., 2008), is a web-based Virtual Reality (VR) - 3D environment with the aim of promoting a meaningful interaction with artistic heritage. The users interact with virtual representations of European cities and being encouraged to accomplish missions in a treasure-hunt manner. That is, in a typical game scenario, potential visitors travel to some cities around the European territory and virtually explore places of artistic interest.

2.1.4 DGBL for teaching engineering

Educational computer games have contributed in teaching complex theoretical engineering knowledge in higher education (Ebner and Holzinger, 2007, Zechner and Ebner, 2011), and in increasing academic achievement and motivation compared to traditional teaching in areas such as computer science and engineering (Papastergiou, 2009), mathematics, etc.

The research project entitled *interactive Visualization in Civil Engineering (iVISiCE)* (Ebner and Holzinger, 2002) aimed to assist students of civil engineering during their learning process through the use of visualizations and animations. The project contributors developed the *Internal Force Master (IFM)* (Ebner and Holzinger, 2007) which is an educational game targeted to students of civil engineering. Specifically, dynamic simulators that embed game play, provide a useful concept for developing online learning resources within the engineering domain, especially for undergraduate courses.

In the same context, a simulation Web-Based VR-oriented Marine Training tool (WBMT) based on 3D objects for visualizing essential components for marine training was examined by Xie et al. (2005). This tool creates an interactive and immersible virtual navigation world and allows end-users to perform ship handling and decision-making training from anywhere, anytime in an on-line, interactive environment. According to the authors, *WBMT* prototype offers several basic services such as: a) information provision, b) accessing to WBMT web-site, c) presentation of marine course material, d) tutorials, e) marine skill training, f) sharing knowledge/skills facility (chatting room), etc.

Bottom Gun (Garris et al., 2002) is a single player game-based submarine periscope simulator developed for the U.S. Navy. Specifically, as further discussed in section 2.2, this game takes advantage of the Constructivism learning theory to enhance submarine technical skills via the use of simulation, and assess the effects of the game-based training approach on student motivation. Also, it provides an entertaining way to practice by "making estimates of critical visual variables".

PIDstop presented by Foss and EIKAAS (2006) is a single player simulator game for teaching conceptual engineering knowledge focusing on harmonic oscillations, magnetic levitation, and hydrodynamics. This game is based on Learning by Doing theory discussed in section 2.2. A similar but multiplayer game simulator entitled *Racing Academy* (Joiner et al., 2007) was implemented to teach fundamental principles of applied dynamics within the engineering context. Racing Academy is also based on Learning by Doing theory to enforce decision making in system design and modelling.

Groupthink (Ernst, 2006) comprises a group-based game developed especially for the needs of software engineering. Its aim is to teach students the importance of software specifications. Similar to the previous one, *SimSE* (Navarro and van der Hoek, 2004) is a 2D single player RPG simulation for teaching software engineering. Both the aforementioned games engage students in learning concepts about the fundamentals of software specification and principles of software engineering.

Another interesting educational game in this category is *ROBOCODE* one (Hartness, 2004). This is a Java-based virtual robot game, that allows users to develop virtual robots using the Java language. ROBOCODE provides students with tools for developing practical versions of the algorithms being discussed in an artificial intelligence class. The game exploits Java programming language concepts, such as the usefulness of inheritance and object-oriented programming in general. The authors argue that with the help of the tool, students are able to better appreciate the theory and develop greater confidence in their understanding of it.

In the same context, the work of Rajaravivarma (2005) examined *Nim* (Greco, 2004) and *Hangman* (Meyer and Dwyer, 2000) terminal-based learning games destined to higher education students for acquiring introductory programming skills. In Nim, by following a strategy, the players attempt to solve a problem by popping out objects from two stacks in their effort to win the game. On the other hand, in Hangman a player receives a cryptographic word and tries to find a way to decrypt it. The player wins the game having the ciphertext decrypted within a predetermined number of tries. According to the authors, the game's scenario aims at enhancing programming skills by motivating players to cultivate basic programming thinking which is of essence in computer programming.

Chang and Chou (2008) developed a game named *Bomberman* to teach students the basic concepts of C programming language. This is a web-based strategic maze-based game that incites students to find a solution to a given problem. Bomberman consists of the next six stages: "Road Map", "Presentation", "Example", "Exercise", "Test", and "Progress Evaluation". According to the authors, teachers can use this game with the aim to design a meaningful sequence of learning concepts in C programming language, while learners can play different game scenarios to practice their skills and test their knowledge on a given topic. Also, the game collects player's data with the purpose to produce a learner's "progressive evaluation chart". This output is visible to the learners using a web-browser and provides them with a meaningful information regarding their own test results per game stage.

To help children learn about mathematics and computer programming in high schools, Edwards et al. (2001) developed *AquaMOOSE 3D*. This is a multiplayer virtual environment that provides learners with an underwater-themed world along with the ability to chat, move around, and program their avatars to "swim mathematically". That is, any motion in the virtual world can be specified mathematically using parametric equations. As a result, each time a (mathematical) movement is being executed, the avatar roams in 3D space along the programmed function by running Logo programming language commands.

Kordaki (2011) designed a computer-based card game for introducing the fundamentals of binary arithmetic to pupils of primary education. At first, the game visualizes a digital card that indicates a decimal number up to five digits. Then, the student tries to analyze this number by breaking it down in thousands, hundreds, etc. This is a fundamental task since pupils become able to link between the place of a decimal digit and the meaning of its value, and thus they can proceed more easily to the next step, which is the conversion of the binary number into its decimal value. That is, a digital card with a binary number appears on the screen, and then the pupil tries to convert it to the decimal system. At the same time, a helping hint (*"help pattern"*) appears to assist the pupil into selecting the right digit weight in order to proceed properly with the conversion. The game follows a similar procedure in the opposite direction, i.e., to help pupils convert a decimal number to its binary equivalent.

The work in (Couceiro et al., 2013) designed a game that engages students in learning basic computer processes through storytelling scenarios, via the use of a virtual environment. Each scenario consists of several puzzles that the student needs to solve in order to discriminate and conceive the relationship among the terms "computer program", "data", and "process". Putting it simply, the main aim of this game is to teach students about the way a computer receives the data, processes them by executing the appropriate program instructions, and finally outputs the results.

2.1.5 DGBL in music

Collecting high-quality, semantic annotations of music can be proved a very difficult and time-consuming task even for a machine to handle within the field of "information retrieval", since a well-defined answer is hard to find given a searching string. Specifically, music information retrieval systems, depend on semantic annotations that try to find an association between acoustic features and word description. Such an association can be used to retrieve the song of interest. For example, one may wish to retrieve songs that *"have a rock style"*, or *"be a ballad with folk influences"*, etc from a database. This can be done by entering keywords from heterogeneous areas (e.g., "type", "description", "feeling", "emotions", etc.). Therefore, annotations of audio files can be used to search and index music and sound databases, provide data for system evaluation, and generate training data for use with machine learning techniques.

In the same setting, a game called *Listen Game* (Turnbull et al., 2007), has been designed as a web-based, multiplayer one with the aim of measuring the semantic relationship between music and keywords that best describe the song such as those discussed above. Specifically, this game is used to collect associations between audio content and keywords related to a song such as "Emotions", "Instruments", "Usages", etc. This is called semantic music information, and is used to build *Music Information Retrieval (MIR)* apps.

TagATune (Law et al., 2007) is an audio-based online game that aims to extract descriptions of sounds and music from human players. In this respect, TagATune is a human computation tool that is capable of gathering perceptually meaningful descriptions for audio data that are agreed upon by multiple players. Players of TagATune are working in pairs. This means that they must collaborate with their partner to label a given tune and collect music tags.

A similar work in this category is called *MajorMiner* (Mandel and Ellis, 2008), and comprises a web-based game that according to its authors makes collecting descriptions of musical excerpts fun, easy, useful, and objective. The players collaborate to characterize short audio clips of songs, and score points when their descriptions are equal to those of other participants.

Another problem related to information retrieval for musical content is that of emotional labelling (i.e., the mood of a given song). Under this prism, *MoodSwings* (Kim et al., 2008) has been designed to explore the nature of musical moods. This web-based game dynamically collects labels of users' mood as players hear the music in real time. As in prior collaborative game approaches, players are partnered to verify each others' results and the game is designed to "maximize consensus building between users". At the start of a match, a player is partnered with another player anonymously across the internet. The goal of the game is for the players to dynamically and continuously reach agreement on the mood of 5 short music clips drawn from a database of popular music.

2.1.6 DGBL for teaching foreign languages

Computer games for educational purposes are also explored for teaching foreign languages. The authors in (Ang and Zaphiris, 2008) discuss the potentials of using a DGBL environment in language learning and identify a number of computer games that are destined to this field. We hereby complement the aforementioned research work by identifying additional DGBL contributions in this specific field.

The authors in Li et al. (2012) designed the "Millionaire Language Game" for teaching Chinese language at elementary school. The game was inspired by the homonymous TV game "The Millionaires". By playing the game, a group of pupils try to answer a number of questions that are stored (in a "question bank") guided by a Chinese handbook. According to the authors, this game helps the participants to learn the principles of the Chinese language.

A second entry in this category is the web-based game designed by Sahrir and Yusri (2012) for teaching and learning the Arabic language. This game consists of 34 mini-games, supports an online translator, a glossary, and a digital dictionary. Unfortunately, the authors do not provide further details on either how these mini-games are played or how they contribute to the teaching and learning experience.

2.1.7 DGBL in environmental education

Environmental learning and awareness is another interesting science topic that a DGBL system can prove valuable to the learning process.

For teaching interested groups and individuals about biodiversity Vasconcelos et al. (2009) designed a web-based, role-play game named *SimParc*. The main objective of this game is to enable one to perceive and find out which are the major factors that influence the management of a park. Specifically, the game revolves around a discussions and negotiations that take place during a park council. This council is supposed to have a "consultative nature" role and consists of various stakeholders. The player takes the role of a stakeholder and participates in virtual conversations in order the council to conclude to a decision regarding, e.g., the levels of biodiversity conservation within the various park zones.

Pereira and Roque (2009) designed a 3D simulation game named *Living Forest* to explore the relationship between the development of human settlements and forest protection. The main scope of this game is for the student to administrate a forest area and maximize the benefits of sustainable ecosystem development by finding the balance among economical development, social enhancement, and environmental consciousness. In the game scenario, a student takes the role of a guardian who is tasked with protecting a given physical ecosystem. For example, in order for her to prevent a fire scenario in the forest, she must take specific measures by allocating an annual budget for guarding it using fire brigades.

Yongyuth et al. (2010) designed a 3D web-based game, namely *AgriVillage* to stimulate student's agricultural awareness. This is a simulated virtual world that enhances student's awareness on agricultural issues that are closely related to weather conditions and water existence due to the effect of "fertilizers and deforestation". The game scenario involves students to vegetable growing activities in a selected virtual area within the forest in order to sell them to the market. To succeed it, the player must consider a variety of factors that influence the vintage and others related to weather changes, climate condition, etc. Also, the player is motivated toward finding the golden mean between a proper cultivation and minimal use of fertilizers.

TABLE 2.1: Non mobile DGBL apps per area of interest, according to their basic characteristics.

Field	**Author(s), year**	**App. Name**	**Players**	**Characteristics**	**Learning Theories**	**Collaborative**
Security	Sheng et al. (2007)	Anti-Phishing Phil	SP	Simulation, SB	Procedural and Conceptual, Reflection	No
	Srikwan and Jakobsson (2008)	Security Cartoons	SP	non-Digital, RP	N/A	No
	Kumaraguru et al. (2010)	PhishGuru	SP	Simulation, SB	Learning by doing, Procedural and Conceptual, Reflection	Yes
	(Dasgupta et al., 2013)	N/A	SP	PB	N/A	No

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Table 2.1 – cont'd from previous page

Field	**Author(s), year**	**App. Name**	**Players**	**Characteristics**	**Learning Theories**	**Collaborative**
	IASE (2014)	CyberProtect	SP	Simulation, WB	N/A	Yes
Medicine	Wyckoff (2002)	MEDGAME	SP	WB, DC	N/A	No
	Ogershok and Cottrell (2004)	The pediatric board game	SP	WB, DC, BB	N/A	No
	Sabri et al. (2010)	Total Knee Arthroplasty (TKA)	MP	3D, VR	Experiential	No
Tourism & Place exploration	Schaller et al. (2002)	Ways of Knowing Trail	SP	WB, RP	N/A	No
	Din (2006)	Be a Patron of the Art	SP	WB, RP	N/A	No
	Bellotti et al. (2008)	Travel in Europe (TiE)	SP	WB, 3D, VR	N/A	No
Engineering	Meyer and Dwyer (2000)	Hangman	SP	TB	Brain-based Learning, Problem solving	No
	Edwards et al. (2001)	AquaMOOSE 3D	MP	3D	Constructivism	Yes
	Garris et al. (2002)	Bottom Gun	SP	Simulation	Constructivism	No
	Navarro and van der Hoek (2004)	SimSE	SP	Simulation, RL	N/A	No
	Hartness (2004)	ROBOCODE	SP	VO	N/A	No
	Greco (2004)	NIM	TP	TB	Brain-based Learning, Problem solving	No
	Xie et al. (2005)	WBMT	SP	Simulation, 3D, VR	N/A	No
	Ernst (2006)	Groupthink	GB		N/A	Yes

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Table 2.1 – cont'd from previous page

Field	Author(s), year	App. Name	Players	Characteristics	Learning Theories	Collaborative
	Foss and EIKAAS (2006)	PIDstop	SP	Simulation	Learning by doing	No
	Ebner and Holzinger (2007)	Internal Force Master (IFM)	SP	Simulation	N/A	No
	Joiner et al. (2007)	Racing Academy	MP	Simulation	Learning by doing	No
	Chang and Chou (2008)	Bomberman	SP	MB, WB	N/A	No
	Kordaki (2011)	N/A	SP	DC	Constructivism, socio-cultural	No
	Couceiro et al. (2013)	N/A	SP	SB, VR	Social, Constructivism	No
Music	Turnbull et al. (2007)	Listen Game	MP	WB	N/A	N/A
	Law et al. (2007)	TagATune	TP	Simulator	N/A	Yes
	Mandel and Ellis (2008)	MajorMiner	SP	WB	N/A	Yes
	Kim et al. (2008)	MoodSwing	GB	WB	N/A	Yes
Foreign languages	Li et al. (2012)	Millionaire Language Game	GB		N/A	Yes
	Sahrir and Yusri (2012)	N/A	SP	WB	N/A	No
Environmental education	Vasconcelos et al. (2009)	SimParc	SP	WB, RP	N/A	No
	Pereira and Roque (2009)	Living Forest	SP	Simulation, 2D, 3D	N/A	No
	Yongyuth et al. (2010)	AgriVillage	SP	Simulation, WB, 3D	N/A	No
General	Leemkuil et al. (2003)	KM Quest	GB	Simulation, WB	Constructivism, Problem solving	Yes
	Pivec et al. (2004)	UniGame	GB	RP	Constructivism, Problem solving	Yes

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Table 2.1 – cont'd from previous page

Field	**Author(s), year**	**App. Name**	**Players**	**Characteristics**	**Learning Theories**	**Collaborative**
	Hwang et al. (2012b)	N/A	SP	WB, BB	Flow experience, Problem solving	No

Note: VR: Virtual Reality, RL: Role Play, SP: Single Player, MP: Multiplayer, TP: Two-Player, GB: Group-based, WB: Web-based, SB: Story-based, DC: Digital Cards, BB: Board-based, MB: Maze-based, PB: Puzzle-based, TB: Terminal-based, VO: Virtual Objects.

Table 2.2: Non mobile DGBL apps according to the number of participants, evaluation method, target group, and type of publication (C: Conference, J: Journal, E: Electronic).

Field	**Author(s), year**	**App. Name**	**Target group**	**Participants**	**Research method**	**Pub. type**
Security	Sheng et al. (2007)	Anti-Phishing Phil	General	14	Screening questions, Case study, questionnaire, observation	C
	Srikwan and Jakobsson (2008)	Security Cartoons	N/A	N/A	General	J
	Kumaraguru et al. (2010)	PhishGuru	General	30	Case study, Questionnaire, Interview, Tests	J
	IASE (2014)	CyberProtect	Professional	N/A	N/A	E
Medicine	Wyckoff (2002)	MEDGAME	Professional	80 (groups of 50 and 30)	Quasi-experiment	J
	Ogershok and Cottrell (2004)	The pediatric board game	Professional	49 (groups of 37 and 12)	Questionnaire	J
	Sabri et al. (2010)	Total Knee Arthroplasty (TKA)	Higher education	N/A	N/A	J
Tourism & Place exploration	Schaller et al. (2002)	Ways of Knowing Trail	General (Zoo Visitors)	50	Questionnaire, Data logs	C/E

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Table 2.2 – cont'd from previous page

Field	Author(s), year	App. Name	Target group	Participants	Research method	Pub. type
	Din (2006)	Be a Patron of the Art	General (Museum visitors)	N/A	N/A	C
	Bellotti et al. (2008)	Travel in Europe (TiE)	General (Trav-ellers)	N/A	Tests	C
Engineering	Meyer and Dwyer (2000)	Hangman	Higher ed-ucation	18	Screening questions, Question-naire, Quiz	C
	Edwards et al. (2001)	AquaMOOSE 3D	High school	3	Case study, Observation	C
	Garris et al. (2002)	Bottom Gun	Professionals	N/A	N/A	J
	Navarro and van der Hoek (2004)	SimSE	Higher ed-ucation	N/A	N/A	C
	Hartness (2004)	ROBOCODE	Higher ed-ucation	N/A	N/A	J
	Greco (2004)	NIM	Higher ed-ucation	N/A	N/A	C
	Xie et al. (2005)	WBMT	Higher ed-ucation	N/A	N/A	C
	Ernst (2006)	Groupthink	Higher ed-ucation	N/A (groups of 7-10)	Questionnaire	C
	Foss and EIKAAS (2006)	PIDstop	Higher ed-ucation	250	Questionnaire	C
	Ebner and Holzinger (2007)	Internal Force Mas-ter (IFM)	Higher ed-ucation	108	Questionnaire	J
	Joiner et al. (2007)	Racing Academy	Higher ed-ucation	161	Observation	C
	Chang and Chou (2008)	Bomberman	Sec. & Higher ed-ucation	N/A	N/A	C
	Kordaki (2011)	N/A	Primary education	20	Questionnaire	J

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Table 2.2 – cont'd from previous page

Field	Author(s), year	App. Name	Target group	Participants	Research method	Pub. type
	Couceiro et al. (2013)	N/A	Higher education	103	Questionnaire	J
Music	Turnbull et al. (2007)	Listen Game	General	225 (songs)	Questionnaire	C
	Law et al. (2007)	TagATune	General	11	Questionnaire, Observation	C
	Mandel and Ellis (2008)	MajorMiner	General	434 (groups of 252 and 182)	Case study	J
	Kim et al. (2008)	MoodSwing	General	100	Case study	C
Foreign languages	Li et al. (2012)	Millionaire Language Game	Primary education	42 (groups of 36 and 6)	Observation, Interview, Test	C
	Sahrir and Yusri (2012)	N/A	Primary education	128 (groups of 115 and 13)	Questionnaire, Observation, Interview, Testimonials	J
Environmental education	Vasconcelos et al. (2009)	SimParc	Professionals	30	Interview	C
	Pereira and Roque (2009)	Living Forest	Primary & Sec. education	30	Questionnaire, Video recording	C
	Yongyuth et al. (2010)	AgriVillage	Higher education & Professionals	20	Questionnaire	C
General	Leemkuil et al. (2003)	KM Quest	Professionals	41 (groups of 18 and 23)	Questionnaire, Interview	J
	Pivec et al. (2004)	UniGame	General	N/A	N/A	J
	Hwang et al. (2012b)	N/A	Primary education	50 (groups of 29 and 21)	Questionnaire, Tests	J

2.2 DGBL & General pedagogical approaches and theories

Speaking about learning, special considerations should be given into identifying and analysing all these parameters that a DGBL system should incorporate in order to fulfil its educational scope and cover the purpose of its design. Thus, in parallel with everything else, special analysis and discussion should be made on the pedagogical theories that a (m)DGBL system may embed and capitalize on.

In this context, there are several learning approaches and knowledge space theories that one could identify within a (m)DGBL environment, and concentrate on their impact in learner's progression as well as on the ways learners learn, such as: *Problem Solving* (Mowrer, 1947), *Exploratory Learning* (Bruner, 1961), *Constructivism* (Piaget, 1970), *Scaffolding & Social Constructive* (Vygotsky, 1978), *Problem-based Learning* (Barrows and Tamblyn, 1980), *Experiential Learning* (Kolb, 1984) that builds upon the work of Piaget and Lewin, *Task-Based Language Learning (TBLL)* (Candlin, 1987), *Situated learning* (Lave and Wenger, 1991), *Brain-based Learning* (Caine and Caine, 1995), *Procedural/Conceptual knowledge* (McCormick, 1997), *Self-Determination Theory (SDT)* (Deci and Ryan, 2011), *Experimental Learning* (Nielsen-Englyst, 2003), to mention just a few. In the following we briefly refer to the most important and relevant of these learning theories and present some characteristic examples of their app in the (m)DGBL ecosystem where applicable.

Aristotle once said, *"For the things we have to learn before we can do them, we learn by doing them"*. Based on this philosophical statement, various pedagogical terms have been arose to label the process of learning from experience. John Dewey discussed Learning by Doing, while much later Wolfe and Byrne (Wolfe and Byrne, 1975), used the alternative term of Experienced-based learning having four phases: "design", "conduct", "evaluation", and "feedback". Another commonly used term for the same theory is that of Experiential Learning (we will keep this term within this section). Pervading a DGBL environment with these theories, is being considered that motivates learners' experience since it stresses out the importance of direct experience (by-doing) and reflective observation. Under this prism, learning begins with a concrete experience followed by collection of data and reflective observations about that experience. According to the "abstract conceptualization stage", which is a basic component of these theories, learners shape new knowledge by drawing hypotheses stemming from newly generated experience. This process starts with the formation of generalizations on the learner's side followed by conclusions. In the final stage, learners use the active experimentation process to test fresh viewpoints and hypotheses under new circumstances. To sum up, this model emphasizes on the continuous nature of learning and the appropriate feedback, which provides the basis for a continuous process of goal-directed action (Kolb, 1984). In the literature, there exist several examples of games built on the basis of experiential theory. The vast majority of them are simulation games such as Total Knee Arthroplasty described in subsection 2.1.2.

Within the same context, Constructivism Learning approach was built upon the Experiential Learning theory. Under this approach, learners rely on real life experience to construct and conditionalize knowledge by bringing their prior skills and knowledge to the class community. By doing so, they become self-directed. The educator's role is to mentor the learner during heuristic problem solving of ill-defined problems (see next section) by enabling quested learning. Enforcing the problem-driven and adaptive learning approach within a Collaborative Learning setting, learners are expected to collaborate within a team, exchange ideas, and communicate with other groups. This approach leads learners to enhance their skills pertaining to problem solving, an important feature of human skills (Rasmussen, 1983). For accomplishing it, there is a need of using certain methodologies for learners to find solutions to a given problem, shape new knowledge, and draw their own needs and capacities (Vygotsky, 1978).

Generally speaking, knowledge is primarily generated from experience with complex tasks rather than from isolated activities like learning and practising separately. Skills and knowledge are usually best acquired within this context. In fact, this triptyque of problem solving skills of tasks has been clearly pointed out by Vygotsky and includes those performed independently by a student, the ones that can be done with the help of others, and finally those that cannot be performed even with help. Concluding, when a collaborative learning feature is embedded in an education environment it forces teams to exchange information as well as produce ideas and simplify problems toward delivering a solution. This Constructivism methodology should guide the design of an effective learning environment. In literature, one can find several examples of games built on the foundations of this experiential theory. Most of them are simulation games like the PIDstop and Racing Academy ones mentioned in subsections 2.1.3 and 2.1.4 respectively. Other game examples which take advantage of this learning theory are the works of Kordaki (2011) and Couceiro et al. (2013) discussed in subsection 2.1.4, as well as BuinZoo, Evolution, and ZooQuest summarized in subsections 3.2.1 and 3.2.2.

Concentrating on finding a way for learners to be motivated and kept interested in a mDGBL app, one can also refer to the *Self-Determination Theory (SDT)*, that is based on *Cognitive Evaluation Theory (CET)* and *Organismic Integration Theory (OIT)* by Deci and Ryan (Deci and Ryan, 2011). In fact, SDT represents a meta-theory framework that studies the motivational characteristics and personality of humans in many respects. Primarily, the main objective of this learning theory is defining *"intrinsic and varied extrinsic sources of motivation"*, and describing the role and the individual differences of these sources in cognitive and social development of learners. Based on the aforementioned theory, for a mDGBL environment to keep learners' motivation and engagement in high levels, it should address the next three psychological needs of *"autonomy"*, *"competence"*, and *"relatedness"*. Consequently, if any of these three psychological needs is not fulfilled or thwarted during (m)DGBL activities, this is anticipated to have a negative impact on the wellness of such an environment.

Concentrating on DGBL, one can find in the literature several instances of adaptation of the above mentioned learning theories to the digital educational games terrain. A characteristic example of this situation is *UniGame* proposed by Pivec et al. (2004). This software embeds in its logic both the Constructivism Learning and Collaborative Learning theories. Actually, it is a social skills and knowledge training game that can be classified as an RPG. According to the game's plot the teachers are able to define various topics, thus parameterising the game depending on the particular case. After logging in, users are able to select between different game themes and decide for a team. Another example, but this time within the business domain, is *KM Quest* (Leemkuil et al., 2003). This is a web-based simulation game aiming at developing core knowledge management skills with situated problems, using Collaborative Learning. It is played by teams up to three players who are put in charge of a virtual company. The general goal of this game is to optimize the level of a set of general organizational effectiveness variables such as market share, profit, and customer satisfaction index. Note that UniGame and KM Quest are mentioned here because they do not fall within any relevant category in section 2.1. However, they are also included in tables 2.1 and 2.2 for reasons of completeness.

On the other hand, Conversation theory proposed by Pask (1975) attempts to explain how interactions lead to "construction of knowledge". This theory derives from cybernetics, i.e., the study of communication and control in natural and artificial systems, and its more recent extension to second order cybernetics, the study of the mechanisms by which a system can understand itself. According to Pask, communication cannot be seen only as message exchange through a passive and transparent infrastructure. Rather, he re-conceptualized it as a program sharing and linguistic interaction deployed over a pervasive computational medium. Under this prism, media are considered as active computing systems in which all the relevant individuals (people and systems) converse. Sharples (2002) explored how Conversation theory could facilitated even on mobile devices in a variety of contexts. According to the author, technology should be utilized and placed within the context of conversational space in one or more ways as follows: a) use of computer to take the role of (human) teacher, and thus provide computerized instructions, b) use of an electronic environment which enables and stimulates conversations between learners, or c) use of mobile devices to assist such conversational learning practices by integrating learning materials across different places. For example, by making the necessary connections between exhibits in a museum, and by storing the relevant information of learning actions for later retrieval and reflection.

A more pedagogically-oriented game is *Virtual Interactive Student-Oriented Learning Environment (VISOLE)*, which comprises a DGBL environment (Jong et al., 2010) that takes into account several pedagogical approaches, including: constructivism, situated learning, scaffolding, and reflection. This game revolves around an online interactive virtual world model that comprises a set of multiple components that are not fully "virtual", but come across and function much like their real-life counterparts. By acting in this "virtual world" students shape and develop their own knowledge. Apart from giving the chance to the students to gain the necessary knowledge on specific subjects, the major purpose of VISOLE is to sharpen their skills and augment their knowledge of how to solve a particular problem. Another game that makes use of the principles of situated learning is the EcoMOBILE one discussed in subsection 3.2.1 of the thesis.

Farmtasia (Cheung et al., 2008) is another online game based on the VISOLE philosophy. This game encompasses subject areas from distinct fields including biology, government, economics, technology, production system and natural environment, and provides players with a first-hand immersive experience to interact and to shape the development of a realistic virtual world.

In relation to what was mentioned in the start of this section, another learning theory is that of Discovery Learning. It is a theory of Inquiry-based Instruction and is considered as a Constructivism-driven approach to education. This theory is supported by the work of learning theorists and psychologists J. Piaget, J. Bruner, and S. Papert. Actually, Discovery Learning takes place in *"problem solving situations where the learner draws on his own experience and prior knowledge"*. This is a method of instruction through which students interact with their environment by performing experiments, exploring and manipulating objects, and dealing with questions. Hence, designing a game to take advantage of both Problem Solving along with Discovery Learning, motivates learners to build new knowledge upon the design of new ideas, rather than use barren teaching information. Taking the simulation games category as an example, it is clear that such games offer possibilities to students to interact by exploring and manipulating objects in an attempt to reach to a conclusion by testing a number of hypothetical solutions. Thus, while experiencing the game world, students become active participants in the learning process and their motivation may even shift from extrinsic to intrinsic rewards. Simulation games such as MOBOCity and Space Goats ones discussed in subsection 3.2.3, seem to have been greatly influenced by this learning theory.

On the other hand, the Problem Solving theory Pivec (2007) delves into the features that an educational game should possess for learners to acquire skills: a) "narrative-based" games where chance is a factor, b) "real-time action", c) "game situations" must be divided into scenarios and/or specific goals relatively simple to reach, d) "accurate problem descriptions", e) "real-time monitoring" of the other players/opponents position and activities, f) "open-endless", g) "background knowledge" of content, which is vital for a successful completion or victory. Characteristic examples of games built having the aforementioned learning theory in mind are BuinZoo discussed in subsection 3.2.1, and Evolution referenced in subsection 3.2.2.

Beyond the term of Problem Solving, in literature one can find teaching methods based on Problem Posing (Moses et al., 1990), which also incorporates a problem solving phase. In scientific inquiry, the correct formulation of a problem is often a more significant task than finding a solution to the problem itself. In addition, by focusing on how students pose problems makes it easier to understand what can be learned from studying the way students solve problems, and vice versa (English, 1997). Thus, the authors in Chang et al. (2012) propose a system that embeds DGBL problem solving method into a problem-posing system with four phases in mathematics learning: "problem posing", "planning", "problem solving", and "looking back" (feedback). The problem solving phase is implemented via game-scenarios to support students in the process of problem-posing, allowing them to fully engage in the problem-posing activities. In the same study it is also investigated the effect of the designed problem-posing system on students in the following ways: "problem-posing", "problem-solving ability", and "flow experience".

Another key element that should be examined when designing a game, is whether or not it needs to embed meta-cognitive instructions. Cognitivism is rooted on the progress and development of humans cognitive abilities that are being characterized by a mental process that takes place through a spiral action of the following stages: *"recognizing", "recalling", "analyzing", "reflecting", "applying", "creating", "understanding", and "evaluating"*. Cognitivists such as Piaget, Bruner, and Vygotsky consider that learners fall into an active learning process that is being structured from specific procedures and techniques that lead learners to build internal cognitive mechanisms. Within this process, learners need to create a learning schema that will be built upon Scaffolding in order to adopt their knowledge. The educator's role is pedagogical in that the instructor should develop conceptual knowledge by managing the content of learning activities. This perspective relates to the early stages of learning where the learner solves *well-defined* problems (see section 2.3) in order to learn.

In relation to what was mentioned in the start of this section, Brain-based Learning was introduced to DGBL environment for teaching introductory programming courses among others. Under these circumstances, the cultivation of meta cognitive skills such as: *How do you know what you know?*, is fundamental since this process helps learners to leverage the information gained throughout the learning process and guide them to transform it into knowledge. Following this approach, learners are stimulated to explore, gather and use the necessary information to reach a learning goal. Additionally, working in teams to solve complex problems promotes collaborative learning and strengthens student's interpersonal communication skills. As discussed in subsection 2.1.4, Nim and Hangman are two characteristic examples of games capitalizing on Brain-based learning. In these two games the learners are able to observe the different outcomes produced after applying different inputs. The process can be repeated again and again in order learners to experience and explore different results. Using this iteration of such action and reaction cycles, learners are being kept active within the learning process (Rajaravivarma, 2005).

On the other hand, regarding the cognitive process, different types of games own dissimilar sets of features that need to be considered in respect to their app for educational purposes and according to their knowledge genre (type). A type of knowledge that enhances students' cognitive process is the so-called *Factual Knowledge*. This is knowledge basic to specific disciplines and refers to essential facts, terminology, details or elements the students must know or be familiar with to understand a discipline or solve a problem in it. An example of a DGBL environment in this category is *EMERGO* (Nadolski et al., 2008). This game provides a methodology and generic toolkit for developing and delivering games aimed at the acquisition of complex cognitive skills in higher education. The EMERGO methodology has been designed as a game implementation following the *"Analysis", "Design", "Development", "Implementation" and "Evaluation" (ADDIE)* approach (Branch, 2010). In EMERGO, learners interact with realistic problem situations within a rich and challenging learning environment. Through this interaction, they encounter and observe the results of their actions. Based on this experience the learning process gets personalized and therefore more attractive to students.

Another parameter that should be taken into consideration is whether or not *adaptation* needs to be embodied in a DGBL environment, and how this quality enhances learning experiences and improve learning success. This can be done by enabling a game to constantly and dynamically adapt its learning and gaming activities to meet the individual learning progress and underlying pedagogical strategies. In this direction, there are a lot of characteristics (capabilities) that a learning environment should incorporate in order to be classified as adaptive. According to Paramythis and Loidl-Reisinger (2003) a learning system should be capable of actively monitoring learners' activities and act according to their needs. Particularly, it should record and analyze learning process, interpret the outcomes, and dynamically adjust the learning aims based on the feedback received. According to the authors, adaptation in learning environments can be categorized as: *"Adaptive Interaction", "Adaptive Course Delivery", "Content Discovery and Assembly", "Adaptive Collaboration Support".*

Adaptivity has been considered by the *ELEKTRA* model (Kickmeier-Rust and Albert, 2007), which is grounded on *Competence-based Knowledge Space Theory (CbKST).* As the authors of ELEKTRA model highlight, this intervention is not only related to the learner's cognitive background and the progress they have made during their learning stages, but also to the pedagogical strategies and the motivational characteristics the educational environment encompasses. They also mention that while this model has been developed for a specific app, it can also used as a reference model for building other adaptive DGBL systems.

Last but not least, special consideration should be given in methods of how the mistakes being made by the learners are being evaluated and used by the DGBL environment for improving learners' achievement and progression. In this respect, *Learning from Mistakes* theory (Prensky, 2001), could be valuable toward this important goal. Most would agree that in a DGBL environment, mistakes and trial and error processes can be seen as a perfect challenge to learn, due to its motivational power that keep players in a constant try-feedback loop, so as to help them to reach to a final solution (Pivec et al., 2004).

In the next section, we elaborate on the problem formation, theoretical frameworks, and other characteristics within a learning system.

2.3 Problem formation

According to the previous discussion, there are learning theories that are being characterized as problem-oriented. Putting this feature into a (m)DGBL environment it becomes clear that problem formation (referred to as "problem" in the following) is actually more critical than that of finding its solution, and thus special attention needs to be given to its structure and the process of shaping it. In the previous subsection, we elaborated on *"problem solving"* and *"posing"* methods being used in learning environments in general for students to find a solution to a given *problem.* Within this context, we identify and analyze two types of problems for each of the aforementioned methods. This will allow one to constructively choose how to embed them in a (m)DGBL environment that is being characterized as "problem-oriented", in a way that will motivate and fulfil specific learning goals.

Regarding the problem solving method, problems can be classified into *well- or ill-structured* (Jonassen, 1997). A problem that belongs to the former category has specific goals, well-defined solutions and answers. Opposite to that, the latter are usually those whose structure lacks definition. One can say that ill-structured problems have unclear goals and incomplete information with reference to the challenging tasks. The selection of the problem structure type depends on the priorities pertaining to the situation at hand. Despite the fact that a well-structured problem answers a well-defined workflow and reaches many times to a specific and clear procedure that gives emphasis to a specified final solution, ill-structured problems are more meaningful for the problem solver, because they offer them more opportunities to use different problem solving strategies (Papert, 1993).

Similar to the problem formation, in the context of problem solving, an equal level of attention should be paid to the problem formation in the problem posing method. A well-posed problem stems from a definition given by Jacques Hadamard and examined further by Jaynes (1973). Hadamard was a mathematician, and like the others, believes in the same principle that the physical phenomena could be modeled using mathematics. This is because any physical phenomenon has a unique and known solution that continuously changes in relation to its initial conditions. Problems that are not well-posed in the sense of this principle are termed ill-posed, similar to ill-structured ones. Inverse problems are often ill-posed. For example, the solution of the heat equation is being considered as a well-posed problem, since one can easily conclude to a final solution from the given data (temperature). Examining now the reverse way of the heat equation, the solution cannot be characterized as well-posed, since it is very difficult to determine the temperature from the final data.

In the next section we identify game characteristics that are of vital importance when it comes to (m)DGBL.

2.4 Game orientation and other characteristics

During the analysis and design phase of a (m)DGBL environment, a plethora of issues should be examined in order to determine several aspects of the game, including: game orientation (which target group the game should focus on?), the number of players that interact with the game (be a single player or multiplayer?), levels of interactivity (response-feedback, observe, chase and catch, etc), the type of graphics that the game should embed, the platform (hardware and/or operating system) that will be destined to, etc.

Under these circumstances, a first major step is that of determining game's orientation by identifying the target group the game should concentrate on. Regarding this strategic direction there are several choices for one to select from. To name just a few: a) the educational needs, e.g., at higher education and for which course?, b) support the curriculum of secondary and primary schools and for which lesson?, c) corporate education and for which topic?, d) cover in generally a lifelong learning program and for which topic? The above analysis is crucial, since the collected educational material is important to match the different learning skill levels and meet the diverse learning challenges. All the above mentioned questions that arise regarding the need, the kind and the use of a game in higher education are being discussed in detail in the analysis phase of EMERGO methodology given in section 2.2.

Also, as already pointed out, the number of players is of major importance when designing a game. Putting it another way, independently of the purpose a game is designed for it can be very different in its single and multiplayer versions. For instance, as detailed in section 2.2, a multiplayer game could promote team's collaborative skills. This can be achieved in a collaborative environment, where 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 her self-confidence. Table 2.1 shows that from the total of 36 non-mobile games, the 25 are characterized as single player, 4 as multiplayer, 5 as group-based, and 2 as a two-player one. Similarly, from the total of 35 mobile games included in table 1, 25 offer single player functionality, 3 are both single player and group-based, 1 is designed solely for two-players, 2 are implemented as multiplayer and group-based, 1 solely as group-based, and finally 1 is purely multiplayer. The MRLS game described in subsection 3.2.2 supports both single and two-player gaming. Also, TimeWarp described in the same subsection, offers both single and multiplayer functionality.

Another characteristic that should be examined is the level of interactivity (Thornton and Cleveland, 1990) that is of great importance for a game in order for it to possess characteristics such as action-reaction, experimentation, test of a solution, observe and response-feedback, and so on. Johnston and De Felix (1993) suggest that the *"dynamic visuals", "rules", "goal" and "interaction"* are essential features for a game to have. Baranauskas et al. (2001) on the other hand stated that the essence of playing is *"challenge and risk"*. Similar to the previous work, the author in Malone (1981) argued in favor of a more general approach identifying four elements deemed necessary for virtually any game: *"fantasy", "curiosity", "challenge" and "control"*. Following the same point of view, we argue that it is critical to place the right player's goals when designing achievements, and choose between if they succeed them individually or throughout their collaboration with others.

Taking Graphical User Interface (GUI) into account, one needs to examine the visualization techniques that should be used. This is important, since a well-designed GUI will keep learner's attention in a high level and lead them into choosing the game over any other educational material in their study. Opposite to that, a game designer should take into consideration not only the usability issues -*dash think of a game and how this could be more attractive and playingfull* -dash but should also focus on which mobile platform the game will be deployed. In addition to this last point, one needs to take into consideration mobile device idiosyncrasies such as hardware limitations for assuring that the final outcome would be lightweight in terms of resource utilization.

Given the mDGBL orientation of this work, within the next section, an attempt is made to discuss usability issues that are strongly related to mobile device constraints, e.g., screen size, and the technologies being used so far for content adaptation pertaining to small-screen devices.

2.5 DGBL theoretical frameworks

An DGBL framework encompasses a general conceptual model and a reference architecture for designing learning systems that put emphasis to gaming. In this respect, among others, such a framework can be used a) to bind the different components the learning system embodies with the corresponding educational and pedagogical theories, b) to describe the applied technological infrastructures (e.g., servers, proxies, etc), c) to discuss methods for delivering adaptive content throughout various communication interfaces, d) to describe techniques for effective content adaptation due to hardware constraints such as those discussed in section 3.4, e) to assess the effectiveness of a DGBL product from a pedagogical point of view.

Connolly et al. (2008) survey a great mass of research works germane to DGBL and propose a framework that can serve as a reference towards evaluating DGBL products based on the following basic criteria: a) Learner's performance, motivation, perceptions, attitudes, and preferences, b) Game environment, c) Elements of collaboration, and d) several sub-criteria, including usability, level of social presence, deployment, etc. Also, the framework takes into account characteristics closely related to the DGBL's virtual world such as: "background environment and characters", "environment alteration factors", "advice importance", "game difficulty", and others. Some criteria are evaluated with reference to the pedagogical aspects and learning outcomes, including "advices and resources", "task completion time and easiness", "conversation analysis", and so on. The framework uses an experimental methodology that focuses on both pre- and post-test evaluation processes. Finally, the authors propose an adaptable example of this framework and explain how to extend it for evaluating any DGBL environment that supports a specific learning topic, under specific requirements, and addressed to a specific educational level.

From a pedagogical theory point of view, *NUCLEO* (Sancho et al., 2009b) is a characteristic example of a DGBL framework rooted in social constructive pedagogical theories, discussed in section 2.2. In fact, NUCLEO is an e-Learning framework that encompasses a pedagogical strategy along with the technological infrastructure to support it. It combines *Problem Based Learning (PBL)* (Savery and Duffy, 1995), *Computer Supported Collaborative Learning (CSCL)* (Koschmann et al., 1996), and a multiplayer RPG scenario within a 3D graphical interface. In NUCLEO, learners participate in an imaginary scenario, fighting enemies in order to become a *"Paladin"* by completing a number of missions within a *Multi User Virtual collaborative learning Environment (MUVE).* In this environment, team formation and role assignment follows Vermunt's classification and adaptation model of learning styles. Specifically, the framework applies the *Inventory Learning Styles (ILS)* (Vermunt, 1994) for identifying those learners who need more support and guidance during their learning process, in contrast to others who are capable of keeping up with the syllabus. Also, NUCLEO embeds the experience gained from other Learning Management Systems (LMS) and is being integrated within *Moodle*

LMS. So far, two different prototypes were developed based on this framework, namely *Mundo NUCLEO* (Sancho et al., 2009a) and *Mare Monstrum* (Sancho et al., 2009c).

The ELEKTRA model discussed in section 2.2, is mainly devoted to educational content automatic adaptation by providing the necessary interventions during gaming for keeping the appropriate balancing between the challenges created by the game and player's ability. This is important not only for designing and implementing the appropriate learning scenarios, but also for keeping learners motivation in a high level. This framework models problem solutions on both a macro and micro level for a problem solving task by implementing the necessary interventions within the game environment. Additionally, according to the authors, due to the growing demand for standardizing rich resources (learning objects) for easy reference and global use, this framework is supposed to address the growing demand for the reusability of such learning content within the field of educational technologies (Kickmeier-Rust and Albert, 2007).

Another gaming framework that encompasses experiential learning to utilize flow experience is described in Kiili (2005). The *"Flow Theory"* presented by Boredom (1975) is used as a framework for facilitating positive user experience in work and gaming. Csikszentmihalyi (1992) described "Flow" as a fuzzy zone in which "psychic entropies" of "anxiety" and "boredom" might not occurred when the designed activity is too boring or its challenging levels are too low. Regarding "flow" and DGBL there are several works in the literature that examined it from several perspectives. Finneran and Zhang (2003) proposed the model *"person-artifact-task (PAT)"* to conceptualize human and computer interaction at every stage of "flow" experience. According to the authors, "artifact" is a broad term to describe the elements being used in a game (i.e., "both tools and toys"). Skadberg and Kimmel (2004) deal with major usability factors such as speed and easiness of use. Taking the above into account, Kiili's framework focuses on the importance of providing accurate and immediate feedback to payers' actions, with specific, clear goals and challenges according to their special skill levels. A game example that relies on flow theory is ZooQuest discussed in section 3 of the main manuscript.

The game proposed by Hwang et al. (2012b) seems to capitalize on the principles of experiential learning in an effort to promote flow experience. This is a web-based boardgame that aims to improve learners' learning performance. To do so, students conduct problem solving activities by answering questions that are hidden on a digital board.

After rolling a digital dice, the student makes a move on the board, and depending on the current position, a task is assigned to her. This task is either an "information-searching question" that requires the player to search the relevant information on the web with the aim to answer a series of questions related to a specific learning topic, or a "mini-game". The latter helps the students to acquire further educational material for the targeted learning topic, which normally cannot be easily found on the web. Note that this game is mentioned here (and included in tables 2.1 and 2.2) because it does not fall within any category of science education identified in section 2.1.

Last but not least, a general framework for designing a *Serious Educational Game (SEG)*, is proposed by Annetta (2010). The author concentrates on the following six basic "nested" elements for educational game design: *"identity", "immersion", "interactivity", "increasing complexity", "informed teaching", and "instructional"*. Each of them is being discussed in detail in conjunction with the relevant theory pertaining to the educational and psychological field of interest. According to the author, this work also capitalizes on the research results obtained from long-lasting experience on educational games development and others gathered after testing numerous commercial video games.

Chapter 3

Mobile Digital Game-based Learning

3.1 Learning through mobile games

Modern mobile phones, also known as smartphones, have emerged as one of the most developing markets worldwide. Ericsson's mobility report (Ericsson, 2017) estimates that the actual number of subscribers around the world is estimated to rise up to 9 billion and 5G subscriptions will exceed half a billion by the end of 2022. Given this dynamism, m-Learning can play a significant role not only for formal learning, e.g., either in a classroom or on the move where students can use their mobile devices to access course materials, but also for informal lifelong learning, which is not necessarily tied to a program of study and takes place on an ad-hoc basis.

Therefore, designing a game for teaching purposes is far from being straightforward since there are a lot of issues that should be taken into consideration. Precisely, game developers need to be ready to answer a lot of questions and clarify the general orientation of the game before start implementing it. This debate is even more important when it comes down to mDGBL. This is due to the intrinsic limitations of mobile devices, including limited computation power, limited battery capacity, restricted user interface, etc.

Having explored the DGBL domain in the previous chapter, this one moves up to the second milestone by investigating and detailing on the various mDGBL apps found in the literature in a time period of 12 years, i.e., from 2004 to 2016. It also defines a six-dimensional framework, which is used to ease the study and classifications of the various characteristics observed in each work of interest.

Based on the above theoretical considerations, the framework consists of the following dimensions:

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

Specifically, we consider the above dimensions as an appropriate framework for systematically studying existing mDGBL implementations for two reasons:

I. They align with most approaches found in the literature of m/u-Learning, as previously outlined in this section.

II. They are most relevant with the characteristics of mDGBL apps found in the literature so far, i.e., challenge, competition and collaboration, role play and identity, place-based contextual learning (Squire and Jan, 2007).

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

I. In the first axis, we have identified specific *mobile game characteristics* of the mDGBL apps 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 technology could be utilized in different platforms, such as the mDGBL 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 as characteristics of games on mobile platforms and they identified 75 new patterns. We are based on these latter patterns, having proposed some additional GDPs that were identified in the mDGBL apps included in this survey.

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

Using the above framework we do not assume that existing mDGBL 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 mDGBL apps.

For the survey part of this work, a review of key literature published in English to identify relevant contributions has been performed. 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 mDGBL products or other non-published efforts remain outside the scope of this thesis, 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 7,340 articles. After the initial screening of articles, by reading first the abstracts and the conclusions, and later 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 mDGBL environments, while the others were utilized for the related work and for supporting our arguments. In this regard, the survey of mDGBL works presented in this thesis is as far as possible exhaustive, and to the best of our knowledge the sole one in the literature so far.

3.2 Context-aware m/u-Learning and mobile games

As already pointed out, in this section, we succinctly discuss existing work found in the literature regarding the mDGBL ecosystem between the specified time frame. Firstly, this is done by identifying the mobile Game Design Patterns (GDPs) (Davidsson et al., 2004) that a mDGBL environment incorporates in its design in order to accomplish its learning strategy. Secondly, 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 mobile, ubiquitous, and context-aware learning experience.

Figure 3.1 categorizes every mDGBL work found in the literature. Specifically, in the left part of this figure the classification is done per framework dimension, and each work is discussed based on the various GDPs and learning activity strategies that belong to the corresponding dimension where applicable. Note however that the classification is rather loose, meaning that the same work may be present in more than one dimensions.

3.2.1 Spatio-temporal dimension

Portable devices, due to the 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. Thus, modern mobile devices utilize this dimension to deliver learners a meaningful learning experience, by placing them in an authentic learning context anywhere and anytime. Even the most basic learning activities can be encapsulated within a meaningful learning context

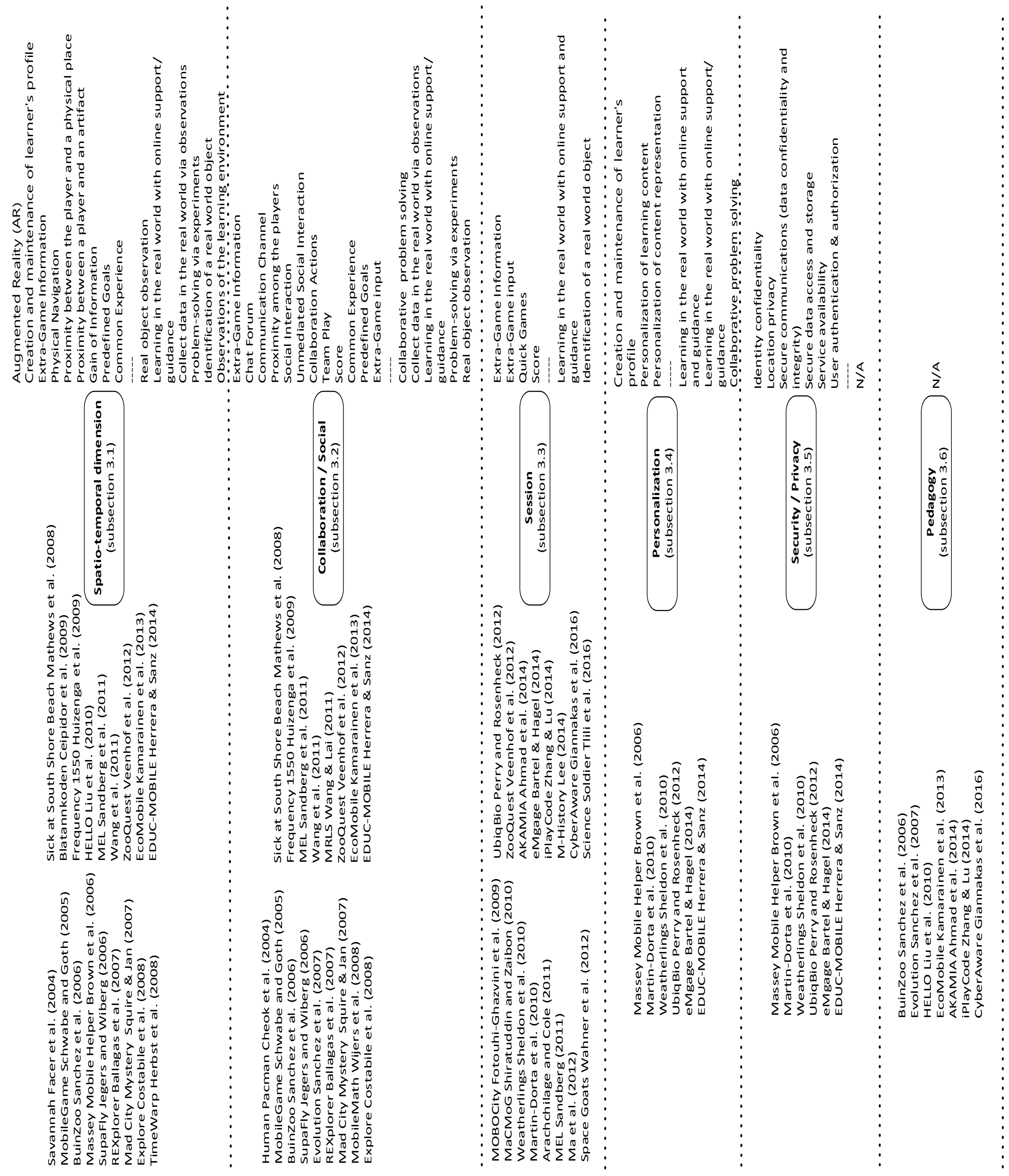

Figure 3.1: A loose categorization of works per dimension. The associated with each dimension, learning activity strategies and GDPs (separated by a dotted line) are shown at the right side of the figure.

in different situations and activities. More 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 also engage them in a context-aware u-Learning activity as well.

The spatio-temporal dimension may be addressed in different learning scenarios in order to increase learners' motivation by triggering specific learning activities, and give them 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 app 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 mDGBL apps for addressing mobile and ubiquitous, and/or context-aware learning experience. An example of this situation was given by Sánchez et al. (2006) who developed a situated mDGBL app named *BuinZoo* in order to support learners' navigation in a zoo. The app 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 proximity pattern is supported by blending the game scenario with ubiquitous technology characteristics such as the QR code. In the learning scenario, the players must decode a sequence of riddles by scanning the relevant QR codes scattered around the museum that 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 (Herrera and Sanz, 2014) with *EDUC-MOBILE*, and English language learning (Liu et al., 2010) with *HELLO*. These two games trigger certain educational activities, such as question answering, upon proximity with certain artifacts tagged with QR labels, while 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 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, and uses these positions 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 mDGBL apps. 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 also operates in the real world and a virtual world of the animal inhabitants is digitally reproduced, giving a sense of immersion in its players. 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 mDGBL apps 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. 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), and then a mini game starts (e.g., *Jigsaw puzzle, Memory, Multiple choice quiz, Spelling quiz, Yes or No*). In order a student to catch the animal and return it to its cage, she needs to answer correctly three questions in the English language in a row.

Data collection in the real world via observations learning activity strategy is also identified in several mDGBL apps. 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 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 it and search and 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 conclude to 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 app towards providing students with further information regarding the visited places 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 mDGBL environments. For instance, as previously discussed, *EcoMOBILE* (Kamarainen et al., 2013) combines learning in physical space with AR experience in order to assist middle-aged school students to understand different concepts and perform experiments related to the physical space. This type of activities are 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 mDGBL apps. Hwang et al. (2008) argued that in order for a learning environment to provide 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 app continuously tracks learner's physical position using GPS. When a player is in proximity with a specific location in the University (laboratory, library, etc.), then the app 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 mDGBL app 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 are 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 having special historic interest. If an interesting historical place is in proximity, a *heartbeat* 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) mDGBL app 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 app 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, say, a lion could better survive in its physical environment.

A quite similar approach is met in mDGBL apps 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 learning 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 mDGBL apps 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 aiming of guiding the learner to identify an animal in the real world.

3.2.1.1 Summary of spatio-temporal characteristics and strategies

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

- *Augmented Reality (AR).*
- *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 context information in the physical space during the time. When implementing a 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 general known to give further value to the learning process (Liu et al., 2010, Kamarainen et al., 2013). For instance, an mDGBL 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 mDGBL 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 that we identified in the discussed mobile game apps, as proposed by Hwang et al. (2008). 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 mDGBL 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 mDGBL 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 mDGBL app utilizes both 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 the next subsection, augments only physical space characteristics for teaching the learners mathematical concepts. This is done by having the players to virtually draw four 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, *Frequency 1550* (Huizenga et al., 2009) augments both spatial and temporal characteristics for assisting the learner to navigate in medieval Amsterdam.

3.2.2 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, development of critical thinking, and so on. Within this context, learning and context awareness in an m/u-Learning environment may be formulated 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 mDGBL environment it is well known to not only enhance knowledge acquisition, but also to nurture and foster the development of several skills, in addition to those discussed above, such as self-direction learning, problem-solving skills, peer assessment, socializing, etc.

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 mDGBL app 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 collaborative 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 here is the *Collaborative problem solving* one. 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 eight teams are equipped with a mobile device and scattered to a certain, pre-determined physical area. There, each team needs to score as many points, as possible by drawing four 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 subsection 3.2.1, contains a sub-game, named *The evolution game*. In this sub-game, groups of four learners must cooperatively solve a problem regarding the colonization of three species, among four classes (fish, amphibians, reptiles and birds).

MobileGame (Schwabe and Göth, 2005) also falls under the umbrella of the Collaboration/Social dimension. Recall from section 3.2.1 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 the implementation of a chase and catch type of sub-game based on specific hunting rules. Specifically, 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 mDGBL app introduced by Wang et al. (2011), the students are informed for nearby players in order to meet with others and get socialized. The game also 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 to accomplish a task.

The authors in 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 mDGBL apps 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 to acquire rhythm skills that is 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.

The *Unmediated social interaction* describes any type of communication that takes place among players, without the (m)DGBL app 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 app. 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, and after observing an interesting place, to publish relevant to it 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 mDGBL apps. 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.

3.2.2.1 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 mDGBL app, 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 mDGBL 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 mDGBL scenarios that utilize the aforementioned GDPs from different perspectives. Thus, we summarize below the learning activity strategies that we identified in the discussed mobile game apps, as proposed by Hwang et al. (2008). 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 mDGBL app 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, mDGBL apps 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 collaborations activities in their learning strategy.

3.2.3 Session dimension

A GDP that is definitely well-suited in mDGBL apps 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, puzzles, etc, are types of quick games that are considered in mDGBL scenarios with the aim of making the learning process more attractive from a learner's viewpoint.

As already discussed in subsections 3.2.1 and 3.2.2, both the aforementioned learning strategies are 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 the various activities.

Several other works utilize the aforementioned GDPs for delivering m-Learning experience without incorporating any context-aware learning activity strategy. In the context of chemistry education, Ahmad et al. (2014) designed an adventure mDGBL app for high school students named *AKAMIA*. According to the authors, 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), *Science Soldier* (Tlili et al., 2016), destined to 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. More 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 accordingly their strategy.

3.2.3.1 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 mDGBL 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 mDGBL scenarios from different perspectives. Following the methodology of the previous subsections, we identified below the learning activity strategies that these mDGBL apps elaborate with reference to this dimension (Hwang et al., 2008). These are associated with:

- *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 mDGBL apps.

3.2.4 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 personalized 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.

3.2.4.1 Personalization strategies

In general, a learning environment and specifically an mDGBL 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 be based 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* (Brown et al., 2006) game constantly records learner's physical location and other information for creating and updating her profile. After that, based on the gathered personal information, a server delivers to the student personalized contextual data to ameliorate the game experience.

In the literature there is also a variety of mDGBL apps that support learners and track their learning curve, by recording quantitative information, say, how much time a learner spent in a task, if the learner accomplished it successfully or not, and others, 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 mDGBL apps given in Martin-Dorta et al. (2010), *eMgage* (Bartel and Hagel, 2014), and *EDUC-MOBILE* (Herrera and Sanz, 2014), where the player logs in the system for retrieving specific learning material, viewing 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 context of

English language learning, *MEL* (Sandberg et al., 2011) builds learners' personal profile in order to support them with custom-tailored learning content.

3.2.4.2 Summary of Personalization characteristics and strategies

As previously discussed, in a context-aware u-Learning environment, data collection from mobile sensors are considered vital for supporting the learning process in a more personalized way. This requires the app to constantly track 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 mDGBL app:

- *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 mDGBL app due to certain hardware limitations, including the smaller screen size.

Following the discussion of the existing mDGBL works, we summarize below the learning activity strategies that an mDGBL app elaborates with reference to this dimension (Hwang et al., 2008). These are associated with:

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

To sum up, personalization is a quality that greatly contribute to the effectiveness of any mDGBL app. 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 app and contextual data sensed from the physical environment and via the appropriate sensors. Wang (2004) described it as *identity dimension*, meaning that the learner's unique ID is used to firstly authenticate her and then to deliver personalized learning content as the case may be. 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.

3.2.5 Data privacy and security dimension

Excluding player authentication and authorization issues, the constant engagement of the mDGBL app 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 mDGBL 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, mDGBL apps should include privacy policies that clearly inform the learners about sensitive data collection and usage, and request their implicit 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 mDGBL app. 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. The potential interaction of the mDGBL app 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 mDGBL apps deploy special security and/or privacy-preserving measures. In fact, none of the surveyed works takes into serious consideration all the aforementioned characteristics, but 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. To do so, learners use an authentication procedure to log into the system and obtain access to information regarding past learning actions. A password-based authentication is also supported in mDGBL apps developed by Martin-Dorta et al. (2010), *eMgage* (Bartel and Hagel, 2014), and *EDUC-MOBILE* (Herrera and Sanz, 2014). That is, both the 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 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.

3.2.5.1 Summary of Data security and privacy characteristics

Considering the above observations, we proposed the following characteristics that should be addressed by an mDGBL app. Note that 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 mDGBL apps included in this survey.

- *Identity confidentiality.*
- *Location privacy.*

- *Secure communications (data confidentiality and integrity).*
- *Secure data access and storage.*
- *Service availability.*
- *User authentication/authorization.*

Concluding, it is to be underlined that while the great mass of apps collect a significant amount 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. So, it is to be emphasized that today this dimension is becoming a sine qua non and must not be neglected by mDGBL implementations. The developers owe to be occupied with issues regarding end-user security and privacy when designing and implementing a context-sensitive mDGBL app, especially when this is destined to non security-savvy users. Putting it another way, the users of any mDGBL 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. As further discussed in Chapter 5, this should be highlighted as an important factor for current and future mDGBL implementations.

3.2.6 Pedagogy dimension

Sometimes, within the context of mDGBL, 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 because the content is housed inside a game. Nevertheless, the educational benefits in a leaning environment can be enhanced if it takes into account several extrinsic, intrinsic, and psychological learner's properties that occur during the learning process. These can be cognitive properties, 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 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 mDGBL environments. For instance, an important factor that also influences the design of a learning game is the learners' characteristics. In this case, there are various characteristics that a designer should take into account when designing a mDGBL app, such as the age, cultural background and needs, educational level, socio-economic background, learning styles and preferences, etc. This is crucial for the success of the mDGBL app, since each participant, depending on the target group that he/she 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 mDGBL apps. These aspects can be summarized as follows:

- The learning theories, the number of players, and the target group that characterize the philosophy and steer the design of the surveyed games.
- The educational benefits derived from each mDGBL app.
- The methodologies adopted from the authors for assessing and evaluating the pedagogical efficiency of the mDGBL apps.

3.2.6.1 Educational benefits & 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 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, they conduct 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 figure 3.3 summarizes the evaluation methods used in mDGBL works under the umbrella of the survey at hand. Additionally, table 3.3 shows each evaluation method used by the various mDGBL works.

We have also identified the educational benefits for each reviewed paper, as reported by the corresponding authors. The results are summarized in table 3.1. As observed from the table, main educational gains from mDGBL apps comprise increasing motivation, self-directedness and self-efficacy, social and inquiry skills.

3.2.6.2 Learning theories, number of players, and target group

On the other hand, the creation or amendment of a pedagogical approach by elaborating specific learning theories is the key element for building truly effective mDGBL context-aware educational games that focus on specific learning goals. The purpose 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* was based on the Attention, Relevance, Confidence, and Satisfaction (ARCS) (Keller, 1987a) motivational model.

Bar chart (D) in figure 3.3 illustrates the learning theories that drove the design in mDGBL environments. Same, table 3.2 summarizes the learning theories for each mDGBL, 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 is used 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 mDGBL environment. This is because learners are motivated in different ways. Thus, in order to stimulate learners, with the aim to keep them in learning track and maximize the learning outcomes, the learning content should be organized and presented to them in different ways, based on their special characteristics. Bart chart (B) in figure 3.3 illustrates the mDGBL apps' target group, based on learners' educational level. The 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 figure 3.3 illustrates that from the total of 36 mDGBLs 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 multiplayers. Also, *MRLS* (Wang and Lai, 2011) described in section 3.2.2, supports both single and two-player gaming.

3.2.6.3 Summary of Pedagogy characteristics

Summarising the educational gains of mDGBL, as reported mainly by the authors of the environments that were reviewed, we see that the main benefits lie in the affective domain. More work needs to be done for investigating cognitive potential 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 this section, we have identified how such strategies are implemented by existing mDGBL apps 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). Figure 3.1 summarizes the analysis of GDPs as well as context-aware u-Learning activity strategies for each dimension of the proposed framework.

3.3 Trends in mDGBL environments

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

3.3.1 Learning domains and technological characteristics

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

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

The mDGBL systems that were analysed in this study address a variety of learning domains. More specifically, bar chart (E) in figure 3.3 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 number of works for this year span, the interest in this area is constant and is anticipated to grow as mobile technology evolves.

Regarding app porting in different platforms, bar chart (F) in figure 3.3, 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 mDGBL apps 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 app to Android is not straightforward and requires significant 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 on building apps that will be suitable running on different platforms and it is sure that 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. Chapter 5 details on this last point.

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

3.3.2 Potentials of emerging technologies

Another factor that enhances learning experience, increases motivation, and spurs the design of context-based mDGBL apps, is that of emerging technologies, including Cloud Computing, Mobile AR, QR codes, etc. From a quantitative point of view, only a handful of works use emerging technologies. Specifically, from a total of 36 mDGBL apps, 3 of them incorporate QR technology, and 6 AR. Nevertheless, the potential of exploring emerging technologies should be highlighted as an important factor for current and future mDGBL implementations.

3.3.3 Summarizing the trends in mDGBL apps

Figure 3.2, gathers in chronological order all the works included in subsections 3.2.1 to 3.2.5. 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 mDGBL apps, 16 of them have been published in journals and 20 in conferences.

Also, table 3.1 summarizes all the works included in subsections 3.2.1 to 3.2.5 based on the GDPs. Recall from Chapter 1 that the term *benefits* refers to the techniques that an mDGBL app deploys in order to spur learners' confidence, satisfaction, and stimulation. Also, Tables 3.2 and 3.3 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 if these games establish collaboration activities, where available. Also, the last two columns of table 3.3 contain basic information about the assessment or description of students learning process or outcomes after using the corresponding game. That is, how many participants were involved in the evaluation process as well as the research method being used by their authors. Note that 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).

Table 3.1: mDGBL GDPs and educational benefits.

GDP def.	**App. name**	**Educational benefit(s)**
Physical Navigation (The player has to roam in the physical world in order to successfully play the game)	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.

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Table 3.1 – cont'd from previous page

GDP def.	App. name	Educational benefit(s)
	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 their daily university life.
	MEL	Learning became more "effective and efficient" since the participants learn the English language when exploring the animals at a zoo.
	MobileGame	Participants feel fun when exploring their daily university life.
	MobileMath	Learners move in the physical space and shape four vertex shapes in order to be engaged and learn about mathematics.
	N/A (Wang, 2011)	Participants learn how to be "shelf-directed" in a university place.
	REXplorer	Participants are engaged in a game quest, in order to learn about a historical place.
	SupaFly	Players develop social skills.
	TimeWarp	Participants gain historical knowledge about a city.
	Savannah	Learners are motivated when "repeatedly search around" and learn 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 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 game or answer a series of questions.

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GDP def.	**App. name**	**Educational benefit(s)**
	REXplorer	When a learner is in proximity with an interesting historical place, then further historical information is displayed on the mobile screen.
	Explore	When learners is in proximity with a historical place, they receive guided information that helps them to acquire historical knowledge.
	Frequency 1550	When a learner is in proximity with a historical place, 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 through their headphones, see still images from 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 an interesting place, she receives historical information about it.
Player-Player Proximity (The distance between the player and another player is a factor which can affect the gameplay and trigger further events in the game)	Human Pacman	Player physically tap on enemy's shoulder to obtain virtual objects.
	MobileGame	Learners get informed about nearby players in order to be met and cooperate and/or exchange information. Additionally, learners participate in a chase and catch type of game based on specific hunting rules.
	N/A (Wang, 2011)	Players are informed about nearby students.
	SupaFly	Players establish face-to-face meetings with others in order to develop social skills.

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Table 3.1 – cont'd from previous page

GDP def.	App. name	Educational benefit(s)
Player-Artifact Proximity (The 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 tags to locate and explore a museum.
	EDUC-MOBILE	The 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 position is located within the university map and contextual information is displayed to her.
	MobileMath	Learners draw four vertex shapes ("squares", "rectangles", or "parallelograms").
	N/A (Wang, 2011)	Learners schedule activities within the university campus.
	Savannah	Students are able to receive supplementary learning material in order to obtain a clearer understanding about the animals and develop new strategies.
	SupaFly	Players increase their awareness about the surrounding.
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 zone, 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.

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GDP def.	App. name	Educational benefit(s)
	TimeWarp	Learners receive augmented information about the visited place.
Communication Channels (Using mobile devices players may find alternative communication channels with which can communicate the status of the game state instead of just using the game device. Or communicate 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 concepts.
	TimeWarp	Towards a self-directed learning, players uses a communication channel in order to retrieve and display on the device screen all the available tools, the remaining time, any relevant information regarding the game, etc.
Chat Forum (A communication channel independent of game instances where players can talk to each other about a game)	EDUC-MOBILE	Players communicate with each other, in order 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 and/or collaborate in order to accomplish a task.
Unmediated social interaction (The game allows players to communicate outside channels controlled by game rules)	REXplorer	Players socialize after communicating with others and publish information to a blog.

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GDP def.	App. name	Educational benefit(s)
Quick Games (Games allowing for quick game sessions are particularly well suited for mobile games given that many mobiles games 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 security awareness.
	eMgage	Learners are engaged in quick game activities and 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.
	Mobile Rhythm Learning System (MRLS)	Students are engaged in short session games to learn about music topics.
	N/A (Arachchilage et. al, 2012)	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.

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Table 3.1 – cont'd from previous page

GDP def.	**App. name**	**Educational benefit(s)**
	Space Goats	Learners are engaged in short session game activities in order to develop critical thinking about software engineering topics.
	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 (Collaboration forces players of a mobile game to work together in order to progress in the game. This can make people who otherwise never would have met to cooperate)	Explore and Frequency 1550	Learners cooperate in teams in order to gain historical knowledge.
	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.
Collaboration (Some goals in multiplayer games can only be reached though a Collaboration Action executed by two or more of the players. 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)	BuinZoo	Biology-focused. The students develop problem solving skills.
	EcoMOBILE	Learners are engaged in pairs to problem solving activities in environmental education.

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Table 3.1 – cont'd from previous page

GDP def.	**App. name**	**Educational benefit(s)**
	EDUC-MOBILE	Learners are engaged and socialized in learning engineering topics.
	Evolution	Biology-focused. Learners are involved in problem-solving activities.
	Human Pacman	Players are engaged in physical activities and develop social skills.
	Mad City Mystery	Learners develop scientific argumentation skills.
	MEL	Learners are engaged in practicing the English language.
	MobileMath	Learners are engaged in learning mathematics.
	Mobile Rhythm Learning System (MRLS)	Students develop social skills when interacting with music concepts.
	Sick at South Shore Beach	Payers are engaged in hypothetical environmental scenarios.

Table 3.2: mDGBL apps according to their basic 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
CyberAware	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

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App. Name	**Players**	**Services, Technologies, Content**	**Learning Theory**	**Collaborative - Cooperative**
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 Pac-man	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
UbiqBio	SP	Simulation, VO, WB	N/A	No
Weatherlings	SP	Simulation, VO, WB	N/A	No
ZooQuest	SP	RP, Video, MG, QB	Constructivism	No

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Table 3.2 – cont'd from previous page

App. Name	Players	Services, Technologies, Content	Learning Theory	Collaborative - Cooperative
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

Note: 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 telecommunications technology.

Table 3.3: mDGBL apps 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
CyberAware	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

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Table 3.3 – cont'd from previous page

App. Name	**Target group**	**Participants**	**Research method**
HELLO	Higher education	20	Questionnaire, Interview
Human Pac-man	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
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

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Table 3.3 – cont'd from previous page

App. Name	Target group	Participants	Research method
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

3.4 mDGBL: Usability issues, Visualization technologies and Content delivery methods

Usability issues in a mobile environment are strongly related to the methods used for: the adaptation and implementation of the educational content, the techniques that support and deliver the educational material via the mobile devices, and the applied methods to implement specially crafted services for learning purposes. This is due to the several inherent constraints of smartphones and other modern mobile devices. These include physical limitations mainly pertaining to the small size of mobile screens, memory and storage constrains, lower processing power, limited battery life, and certain restrictions in network connectivity. Note however that some if not all of the aforementioned limitations are gradually fading out due to the advances of mobile technologies and communication networks.

In this context, a considerable mass of studies in the literature identify a number of impediments that mobile devices face when it comes to learning environments. Stockwell (2008) highlights issues germane to screen limitations, keyboard usability issues, and poor learning environments from a design point of view. Some other studies concentrate on the students' preferences on portable devices (Alvarez et al., 2011). These demonstrate that several students prefer tablets instead of laptops despite the smallest screen size in many cases. For example, the authors in (Alvarez et al., 2011) pointed out that a great percentage of students was *"feeling forced to write more concise answers when constrained to a smaller screen size, and had a positive appreciation of this limitation while portability and the absence of physical keyboard do not cause them any inconvenience for using them"*.

As already pointed out, today, due to the rapid growth of smartphones technology, some of the above hardware limitations are becoming less and less important over time. That is, mobile platform market is becoming clearer (Apple's iOS and Google's Android are the dominant ones), smartphones become more powerful and feature-rich, mobile networks infrastructures support higher data connections as the penetration of 4G and beyond networks increases, and Wi-Fi is becoming widely available, but limitations still exist.

As a result, visualization and GUI issues acquire particular value regarding the ways the educational content is being represented on mobile devices because of the screen space limitations. In this respect, a broad discussion regarding the different aspects of visualizing information between a desktop and a mobile device is made by Chittaro (2006). This work also copes with the different challenges that mobile visualization design faces, with a special focus on the presentation problems being confronted due to the small size of screen and the complexity of the displayed information. Finally, the same work classifies mobile data into five different classes of visualization, namely *text, pictures, maps, physical objects, and abstract objects*, and provides some preliminary results from tested presentation techniques per class. Overall, it is generally agreed that techniques applied on desktop computers for visualizing information are proved to be in their majority non-functional to apply "as is" on mobile devices due to the aforementioned constraints. Moreover, context visualization is becoming more challenging and complicated when it comes to mDGBL because of the demanding educational material, along with the need for aligning it with specific learning goals. In the following paragraphs we succinctly refer to some works on content adaptation with potential interest to mDGBL. However, note that an exhaustive analysis of this topic remains out of scope of this document.

The authors in (Zhang, 2007, Gimenez Lopez et al., 2009) discuss web-content adaptation for mobile devices from several perspectives and focus on obtaining content formats depending on the underlying mobile platform. The main objective of both works is that of code adjustment rather the one of the pure contents adaptation. This is because this resolution works in most of the cases where information is not easily perceived and processed via the small screen of a mobile device. Specifically, the aforementioned contributions examine modification techniques of the design style and optimization of the images and propose Cascade Style Sheets (CSS) adaptation.

Another work on visualization and content adaptation with possible app to mDGBL is given by Roto et al. (2006). The authors proposed a twofold solution called *Minimap* that adapts the web content to fit well on a mobile screen. This is achieved primarily by applying changes in CSS model regarding the size and the text of the viewing content, in a so called *"layout scaling"* phase. Secondly, at the *"scaling down"* phase, the Minimap solution adapts the maximum width of the text paragraphs to the mobile browser viewport dimensions. The work by Zhang (2007) reports on a *"Mobile Web system"* that is based on a three-tier architecture and is able to automatically adapt the content of a web page for delivering it to mobile devices. Further, the authors identify a number of approaches for multimedia content adaptation destined to mobile devices based on the work of Mao et al. (2001). This is done by examining implementations such as: *"Multiple encoding", "Transcoding", "Layered encoding" (transcaling and multicasting), and "Rate shaping"* being used for multimedia content adaptation on mobile devices.

Web content adaptation has been also tackled by Chen et al. (2005). The authors propose a method that analyzes a webpage content to decide its separation point(s) for creating smaller and easily perceivable pieces of data, thus making it more suitable for displaying it in small screen devices. To do so, the authors analyze the webpage with reference to the informational blocks it contains (footers, headers, sidebars). Specifically, they examine the HTML tags used for partitioning the content and those related to page splitting. These tags are the *"explicit"* separators, which in relation with the blank spaces within the web content produce the *"implicit"* separators. The scope of this analysis is to identify the parts of the webpage that could be separated in order to fit their contents on small screen devices. According to the authors, this approach is more suitable for webpages that consist of various topics such as a mDGBL environment.

The work of Laakko and Hiltunen (2005) examines the mobile web browsing adaptation and concludes that it is better to assign the content adaptation tasks to a proxy. Their work is based on transformations being made using the Extensible Stylesheet Language (XSL) during the server-side adaptation phase to succeed the necessary delivery markup of XML content representations for mobile users. Therefore, the proxy performs an *"intermediate"* adaptation by using a group of rules. By taking advantage of the web content separation in stylesheets, if necessary, at the client-side the adaptation uses CSS format to display the contents on the mobile web browser.

Concentrating on visualization issues, a technology that has the potential to blend well in mDGBL, and thus may greatly advance the learning experience, is that of *Augmented Reality (AR)*. This is rather straightforward since AR technology visualizes the learning content in such a way that makes learning process more attractive and user-centered (Chou and ChanLin, 2012). In short, by encompassing AR technology within a mDGBL environment could enhance learners' motivational characteristics, and keep them engaged during the learning process. At the same time the feedback that learners receive from the system remains accurate and fully informational (Klopfer and Squire, 2008). A mDGBL example that facilitates AR technology, is Explore, mentioned in section 3 of the thesis.

Another interesting issue here is that of content delivery in a mDGBL environment. Within this context, one should consider the usual methods employed for transmitting data over a mobile infrastructure. These are the push and pull models. In the first one, also known as *"prefetching"*, the client receives automatically the content without any previous request by it via a push proxy server. Using the pull model, the client sends its requests to a server and then receives the relevant content as a response. This model is also known as *"interactive"* or *"on-demand"*. The advantages and disadvantages of each one of them within the mobile ecosystem have been already examined by several works in the field. However, considering this issue from a narrow mDGBL perspective, one can assert that the selection of a particular model is strictly bound to the situation and the mDGBL app at hand. A major issue is the frequency that the app needs to update its educational content. In a hypothetical mDGBL scenario, the app might need to send quite frequently the data taken, say, from the camera or GPS to the server. Then, the server should respond with an explanation image or an educational video as a prerequisite for the learner to carry on their learning process. So, as a rule of thumb, mDGBL apps cannot solely rely on a single data transmission model; they rather need to follow a mixed one. However, the designer needs to have in mind and carefully take into consideration the interaction of the app with the network. If frequent, then it leads to faster depletion of battery life, and maybe, imposes an additional cost to the user for a specified amount of data usage. Nevertheless, the app is expected to deliver among others a better and context-aware experience to the end-user. On the other hand, if scarce, then the app becomes standalone and less resource-demanding, but losses in terms of interactivity, live content delivery, and perhaps, level of satisfaction.

The aforementioned parameters become prominent when considering a mDGBL app that relies on the live cooperation of its players to achieve a common goal. For example, this is the case with Human Pacman, SupaFly, and MobileGame apps mentioned in section 3 of the main manuscript.

Also, there exist issues pertaining to network availability. Precisely, in most cases, one cannot assume that a network connection will be always available. So, in such cases, the app needs to be able to cache the data and transmit it as soon as, say, an accessible Wi-Fi network is detected. Otherwise, assuming an app failure due to the lack of network connectivity, it may cause user discontent and ultimately prevent them from further using it. Note that while the above observations are rather straightforward are often been neglected by mDGBL implementors leading to poor educational experience.

3.5 Motivation/engagement & 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)DGBL 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)DGBL 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 DGBL 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 DGBL environment. Most would agree that this observation stands true for any mDGBL 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 subsection 3.2.6, we concluded that only few mDGBL apps 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 mDGBL 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 mDGBL app. 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 an potent and supportive dimension within the (m)DGBL 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 app itself.

Indeed, today, several popular mobile games use mobile back-ends as that of Google's cloud platform and others in order 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).

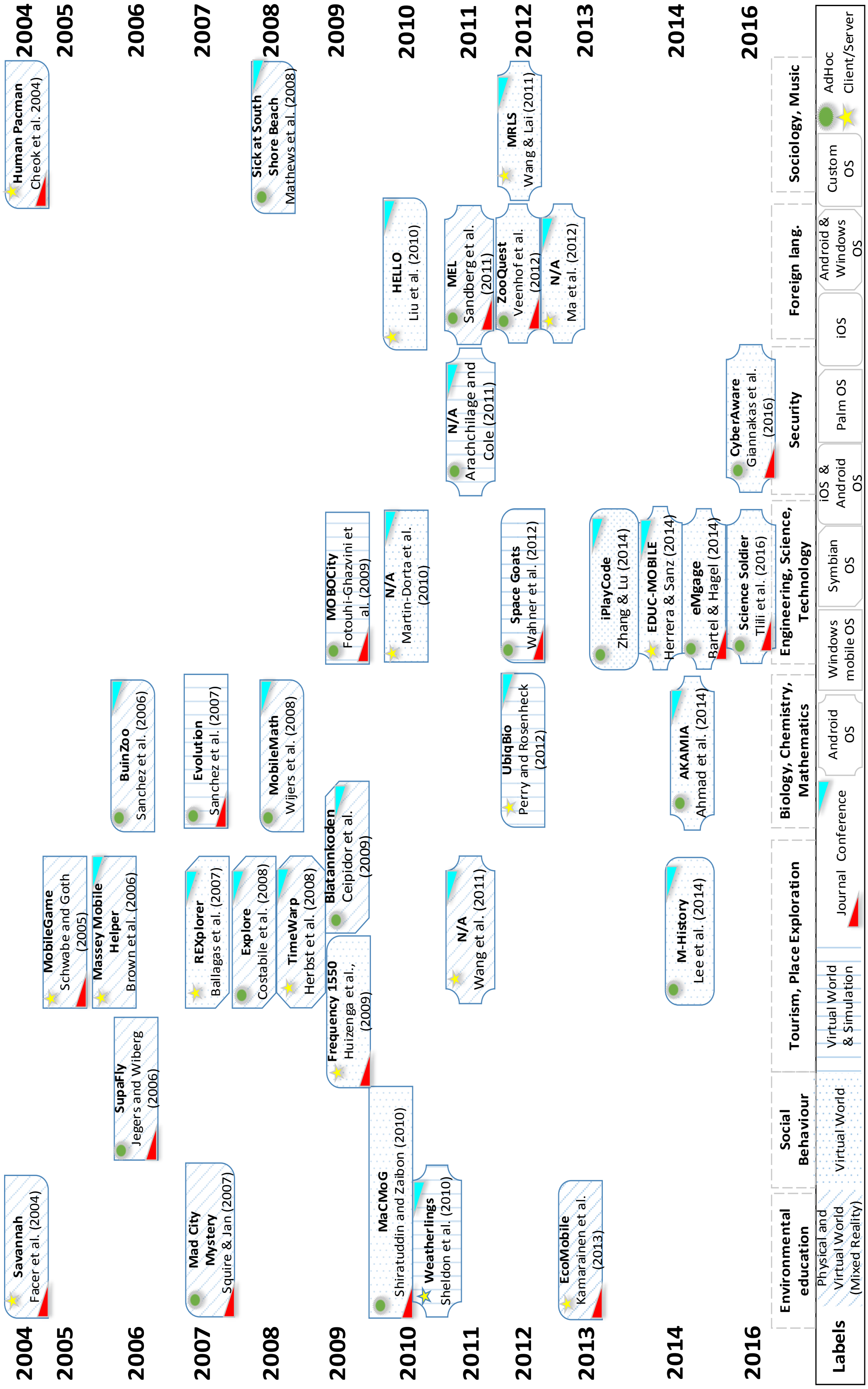


FIGURE 3.2: mDGBL apps in chronological order, grouped by field, type of publication, game type, and mobile platform.

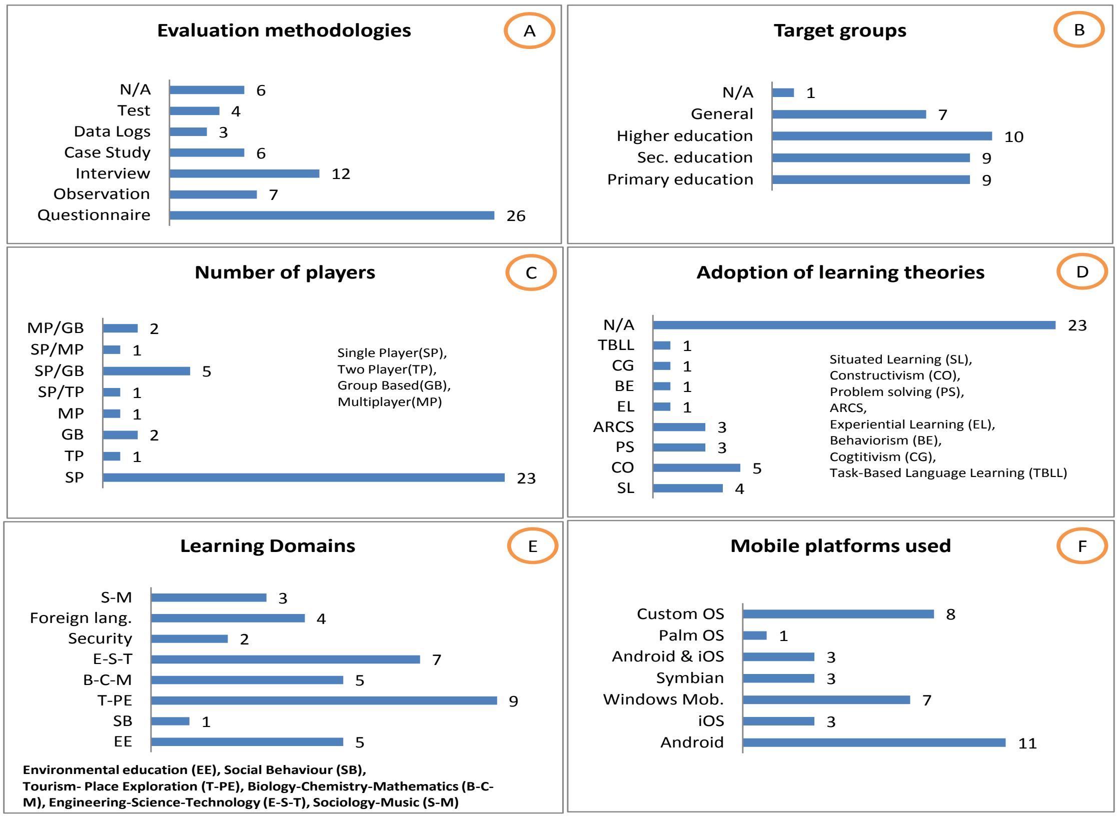


FIGURE 3.3: Key demographics of mDGBL apps included in this survey.

Chapter 4

The CyberAware platform

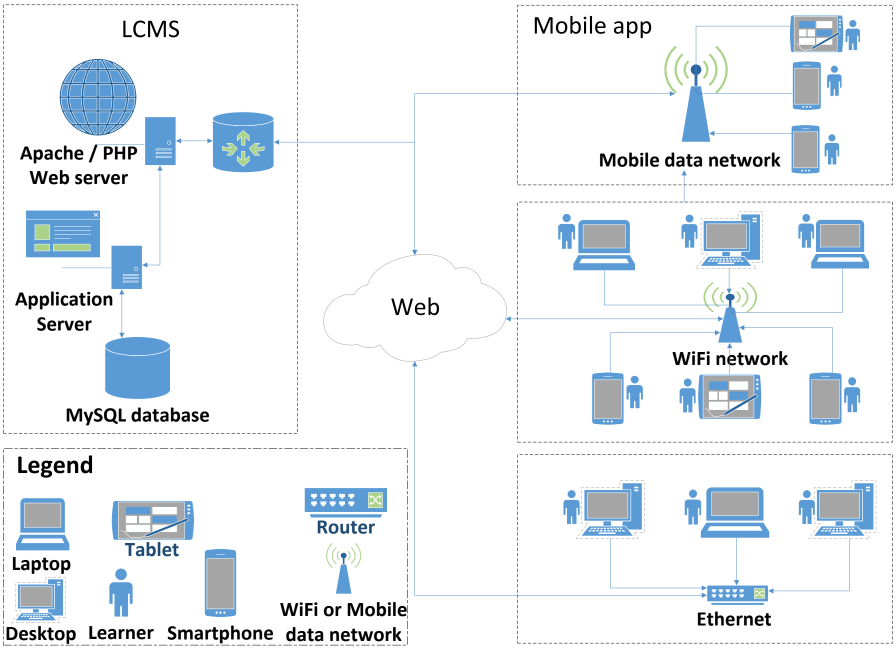
4.1 Overview

After providing a comprehensive review of the area of DGBL/mDGBL and pinpointing the main GDPs, this chapter details on the design and the implementation of the CyberAware platform. We aspire that the CyberAware prototype will be used as a reference to anyone interested in better understanding the facets of this fast evolving area. It is also expected that it will foster further research efforts to the development of full-fledged solutions that put emphasis not only to the technological aspect, but also to human factor. A high level view of CyberAware is depicted in Figure 4.1. As observed from the figure, the platform consists of a web-based custom LCMS and an app as the front-end. The app comprises a suite of seven serious learning mini-games, destined to cybersecurity and privacy education. Assuming a mobile device, the app connects to the LCMS so as to retrieve the appropriate learning and informational material. Additionally, as further discussed in section 4.3, the front-end is designed to be platform independent, which means that the app can run virtually in any computing platform, including Android and desktop ones.

4.1.1 Gaming app

The CyberAware gaming app is a learning environment, where the students actively engage for the purpose of accomplishing a number of quick challenges. The game supports two learning goals. First, to familiarize learners with fundamental cybersecurity

Figure 4.1: A high-level view of the CyberAware architecture



technologies that are required to keep their Internet-connected devices protected against legacy threats, as well as to keep their passwords safe. Second, it aims at raising learners' awareness on privacy issues mostly related to their identity and the protection of their personal information published on the web.

The learner may choose to play the app either in a client/server or standalone mode. In the former mode, using their credentials (username/password), the player must first login to the app. After that, the app interacts with the LCMS and downloads the learning content along with the informational material. In standalone mode, the app does not interact with the LCMS, and the games run using the default settings.

As shown in Figure 4.2, in the game scenario, the player selects a learning topic either from the security or the privacy domain, and accordingly plays a series of short (quick session) mini-games. For spurring learners' intrinsic and extrinsic motivation, upon the successful completion of each mini-game a virtual shield unlocks, allowing the learner to play the next game in the row. If all the mini-games pertaining to the cybersecurity or data privacy topic are successfully completed, then a final virtual shield is removed and the corresponding *Arena* mini-game starts. As explained later in this subsection, the *Arena* game aims at interlinking the knowledge already acquired by the player with real-life situations (case studies).

Before starting a mini-game, the learner is able to read brief guidelines about the rules of playing it and information related to the current learning goal. We choose to include the least but more meaningful learning and informational material we could, in order to overcome long-term reading, and thus to avoid boredom and inattention. The aforementioned minimalistic approach is not only driven by the inherent constraints of mobile devices (e.g., limited screen size), but it is also selected as a learning strategy for increasing learners' engagement and consequently producing better learning outcomes.

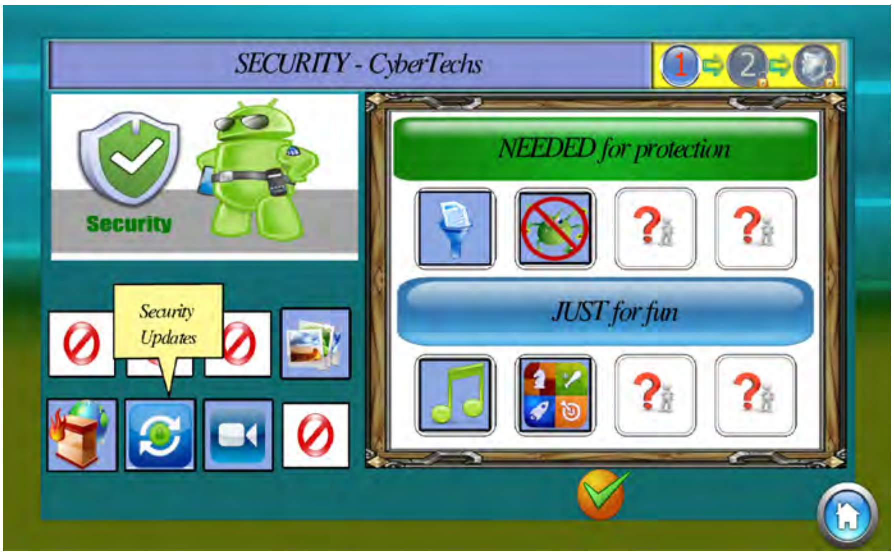
FIGURE 4.2: A map of the games contained in CyberAware

The app is designed to aid autonomous and self-directed learning. Specifically, its main purpose is to steer the learners to discover new knowledge entirely by themselves following specific learning activities. That is, while playing a mini-game, the learners are actively supported by receiving advising tips and hints, when the player's answer is incorrect, towards finding the right answer. Also, as discussed in subsection 4.1.1, the activities which are delivered to the learners by the gaming app intend to promote their critical thinking. This is achieved by motivating learners to extend the knowledge gained from the various concepts being taught, in different real-life situations by playing the *Arena* mini-games. In the following subsections, we detail on the architecture, the conceptual framework, and the ARCS model of motivation on which the front-end app is built.

4.1.1.1 Security section

As shown in Figure 4.2, this part of the app comprises 3 subcategories, namely *CyberTechs*, *Keep it Strong*, and *Security Arena*. The CyberTechs subcategory comprises 2 mini-games where the student learns about the use of basic cybersecurity techologies; Antivirus, Firewall, Security Updates, and email spam filters. As depicted in Figure 4.3, mini-game 1 presents to the learner four relevant and an equal number of irrelevant technologies pertaining to basic cybersecurity technologies. The challenge for the pupil is first to recognize the correct ones and place them in the corresponding "NEEDED for protection" horizontal compartments.

FIGURE 4.3: Game 1: Identify the cybersecurity technologies



After the successful completion of mini-game 1, a second one for the same subcategory starts. A snapshot of mini-game 2 of the same subcategory is shown in Figure 4.4. The goal here is for the player to identify and then associate each already identified cybersecurity technology from mini-game 1 with their correct use in keeping their Internet-connected device safe.

The next subcategory of the security section is that of *Keep it Strong*. The goal of this mini-game is to familiarize the student with basic rules regarding password construction. A snapshot of this mini-game is depicted in Figure 4.5. Here, the student is asked to recognize if a series of given passwords are considered weak or strong. If the answer is wrong, the player receives targeted advices, say, "Nowadays, a strong password should be at least 8 characters long, combining letters, numbers, and special symbols".

FIGURE 4.4: Game 2: Associate each cybersecurity technology with its specific usage

FIGURE 4.5: Game 3: Identify if a password is considered strong or weak

After finishing successfully the first three mini-games, the *Security Arena* mini-game unlocks. Its goal is to engage students in a meaningful learning process by enabling authentic security scenarios. That is, challenging real-life scenarios typically foster student's attention, which in turn amplifies knowledge retention. As such, the purpose of the mini-game 4 is twofold. First, the student needs to understand the threat that a specific online real-life web scenario presents, and then find out the appropriate security technologies for copying with it. The above mentioned learning flow is anticipated to steer students to associate the new knowledge they gained, after they have played the three first games, with real-life scenarios.

More precisely, as shown in Figure 4.6, the learning scenario of *Security Arena* comprises of colorful balls that fly horizontally from the right to the left side of the device's screen. Each ball is randomly assigned to a specific real-life scenario, e.g., "You have just received an email that instructs you to review a product by clicking on a web-link", "You chose to download a file, but before you proceed, you have to consent to a browser alert", etc. At the right side of the screen, is located a toolbox. By using the magnifier tool, the student is able to scan any ball in order to reveal the corresponding scenario. When doing so, the learning scenario corresponding to the selected ball appears at the bottom of the screen.

Then, the player needs to recall the knowledge that they have already gained so far from the previous mini-games in order to correctly identify the threat. Finally, they have to choose the correct data security technology that eliminates or mitigates the identified threat. This is accomplished by first selecting from the toolbox the colorful arrow that is associated with the correct cybersecurity technology (i.e., Antivirus, Firewall, Spam Filter, Security Updates), and then shooting against the ball of interest. For each successful strike, the player collects a number of points. The learner has 4 min to shoot against as many colorful balls they can with the aim of collecting as many points as possible. Note that the game is pre-configured so as the player does not receive any negative points on an unsuccessful attempt. Nevertheless, if needed, negative scoring can be enabled by the educator via the LCMS.

4.1.1.2 Privacy section

As observed from Figure 4.2, this module consists of the *Stay Safe* subcategory, and the *Privacy Arena* mini-games. *Stay Safe* comprises two mini-games. Their goal is to enable students' critical thinking on identifying the information that is considered personal and therefore sensitive. Precisely, mini-game 5 presents to the learner pieces of private or public information in order for the player to decide if each of them is considered sensitive or not. A snapshot of this mini-game is shown in Figure 4.7.

FIGURE 4.6: Game 4: Identify the cyber-threat and face it

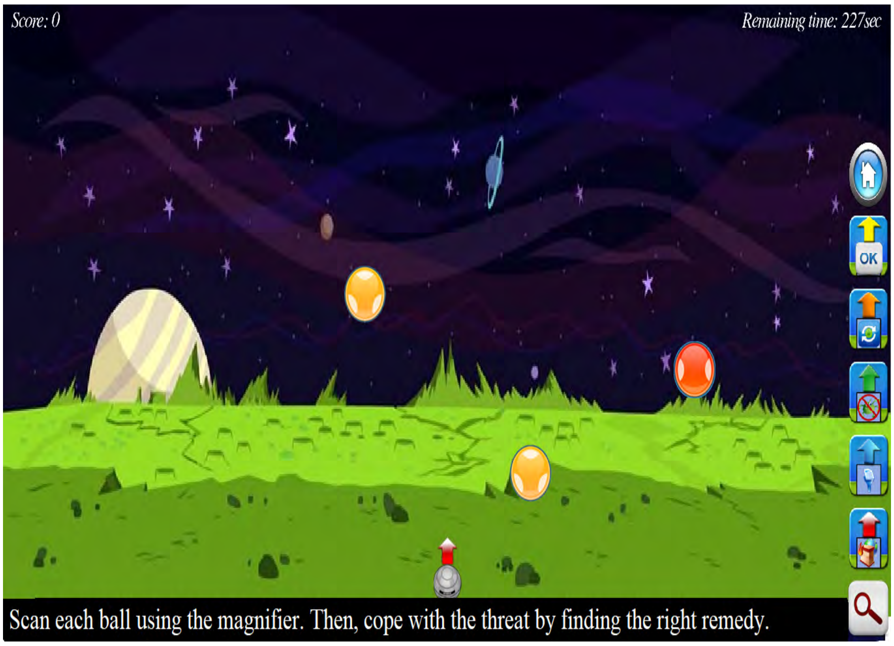


FIGURE 4.7: Game 5: Identify if an information is considered public or private

After the successful completion of mini-game 5, another one starts. This time, as illustrated in Figure 4.8, mini-game 6 challenges the learner to identify if a given short message can be published as is or not on the web without disclosing any personal information. The *Privacy Arena* mini-game unlocks after the player has successfully completed the previous two mini-games. The main objective of this game is similar to the *Security Arena* described in subsection 4.1.1.1. That is, first, the student must identify if the information pointed out by a question is considered public or private, and second to decide if it can be published on the web. Note however that these questions pertain to typical real-life situations. As already pointed out, this challenge helps students to associate the new knowledge they gained after their interaction with mini-games 5 and

6 with real-life scenarios.

FIGURE 4.8: Game 6: Identify if the information can be Published or not on the web

More precisely, as shown in Figure 4.9, the learning scenario of the *Privacy Arena* shows a spaceship that travels in the outer space. There, a number of planets fly horizontally from the right to the left side of the device's screen. Each planet is randomly assigned a specific scenario, e.g., "Hi guys! I will wait for you at my home located at 4325 W. Palm Beach Rd.", "The food I ordered last night was fresh and very tasty", etc. On the lower middle of the screen there exists a scanning tool. The student needs to use it for revealing the planet's corresponding scenario, which, then, is displayed in a panel located at the middle of the device's screen. Based on the acquired knowledge, the student must decide if the corresponding information can be safely published as is on the web. This is achieved by selecting the correct button located in the spaceship. If it is correct, the player collects a number of points. The learners have a handful of minutes to identify successfully as many planet's scenarios as they can in order to increase their score. Similar to *Security Arena*, the default configuration is for the player to not receive negative points. This setting however can be changed via the LCMS by the educator at any time.

4.1.2 Learning Content Management System (LCMS)

Typically, an LCMS is used for centrally administrating the learning content and the associated activities. That is, via the LCMS the learning content is delivered and can be accessed anytime, anywhere. This facilitates the upgrading or amendment of both the learning and informational content of the courses, and simplifies the learning process

Figure 4.9: Game 7: Identify if a real-life scenario contains sensitive personal information

by administering learners' enrolment and managing the virtual classrooms. For the time being, and for achieving maximum compatibility with the app, we implemented a custom LCMS, which from top to bottom comprises five layers, namely Administrator, Educator, Class, Learner, and Learning/Informational material.

An educator can access and register with the LCMS by inserting their personal information. Upon successful registration, they are able to manage their own virtual classrooms, and enrol pupils into it. Recall that the main objective of the LCMS is to deliver to the associated app the appropriate content consisting of learning and informational material. The former comprises the information that is relevant to each mini-game, that is, the questions, the possible answers, the correct answer, and so on. The informational material on the other hand, contains the guidelines, hints, and tips which are displayed to the players. Also, the LCMS stores any information related to client's app configuration and others related to the user's interface, e.g., the remaining time before a mini-game finishes, the number of scenarios or questions, the text shown in the various Graphical User Interfaces (GUIs), and so on.

All the aforementioned functionalities are enabled after the learner successfully logs in the LCMS by using their personal credentials given by the educator. After that, the app retrieves the course material and stores it locally in JavaScript Object Notation (JSON) formatted files, so as to be available for further analysis. At the same time, learner's engagement with the app is constantly tracked and stored locally in JSON formatted files. These files contain information regarding the time each learner spent playing a mini-game, their scores per mini-game, if they answered correctly a given question, and so on. The files are available to the educator for retrieving useful information regarding the learning curve of each player. It is to be noted that the current version of the LCMS does not support an automatic analysis of these logs. This means that the educator must download the JSON log files and manually analyze them locally.

Finally, if the app runs for the first time, and the learner does not log in, then it starts using a standard profile corresponding to default learning material and configuration. Otherwise, the app is launched using the last successfully retrieved material.

4.2 Model of motivation and Conceptual Framework

In educational settings, motivation, whether it is intrinsic or extrinsic, is considered a fundamental element for improving the learning process and associated outcomes (Hodges, 2004). However, the proper consideration of motivational characteristics in any serious DGBL app requires among others careful course design. For achieving such a goal, the DGBL environment needs to at least fulfill the following conditions: be content-rich, be learning effective and efficient, and embrace attractive game characteristics, including interesting plot, and well-designed and easy-to-navigate GUI (Anaraki, 2004, Yee, 2006). In this respect, this section implicitly provides an answer on what are the benefits of incorporating a learning theory into a DGBL app.

Given the previous requirements, CyberAware has been designed with the following principles in mind: a) the learning goals should be clear and easy to comprehend, b) the challenges for the player should be short, attractive, and easy to understand, c) the learning content should be possible to alter or extend at any time, focused to specific learning topics, concise, and easy to comprehend, and d) the app should be able to navigate and run on a variety of modern computing platforms, including mobile ones. To reach the aforementioned four goals, we concluded that the app should be guided by an instructional strategy for ensuring the quality of the learning experience and guaranteeing the learning outcomes. Such a strategy can be properly driven by an Instructional

Design Model (IDM) (Gibbons et al., 2014) that details on how the learning experience can be synthesized so as the acquired knowledge and skills become more attractive to the learners. Broadly speaking, an IDM contains general principles that guide the creation of engaging pedagogical scenarios that contain realistic and unambiguous learning goals.

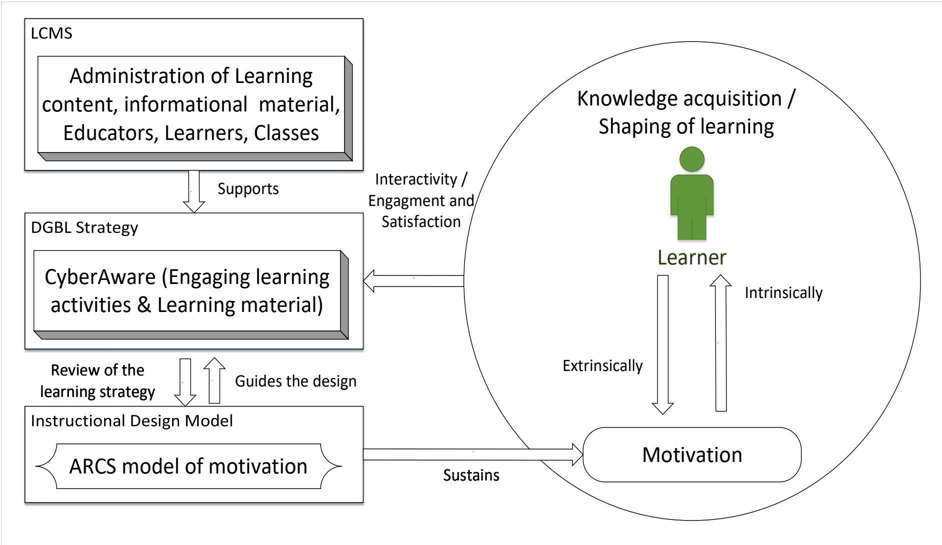
In the literature there exist a variety of IDMs, including Dick and Carey (Dick et al., 2014), ADDIE (Peterson, 2003, Branch, 2009), ASSURE (Heinich et al., 2005), ARCS, and others. In our case, the ARCS model of motivation is chosen for the design of the learning strategy of the CyberAware app. The next subsections detail on the ARCS model and how this is considered in each stage of the mobile app. Also, Figure 4.10 illustrates the conceptual framework of our platform outlining the logical interconnections among four entities; the learning app, the learner's motivation, the IDM, and the LCMS.

4.2.1 Conceptual Framework

A learning process owes to find ways to sustain learners' motivation. If properly done, this situation is anticipated to increase learners engagement and satisfaction, which in turn stimulate them to keep learning in track and meet the expected learning goals (Keller, 1987b, Burguillo, 2010). As already pointed out, the design of CyberAware app is based on the ARCS model of motivation. As further detailed in this section, ARCS comprises four distinct components, each describing specific strategies, guidelines, and learning processes. All these components enable the design of a suitable instructional learning experience that sustains motivation and actively engages the learner during the learning process. Also, the ease of altering the educational material and the associated parameters is also tightly connected to the app's lifespan. Therefore, the easier the amendments the greater the anticipated lifetime of the app.

Figure 4.10 illustrates CyberAware's conceptual framework that details on how the learning app, the learner's motivation, the IDM, as well as the LCMS are interconnected. As observed from the figure, the learner is placed in the center of knowledge acquisition, while they engage and interact with the app and the learning material. The conceptual framework is neither unidirectional nor static. Rather it should be seen as a circular and continuously adjustment process between learner's motivation and the DGBL app. If necessary, the instructor is able to alter the learning content and informational material delivered to the app so as to embed new challenges towards improving the learning experience and outcomes.

FIGURE 4.10: Abstract view of CyberAware conceptual framework

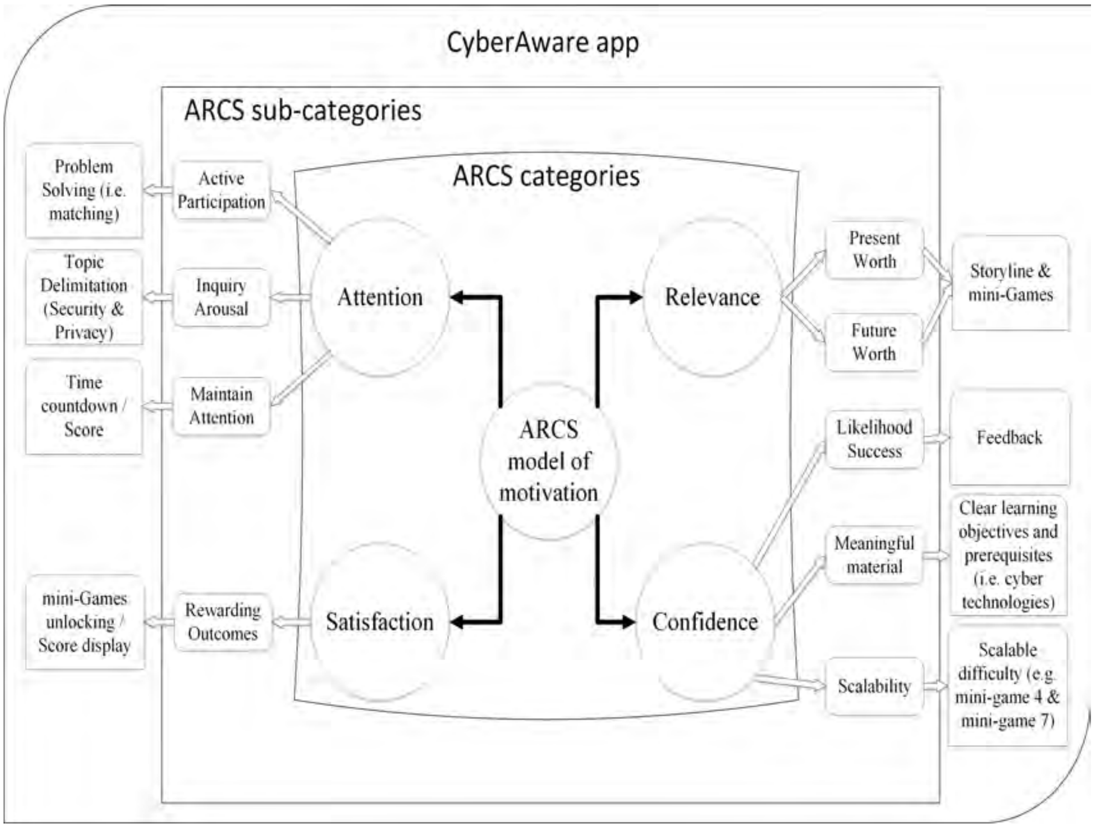


4.2.2 ARCS and app interconnection

The main purpose of ARCS (Keller, 1987a) is to spur motivation by systematically guiding the design of engaging learning activities that produce specific learning outcomes according to the learners' behavior. In general, ARCS comprises different motivational theories, including skills and knowledge, cognitive accounting of individual abilities, behavioral contingency design and management, and expectancy-value theory. In our case, this can be achieved while learners participate to learning activities which are intrinsically interesting to them.

The rationale behind the selection of the ARCS model was based on the existence of four distinct components, namely Attention, Relevance, Confidence, and Satisfaction, for enhancing and retaining learners motivation during the learning process. These components are further divided into several other subcomponents that outline specific learning strategies for instructing self-directed learning and spurring motivation. Figure 4.11 illustrates the logical interconnection of the structural elements of CyberAware with each ARCS component. For instance, starting from the inner part of the figure, we can observe that the *Attention* component is connected to the *Maintain attention* subcomponent, which in turn is related to *Time countdown* and *Score* features of the app. The following subsections discuss the above mentioned components and detail on the way they are incorporated during the design phase of the app.

FIGURE 4.11: CyberAware and ARCS interplay



4.2.2.1 Attention

As already pointed out, the first goal of the ARCS model of motivation is to maintain learners' attention. This quality is proved to be vital, since the challenge is to retain learner's attention at a high level for keeping them engaged during the learning process. As observed from Figure 4.11, our app fulfils the component of attention by enabling the following ARCS sub-components: "Active Participation", "Inquiry Arousal", and "Maintain Attention".

The active participation of the student during the learning process is an important incentive element that intensively retains their attention. In our case, this is achieved when they mandatorily play a number of mini-games in a row. That is, in the security section, the student plays four mini-games in a row, as depicted in Figures 4.3 to 4.6.

Similarly, in the privacy section, they play three mini-games in a row, as illustrated in Figures 4.7 to 4.9.

Additionally, as shown in Figures 4.5 and 4.9, the app engages various features for triggering and retaining learner's attention, such as score and remaining time countdown. Finally, as shown in Figure 4.12, learner's attention is also retained via the use of inquiry arousal screens that are displayed before starting a topic or a mini-game. These screens inform the player about the current learning goal.

FIGURE 4.12: The main information screen of the privacy topic

4.2.2.2 Relevance

Another important component of the ARCS model is that of relevance. As shown in Figure 4.11, this component consists of the "Present Worth" and "Future Worth" subcomponents. Primarily, relevance has to do with the retention of learner's interest. This can be achieved via a number of ways, including a clear explanation of (a) the merit of the course and its goals, and (b) its relevance to real-life problems and situations. In our case, both the aforementioned requirements are fulfilled by enabling special crafted storyline inquiries to the learners. Specifically, for each mini-game, a main inquiry is displayed on the screen that explains to the player the present merit (goals) of the current challenge.

As observed from Figure 4.13, before the Stay-Safe subcategory starts, relevant inquiries are displayed on the screen that inform the pupil for the learning goals associated with the current topic. Similarly, after the selection of each learning module (i.e., security, privacy), similar inquiries are displayed for that specific topic.

FIGURE 4.13: The initial information screen for games 5 and 6

4.2.2.3 Confidence

Confidence is another key component of the ARCS model. As shown in Figure 4.11, this component is divided into "Likelihood success" and "Meaningful material" subcomponents. Based on the model's layout, each learning challenge should rely on the learner's capabilities. It is also important for the learners to feel that they can successfully accomplish a given task in order not to drop out of the learning process. For the CyberAware app this goal is achieved via hints and tips provided during each challenge or after the player chooses a wrong answer. This situation is depicted in Figure 4.14.

Confidence between the learner and the app is also accomplished by designing the learning material in such a way that its objectives are meaningful to the player. This result is also amplified when the learning material encompasses clear and realistic expectations, and if possible, scalable levels of difficulty. Under this prism, the user app is designed to elaborate straightforward learning objectives for both the security and privacy topics.

FIGURE 4.14: Advising tips and hints

Specifically, the objectives associated with the security topic are as follows:

I. The player must be able to correctly identify the right cybersecurity technology for securing their device in the cyberspace.

II. The player must be able to identify the merit of each cybersecurity technology and the level of protection it offers.

III. The player needs to tell between a weak and strong password.

IV. The player must be able to cope with basic real-life situations regarding cyber-threats. That is, they must be able to identify the threat and select the correct remedy as the case may be.

The learning objectives associated with the privacy topic can be summarized as follows:

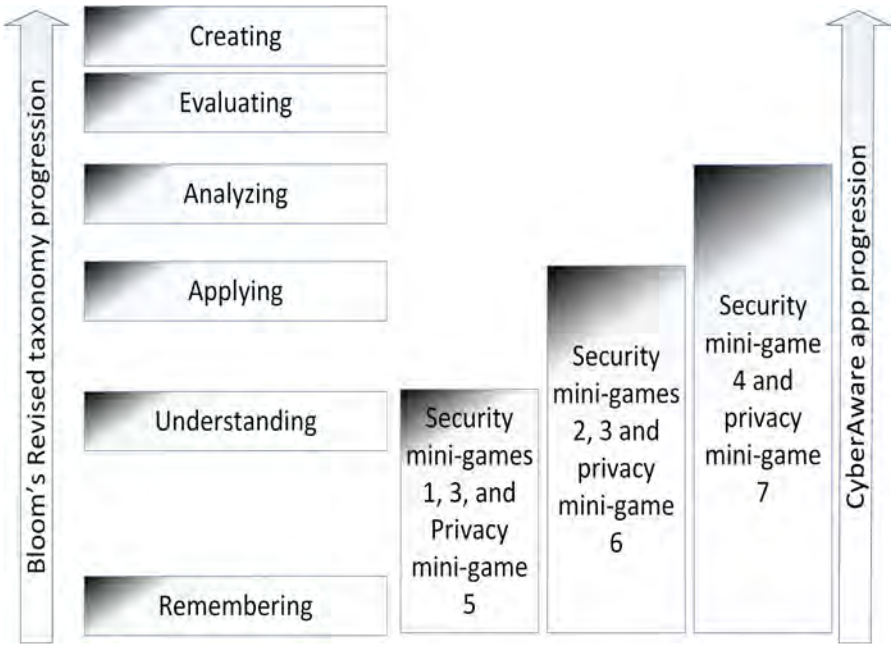
I. The learner must be able to identify if a piece of information contains personal data.

II. The learner must be able to tell if a piece of information can be safely posted on the web without disclosing their identity.

III. Given a real-life Internet usage scenario, the learner must be capable of identifying if it is privacy-invading or not.

The aforementioned educational objectives adhere to the first four levels of the Bloom's revised taxonomy (Anderson et al., 2001). As observed from Figure 4.15, Bloom taxonomy is interlinked from the "Remembering" level up to the "Analyzing" one. Specifically, for the learner to better understand the objectives of each mini-game, they have to recall previously acquired information after participating to traditional teaching process in their curriculum. After that, the learner may proceed to play the Security Arena and the Privacy Arena mini-games. There, the player needs to fetch the newly acquired knowledge for applying it to new situations. It is to be noted that this work follows the basic instructional design principle of clearly specifying the learning objectives of the learning environment under consideration. Therefore, as explained above, the revised Bloom taxonomy, widely used in the literature, was a useful framework for specifying these objectives. Nevertheless, the reader must remember that this taxonomy has received a lot of criticism regarding its validity and usefulness for instructional design (Sugrue, 2002, Case, 2013).

FIGURE 4.15: CyberAware's games series progression and its correspondence to Bloom's revised taxonomy



Confidence is also cultivated by designing scalable learning activities in terms of difficulty. So, in the CyberAware app the difficulty of the learning scenarios of each mini-game augments as the player advances to the next mini-game. More precisely, the *Arena* mini-games are considered more difficult than the previous ones in the same learning topic, since the learner must first understand the given scenario and then recall the knowledge they acquired in order to successfully tackle it.

4.2.2.4 Satisfaction

The fourth component of the ARCS model is also considered an important criterion for preserving learners' motivation. This is because the student is most likely to play the game again if they feel contented about the knowledge they acquired. As observed from Figure 4.11, the app fulfils the aforementioned criterion by implementing specific outcomes for rewarding extrinsically the learners. This component is achieved by enabling new learning challenges, such as those presented in the Security Arena and Privacy Arena mini-games, unlocking virtual shields, and constantly displaying the player's score on the screen during the two *Arena* mini-games.

4.3 Implementation aspects

The development and implementation phases of every serious learning game need to consider several aspects, including ways to extend its lifespan. Nowadays, due to the plethora of computing devices of all kinds, this is becoming more evident since the porting of the app to run on different computing platforms, is considered a critical factor for its success. In fact, app porting is something that developers often neglect since it requires a significant and continuous effort in coding and testing. Consequently, most of the time, the aforementioned implementation practice is proved to be ineffective. Platform independence is also closely related to BYOD scenarios where learners are not using dedicated devices to play the game, but they are free to use their own. From a learner's viewpoint, this is supposed to increase their confidence and satisfaction because the player feels more familiar and comfortable when experiencing the corresponding app via their own personal device. Additionally, considering BYOD from an educational organization viewpoint, it can drastically reduce the development time and the maintenance and upgrading costs of the different versions of the learning app.

Bearing the above into mind, the CyberAware app is developed to run on different platforms, ranging from mobile to desktop ones. That is, for the development of the app, we used standard software tools, including Android studio, Android Development Kit and the open-source libGDX game engine (Zechner, 2012). This game engine was not only selected because it is open source, but also because it enables cross-platform development. More precisely, libGDX framework supports four layers, namely Desktop, Android, iOS, and HTML5. This modularisation enables the CyberAware app to run on both desktop and Android platforms. It also makes possible the extension of the app, to run on iOS and support HTML5 contents, without additional coding efforts.

On the other hand, for the design of the LCMS, we relied on the Model View Controller (MVC) software architectural pattern. This model separates the way the information is stored in a server and how it is fetched and presented to the clients. For the LCMS and app interoperability, we relied on the representational state transfer (REST), i.e., the RESTful web services architecture. Currently, the LCMS is deployed on an Apache server along with a mySQL database.

4.4 Evaluation

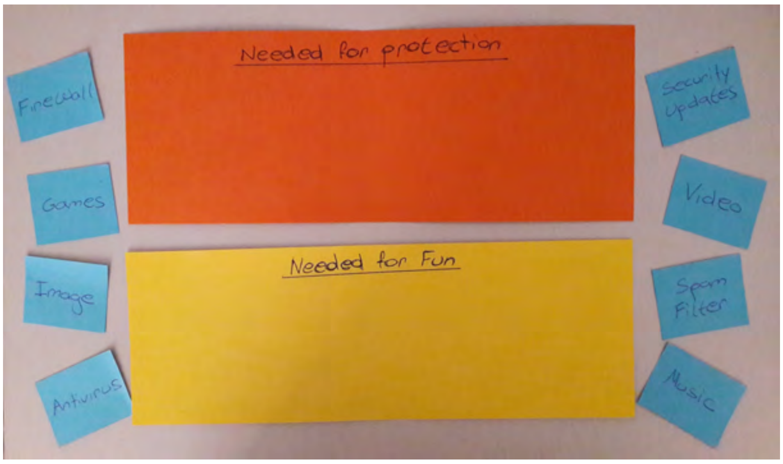
The purpose of the current section is to assess the overall quality of app from a learner's viewpoint. This has been done in three axes. First, we evaluated the app's learning outcomes (effectiveness), by means of both pre- and post-tests, that is, before and after the pupils have experienced the app. Secondly, we assessed the functional characteristics of the app (usability), we well as students' attitude (satisfaction and expectations). In the evaluation process participated 52 elementary-aged students, 25 boys and 27 girls, who ranged in age from 9 to 12 years. All the pupils had a written consent from their parents or guardians to participate in the evaluation phase of the app.

4.4.1 Learning/knowledge acquisition effectiveness

4.4.1.1 Method

Knowledge delivery from external resources, such as e-Learning systems in general or m-Learning in particular, is of great importance in learning environments. In this context, knowledge acquisition effectiveness was examined via tests that learners (referred to as the treatment group) answered before and after playing the app. Notice that, both groups performed a pre- and a post-test in order to assess the increase of performance as a consequence of their treatment. The content of the tests for both the security and privacy sections are given in Tables 2.1 and 2.2 in the Appendix. Specifically, the pupils answered the pre-test after attending a traditional course on basic cybersecurity and privacy topics according to their curricula. The post-test was answered right after learners had interacted with the app. Moreover, a control student group attended a traditional course in the same topics, and they were asked to complete the same pre-test. After that, they played some non-digital activities similar to the gaming app, and they answered the same post-test. For instance, as shown in the Figure 4.16, the learners had to put the blue labels in the correct place (i.e., needed for protection, or needed for fun). The two groups of pupils were assembled randomly without any criteria, and the tests were completed in the classroom under the supervision of a teacher.

Figure 4.16: A non-digital learning activity used for the evaluation



4.4.1.2 Results

We conducted a comparison of the increase of performance according to two conditions, namely, control and treatment. A total of 10 questions were answered in the pre- and post-tests. The total score ranges from 0 to 11. The difference between the performance of each student between pre- and post-test was used as the dependent variable. Table 4.1 summarises the results of the performance difference for the two groups.

Table 4.1: Summary of knowledge acquisition results

Groups	N	Mean	SD
Control	26	0.8846	1.4786
Treatment	26	2.1923	2.7132

The use of the Shapiro-Wilks test showed that the results for the control group do not follow the normal distribution ($W = 0.89791$, $p < 0.05$). A non-parametric analysis based on the Kruskal-Wallis test ($H(2) = 2.975$, $p = 0.085$) showed that the null hypothesis cannot be rejected, so no statistically significant difference among the two groups was found ($a = 0.05$). However the pattern of differences between the two groups indicates that the use of the app had a positive effect on pupils performance.

4.4.1.3 Discussion

The current subsection offers a qualitative analysis based on the data provided by the participants. Specifically, in the test given in Table 2.1, and for question Q1 the learners were asked to select from a provided list of answers about which technologies are needed for protecting an Internet-connected device. As observed, the list contains several relevant and irrelevant cybersecurity technologies aiming to better detect the quality of knowledge acquired by the student. Further, for questions Q2 to Q5, the learners were asked to identify the merit of each cybersecurity technology contained in the corresponding list of answers. Regarding question Q6, learners were invited to identify real-life web activities for which at least one cybersecurity technology is required. This kind of assessment is deemed necessary since the interconnection of knowledge obtained with real-world challenges shuttles learning from the classroom settings to the actual realm of practice (Lebow and Wager, 1994, Anderson et al., 1996, Lee et al., 2012). Finally, Q7 and Q8 investigate the learner's view about the creation of a strong password. For the privacy section, in question Q1 the learners were requested to identify if a piece information is private or not. In Q2, the learners were asked to identify if a certain statement can be safely posted in an online social network.

According to our analysis, before interacting with the security topic of the game, about 30.8% of the learners in the treatment group were able to recognize all 4 technologies that are required to keep their Internet-connected devices protected. After playing it, this result was improved by almost 15.4%. An analogous improvement was also perceived for the rest of metrics measured by the corresponding questions. For example, before playing the game, 69.2% of the learners were able to recognize almost 3 scenarios out of 6 that an Internet-connected device needs to be protected, and only 7.7% all of them. After playing the app, the first of the aforementioned percentages decreased to about 26.9%, while the second one increased to about 30.8%. In regards to the password strength, before playing the game, about 23.1% of the learners were able to recognize all the desirable qualities of a strong password. This finding was improved and reached at 34.6% after the game play. Similarly, before playing the game, a 23.1% of the learners were able to identify the two correctly formatted passwords. This result was improved by almost 34.6% after the game play.

Before the learners interact with the privacy topic, only about 38.5% of them were able to recognize all the sensitive information provided, including those that can be safely published on online social networking sites. This is improved and reached 76.9% after playing the app. Also, while the 42.3% of the learners recognized the 2 out of 3 sensitive information before playing the CyberAware app, this factor was improved at almost 30.8% after playing it. As already pointed out in section 4.4.1.2, although the Kruskal-Wallis analysis did not reveal any significant statistical difference, the above mentioned results show that learners' performance was actually improved after playing the game for both the security and privacy topics.

4.4.2 Usability, and user satisfaction and expectations

To collect students' opinions about the usage of the app, we created a questionnaire that consists of 9 questions. Two of them are Likert-type, while the others were open type, and dropdown or checkbox value lists. Each Likert-type question had 5 alternatives to choose from: strongly disagree, disagree, neither agree nor disagree, agree, and

TABLE 4.2: Descriptive statistics per each answer contained in Table 3.1

Q/A (n=26)	Mean	SD
Q6(a) - It was easy to use.	4.48	.505
Q6(b) - The instructions on how to play were easy to understand.	4.35	.486
Q6(c) - The game's information (game play and learning goals) were comprehensible.	4.29	.776
Q6(d) - The messages displayed on the screen after a given answer were comprehensible.	4.32	.785
Q6(e) - When a given answer was wrong, the displayed message helped me to find the correct answer.	4.48	.542
Q6(f) - Every mini-game was easy to navigate.	4.39	.566
Q6(g) - After an action, it was easy to understand what to do next.	4.41	.603
Q8(a) - It was very funny to learn while playing the game.	4.39	.491
Q8(b) - I liked that the game has a short amount of reading material and more action.	4.58	.449
Q8(c) - I would like to play the game again in my classroom.	4.35	.606
Q8(d) - I would like to play the game again outside the classroom in my free time.	4.50	.577
Q8(e) - I became familiar with what is required for a personal device to be protected against basic online attacks from the Web.	4.44	.574
Q8(f) - I realized the importance of privacy in the Internet age.	4.40	.569
Q8(g) - I will recommend it to my friends.	4.81	.397

strongly agree. The participants had to answer the questions shortly after playing the CyberAware Android app.

As shown in Table 3.1, the questionnaire is split into 3 parts. The first part contains general and demographical questions (Q1 to Q5). The second part aims at investigating the usability issues of the app. It contains the Q6 Likert-type question, and Q7 non-mandatory open type question, in which the users are encouraged to flag any problem they faced during the game play, including those related to the mobile device (e.g., small screen, difficulties interacting with the touch screen, etc). The last part of the questionnaire aims at investigating the overall degree of user satisfaction and expectations. It contains the Likert-type question Q8 and the open type question Q9. In Q8 the players need to express their satisfaction during the game play, while in Q9, they can optionally mark down their expectations about the game. The reader may discern that several questions existing in our questionnaire are more or less similar to System Usability Scale (SUS) tool for measuring the usability. Actually, we did not employed this out-of-the-box industry standard because we preferred to amend the questions for better adjusting it to the young age of the participants.

The internal reliability of the questionnaire was assessed using the Cronbach's alpha parameter and it was found to be sound ($\alpha = 0.8$). Table 4.2 contains the mean and the standard deviation (SD) for each answer contained in Table 3.1.

The highlights of the findings are summarized below.

- 69.2% of the learners had interacted with at least one mobile digital game sometime in the past.
- 88.5% of them had played a digital game using a desktop computer.
- 76.9% of the pupils have not interacted with educational digital games in the past.
- 92.3% of them love to play digital games.
- 65.4% agreed that the app was easy to navigate, while another 34.6% had a neutral opinion on this.
- 100% of the learners agreed that was easy to familiarize themselves with the app.
- 69.3% agreed that information regarding the game play and the learning goals were comprehensible, while another 30.7% had a neutral opinion on this.
- 80.8% agreed that every message displayed on the screen was comprehensible, while another 19.2% had a neutral opinion on this.
- All of the learners agreed that after a wrong answer, the displayed message was comprehensible.
- Everyone agreed that they had understood clearly what to do in each mini-game.
- All of them agreed that after an action, it was easy to understand what to do next.
- All of them agreed that it was really funny to learn while playing. Also, they liked the plot of the game, which is focused on action rather on informational material.
- 80.8% agreed that they would like to play again the app in the classroom, while another 19.2% had a neutral opinion on this.
- Everyone agreed that they would like to play the game again outside the classroom in their free time and they would recommend the app to their friends.
- All the players agreed that they have learnt a lot about how to protect their devices against basic online attacks, and how to safeguard their personal information.

To summarize, it is encouraging to see that all the participants would like to play the game again outside the classroom in their free time. This was one of our goals since the app was designed mainly for anytime and anywhere use. From the results, it is also obvious that the learning material and the instructions provided by the app were found to be comprehensible to the majority of the learners. Also, all the participants expressed a common opinion that the learning objectives across the various learning activities were clear, and easy to navigate. Unfortunately, Q7, Q9 of Table 3.1 were left unanswered by all the pupils. This may indicate that the learners did not encounter any major problem and/or they were satisfied with the overall functionality of the app.

4.4.3 System resources

For evaluating the mobile version of the app, we used the Android Studio Profiler for conducting a benchmarking analysis of the CPU, memory, and network traffic. The results indicate that the current version of the app is lightweight in terms of system resources usage. Specifically, it consumes an average of 6.5% of the CPU, while memory utilisation fluctuates between 30 and 93 MB of RAM depending on which mini-game is currently active. Also, network utilization during app's login and learning content download fluctuates between 2.83 and 81.54 Mbit/s.

Chapter 5

Conclusions and Future Research Directions

In this thesis, we have systematically studied the (m)DGBL environments, and how these contribute to students' education in various learning domains. We have also scrutinized the various implementations in order to identify the main characteristics used for providing to the learners mobile/ubiquitous-Learning (m/u-Learning) experience. After delivering a comprehensive review of the various (m)DGBL works in the literature, we introduced a full-fledge gaming learning platform destined to educating learners on basic information security and privacy concepts. Contrary to other works in the literature, our contribution does not only focus on the technical implementation only but to the pedagogical factor as well. The latter pertains to the way the ARCS motivation model is embedded in the app to maximize the learning outcomes.

All in all, in the context of information security and privacy, CyberAware app addresses two challenges: a) increases learners' knowledge and awareness on basic cybersecurity and privacy issues in a playful way, and b) establishes a meaningful learning experience in an authentic learning context and in an anywhere and anytime fashion.

The current chapter provides our concluding remarks along with our contributions, and elaborates on future research directions. In our opinion, the findings included in this thesis can be of help to researchers toward designing and/or developing similar DGBL environments for educating users in different security and privacy contexts.

5.1 Thesis Contribution

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 app. 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 the development of a procedure that will process the various data collected from different mobile hardware or software sensors during the (mobile device-player) interaction. This may be implicitly utilized by the learning app for the sake of actively guiding and affecting its behavior, i.e., towards addressing a more contextualized and personalized learning experience.

Following the analysis given in the previous chapters, this subsection summarizes our conclusions. Specifically, we discuss the findings of the thesis, mainly concentrating on the mDGBL characteristics, expressed as GDPs, and the learning activity strategies that an mDGBL environment incorporates in its learning scenarios. We also identify potential literature gaps and other major issues that seem to have great potential for future research in the mDGBL ecosystem.

5.1.1 mDGBL characteristics in existing literature

5.1.1.1 u-Learning and context-awareness

Based on our analysis, DGBL and context-aware u-Learning experience mainly fit on mobile apps that encompass spatio-temporal characteristics, placed in a situated learning environment. This includes mDGBL apps 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 mDGBL learning scenarios. This is the reason why in subsection 3.2.1.1, 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 mDGBL apps 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 subsection 3.2.3. Instead, these apps 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 mDGBL context-aware activities for different curricula.

5.1.1.2 Adaptivity

Unfortunately, our findings indicate that the great mass of mDGBL apps are based on predetermined and static learning content. *MOBOCity, Savannah, and MaCMoG* discussed in section 3.2 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)DGBL app. As discussed in subsection 3.2.4, 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 subsection 3.2.1.

5.1.1.3 Personalization

The ability of the mDGBL app 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., 2012a). Yet, our findings indicate that the great mass of mDGBL apps 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 section 3.2.1, 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 this regard, personalization is not implemented by any mDGBL app discussed in subsection 3.2.4. 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 app, 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, for assessing the learning experience.

5.1.1.4 Data privacy and security

As already discussed in subsection 3.2.5, 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 mDGBL apps 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) discussed in subsection 3.2.5 are only some examples of mDGBL apps 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 mDGBL apps included in the current survey makes any provision to preserve this quality. Communication among the players and the app also calls for empowering end-user privacy. This also appears when the mDGBL app 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 apps for the m-Learning realm and inevitably for mDGBL 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.

5.1.1.5 Technological trends

As already discussed in section 3.5, in the quest for more motivating and context-based learning environments, a most challenging issue is that of mDGBL integration with emerging technologies. 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)DGBL 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.

Also, especially for mDGBL, 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 mDGBL design and implementation.

To sum up and following the discussion of chapter 3, currently, the most challenging issues for an (m)DGBL 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 app 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.

5.1.2 The CyberAware platform

In this thesis, we presented a novel DGBL platform for young students with the purpose of addressing certain topics in cybersecurity and privacy education. The platform comprises a web-based LCMS and a DGBL app, and intends to complement traditional teaching rather than replace it. This is fulfilled by enabling short session games for the purpose of applying burst-session learning experience in terms of short time period tasks. This type of mini-games is a strategic design choice for maximizing learner attention and knowledge retention, and subsequently minimize their boredom and distraction. Contrary to similar works in the literature, apart from dealing with the technical issues of the app and the LCMS, we pay special attention to the learning/pedagogical aspects, and evaluate the app under different prisms.

Regarding the technical and architectural aspects, we concentrated on the administration of the learning resources and device platform independence. For the first goal, we developed a LCMS for managing educators, learners, and virtual classes, as well as customizing and delivering the appropriate learning content and information material to the app. For the second, we implemented the app to run in a platform-independent manner. Both of the aforementioned characteristics are major parameters that not only extend the lifespan of the DGBL app, but also make it ideal for BYOD scenarios.

For the educational/learning needs, we focused on ways to keep learners on track and maximize the learning outcomes. This has been primarily achieved with the incorporation of the ARCS model of motivation. The evaluation of the app provided strong indications that, for the particular learning domain, DGBL has greater chances to succeed, and young learners are more likely to learn and retain the acquired knowledge. However, additional evaluation efforts with diverse pupil samples are needed to better assess and estimate the positive impacts of this kind of learning for this particular domain.

Finally, the CyberAware platform can be extended in different ways for better supporting the learning process. More on this issue are provided further down in section 5.3.

5.2 Directions for information security and privacy education

It is well known that in the context of information security and privacy, no app can perfectly guarantee the safety of systems. Preserving the security of a system becomes more problematic since in most of the cases attacks aim to exploit humans' weaknesses and the lack of knowledge about security and privacy rather than taking advantage of vulnerabilities found in operating systems, communication protocols, and so forth. Thus, from our point of view, we strongly believe that it is very important to design a holistic learning approach for educating users in these two timely learning fields. Based on the results of this thesis, we concluded that there are some design principles that could guide the design of future (m)DGBL learning strategies in these two learning domains.

- **Establish a security and privacy learning strategy.**

  Most of the times, security and privacy issues are typically unknown to the non-security-savvy individuals, while for some others, the knowledge on security protection measures and privacy awareness is mostly classified as a secondary task. So, it is important to focus on establishing a long run learning strategy for motivating and educating learners on these two scientific fields. The study of the related literature shows that people who participate in such learning courses, could be better aware of the relevant issues, than people who read a training material in an isolated fashion. So, in this respect, CyberAware is anticipated to keep learners informed about basic cybersecurity and privacy issues.

- **Make the learning intervention fun and interactive.**

  Traditionally, security and privacy courses are deemed to be difficult for the learners to follow, since in most of the cases they contain too much information and technical jargon. Delivering knowledge to the learners in a funny and interactive way, in these two learning domains, it is rather certain that learning has greater chances to be attractive and to positively influence their learning experience. The results of the current thesis shows that by blending a traditional security course with such a (m)DGBL strategy it is anticipated to have more fun, be more effective for the learners, and improve their learning outcomes.

- **Keep the learning material short, simple, and coherent.**

  Even for a learning game, reading long text material tends to be boring to follow by the learners. This becomes more important when the learners need to participate in a full-text course for introducing them difficult learning concepts such as the security ones. The results of our research show that if the (m)DGBL environment keeps the learning material coherent, short and simple, the learners feel more satisfied. In this respect, CyberAware is designed to deliver limited learning material, and meaningful feedbacks for reducing boredom and inattention. This, in turn, increases the learning outcomes.

- **Platform independence.**

  The CyberAware app was designed to be cross-platform. This means that can be run on a desktop or a mobile platform. Platform independence becomes vital not only because it overcomes the different mobile peculiarities and extends app's lifespan, but it is also expected to augment the anywhere, and anytime learning experience. The latter point is also aligned with the BYOD policy, since it is anticipated to increase learners' satisfaction when they use their own devices, and to extend app's dissemination prospects. As a result, platform independence is proved vital for establishing a long term education in security and privacy topics.

5.3 Future Research Directions

This PhD thesis has mainly contributed to the domain of mDGBL for educating and rising learners' awareness in cybersecurity and privacy topics. Nonetheless, apart from what already identified in section 5.1, there are a number of semi-unexplored areas in which future work should be carried out to advance upon what has been achieved in the context of this thesis. In the following, we elaborate on these possible future work directions.

5.3.1 Interaction Analysis

As already discussed in subsection 5.1.1.3, a personalized learning approach deems necessary for a number of reasons. However, this is a part of a more holistic approach that requires the assessment of the learning process for producing meaningful feedback either for the educators in order to differentiate their teaching strategy, or the learners in order to gain insight about their learning performance. In this context, any assessment could be formative or summative. In the former case, learning is assessed in every stage, and learners receive ongoing feedbacks towards improving their learning achievements and performance, while teachers receive ongoing results about the learning process. In the latter, learners receive feedbacks about their performance and achievements that are evaluated and compared against some pre-defined learning standards at the end of the learning process. The same results are available to the teachers too. In the context of DGBL, the assessment of learning is traditionally being summative, and is done in an indirectly way (Palomo-Duarte et al., 2017). In any case, the deployment of such a functionality into a technological learning environment imposes techniques for monitoring/tracking, aggregating, and measuring of learners' interaction. It also requires techniques for processing the collected data in order to produce meaningful feedback in a form that will be easy for the learners to parse and understand (i.e., bar-charts, pies, etc.).

It is to be noted that in the literature data-driven analysis of users' interaction for gaining insights about their behavior is not new. For instance, "Web Analytics" are already used by different services providers (e.g. Google), for measuring, collecting, analysing and reporting of the web data in order to conclude about web usage. In educational settings, "Learning Analytics" exploit educational data that are collected from learners' interaction with a learning environment, for the purpose of understanding and benefiting the learning process, as well as optimizing the context in which the learning process occurs (Siemens and Long, 2011). More lately, in the context of serious games, an emerging research field is that of "Games Analytics" that combines learning analytics and serious games for improving both game quality and learners performance (Loh and Sheng, 2015). In this context, the authors in Hauge et al. (2014) describe two modes of analytics in serious games, namely real-time, and off-line, for improving various aspects of the learning environment, such as game quality, game performance, and game progression, as well as monitoring learning goals achievement and assessment of users' behavior and appreciation. An example of this situation is that of "iSTART-2" (Levinstein et al., 2007) DGBL environment. iSTART-2 collects data about every choice the learners make during their interaction with it. Finally, the collected data are used to evaluate learners' behaviour by applying the "Random Walks" (Snow et al., 2013), "Entropy" (Shannon, 1951), and "Hurst exponents" (Hurst, 1951) methodologies.

Therefore, the real-time assessment of the learning process provided by a mDGBL environment, is not concidered a straightforward task. For instance, the authors in Serrano-Laguna et al. (2014), highlight that applying learning analytics for assessing a serious game "is hard to generalize, expensive to scale and difficult to organize". However, it could be interesting to examine the potentials of adding a functionality to the CyberAware platform, for automatically evaluating the data produced from the students' interaction with the app. It could be also challenging to implement an assessment procedure that will allow learners to gain ongoing feedbacks, and visual representations about their learning achievements.

For better defining this future goal, below we summarize seven different types of log files currently produced by the CyberAware app. Such logs can be latter on used by any researcher who wishes to develop a tool for automatically analyzing the collected data with the aim of producing meaningful feedback about the learning process. The Appendix B shows the structure of each log file.

SECURITY section (refer to subsection 4.1.1.1).

- *selection1ScreenStats.json - (CyberTechs - Game1)*
- *selection1Next2ScreenStats.json - (CyberTechs - Game2)*
- *selection2ScreenStats.json - (KeepStrong - Game3)*
- *gameArenaUserStatistics.json - (Security Arena - Game4)*

PRIVACY section (refer to subsection 4.1.1.2).

- *selection1PrivacyUserStatistics.json - (StaySafe - Game5)*
- *selection1PrivacyNext2UserStatistics.json - (StaySafe - Game6)*
- *gameprivacyArenaUserStatistics.json - (Privacy Arena - Game7)*

Concluding, the tracking and analysis of learners' interaction with the app and the LMS are considered challenging endeavors, and among others, are important factors for the successful widespread and deployment of any educational environment. In fact, this issue has been already pinpointed by Ritterfeld et al. (2009) who correctly observed that "serious games will not grow as an industry unless the learning experience is definable, quantifiable and measurable. Assessment is the future of serious games".

5.3.2 LMS migration

As already discussed in subsection 5.1.1.2, adaptivity issues are also vital in a learning app for a number of reasons. However, in the context of CyberAware, a LCMS is implemented for enabling course and learning content management. Nevertheless, in the literature exists a variety of open source LMS to choose, including Moodle, Bodington, Claroline, dotLRN/ OpenACS, Atutor, LON-CAPA, Sakai, etc. These LMSs provide a variety of features and functionalities for supporting both teaching and learning. These include: course management, content delivery, document sharing, personalized learning experience, synchronous and asynchronous collaboration activities among the learners, tracking of learner's data, and various customization capabilities.

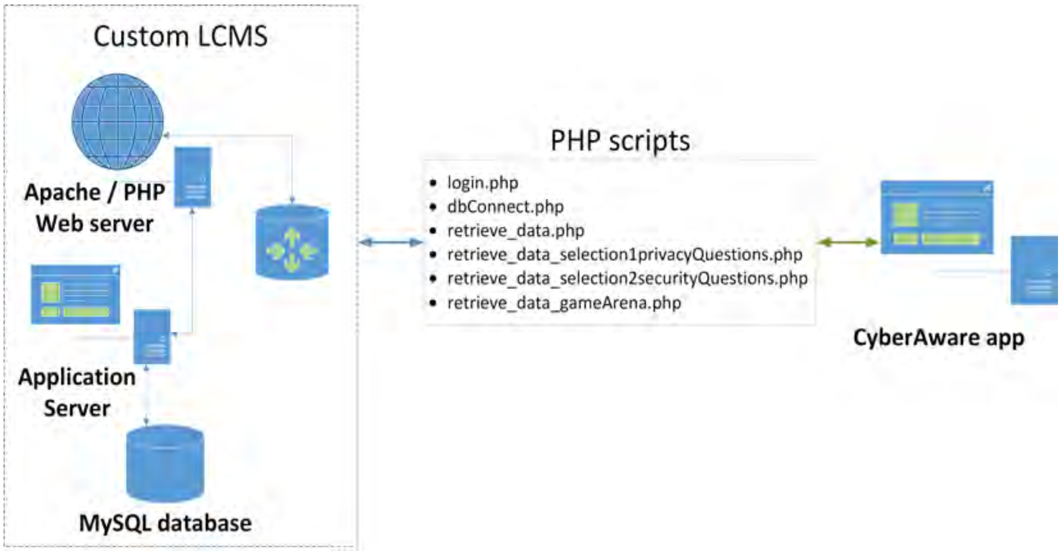


FIGURE 5.1: LCMS and gaming app interconnection

Currently, CyberAware uses the RESTfull technology for interrogating with our custom-made LCMS. Specifically, as shown in Figure 5.1, the app uses 6 PHP scripts for interacting with the mySQL database. However, as a future work, it would be interesting to examine the potentials of integrating our app with a well-known open source LMS platform, aiming to further enhance its learning potentials. In literature a similar approach is discussed by the authors in Livingstone and Kemp (2008) for integrating their web-based 3D learning environment named "Second Life" with the Moodle LMS.

In this context, after examining the plethora of LMS tools, we consider that the Moodle LMS is the most proper one, since it surpasses the rest in the following points: a) its popularity in the e-Learning domain (Kotzer and Elran, 2012), b) it integrates pedagogical features that allows instructors to construct customizable online courses (Berggren et al., 2005), a feature that is largely missing from other LMS tools, c) according to the study by (Graf and List, 2005, Cavus and Zabadi, 2014) it overcomes other LMS tools in terms of adaptivity, personalization, extensibility, communication, and data collection. A last advantage is that Moodle uses the PHP scripting language, and features a rich API that comprises a large collection of scripts for accessing its components.

However, the successful migration of CyberAware database to a new LMS, demands a careful design and the appropriate modification of the PHP scripts currently used by our app. Therefore, for avoiding unnecessary future malfunctions with the new LMS, a more general modification approach should be followed. Specifically, a common communication protocol must be used between the LMS and the gaming app. Additionally, the packaging and delivering of the Learning Objects (LOs) (Polsani, 2006) must be standardized. Thus, since the Moodle is Sharable Content Object Reference (SCORM) 1.2 compatible, we have to examine the modification of CyberAware to be SCORM-compliant. This means that any modifications must follow the standards of Advanced Distributed Learning (ADL) SCORM reference model (ADL-SCORM, 2018), for enabling also the necessary adaptivity to the CyberAware app (Rey-Lopez et al., 2009).

Appendix A

Evaluation instruments

Table A.1: Effectiveness: Test questions for the Security section

Item	Question
Q1	Select and circle from the following list all the items needed to protect an Internet-connected device. List: (i) Antivirus, (ii) Image processing software, (iii) Security updates or patches, (iv) email filter, (v) Music player, (vi) Firewall, (vii) Video player.
Q2	Choose and circle from the following list all the items that justify the use of a firewall to protect an Internet-connected device. List: (i) Prevent hacking attempts against your Internet-connected device, (ii) Protect your device from downloading malware, (iii) When using it, can rest assure that their software is up-to-date, (iv) Blocks spam and other unwanted emails from entering your inbox.
Q3	Choose and circle from the following list all the items that justify the use of an antivirus to protect an Internet-connected device. List: Same options as in Q2.
Q4	Select and circle from the following list all the items that mandate the use of security updates and patches for an Internet-connected device. List: Same options as in Q2.
Q5	Choose and circle from the following list all the items that endorse the use of spam filtering. List: Same options as in Q2.
Q6	Choose and circle from the following list all the real-life scenarios where a user needs to apply at least one cybersecurity technology. List: (i) To play a game on the Web, (ii) After clicking on a web link i was prompted for an authorization approval, (iii) Unwanted advertising emails are entering my inbox, (iv) To play a music file received by email, (v) To type some sentences using the word processor, (vi) A friend of mine sent me an email that contains a web link, (vii) To visit a web site containing comics, (ix) To play music via the computer's CD player, (x) To download a game to my PC, (xi) To paint a doodle using a drawing software tool.
Q7	Choose and circle from the following list all the items that seem to be good (strong) password candidates. List: (i) Your name, (ii) At least eight alphabetical characters long, (iii) A series of alphabets, numbers, and special characters, (iv) 12345678, (v) The word "password", (vi) Five characters long, (vii) Your birth date, (ix) Your dog's name, (x) Your mobile telephone number.
Q8	Choose and circle from strongest passwords List: (i) Filip, (ii) 11111111, (iii) codeA12#$, (iv) nopassword, (v) !2drg456A, (vi) may_the_force_be_with_you, (vii) Hacker123.

Table A.2: Effectiveness: Test questions for the Privacy section

Item	Question
Q1	Select and circle from the following list all the pieces of information that need to be kept private. List: (i) Your favourite team, (ii) Your telephone number, (iii) Your favourite desert, (iv) Your home address, (v) Your everyday schedule, (vi) Your favorite comic, (vii) Your father's/mother's ID number, (ix) Your favorite sport.
Q2	Choose and circle from the following list all the information that can be safely posted on the Facebook. List: (i) George, the spaghetti we ate at that restaurant was delicious, (ii) Tom, i want to invite you at my home located at 4325 W. Palm Beach Rd, (iii) I am so happy because my team won the match today, (iv) Elen, do not forget our appointment today at metro station located at Syntagma, at 18:00 o'clock, (v) Give me a call on +345435325235.

TABLE A.3: The questionnaire instrument regarding app usability, and user satisfaction and expectations

Item	Question
Q1	a. Male, b. Female
Q2	a. 9, b. 10, c. 11, d. 12
Q3	Have you ever played a digital game? (Yes or No)
Q4	Have you ever played an educational game? (Yes or No)
Q5	I love playing digital games. (Yes or No)
Q6	How much do you agree with the following statements regarding the game? (check all the appropriate boxes)
(a) [ ]	It was easy to use.
(b) [ ]	The instructions on how to play were easy to understand.
(c) [ ]	The game's information (game play and learning goals) were comprehensible.
(d) [ ]	The messages displayed on the screen after a given answer were comprehensible.
(e) [ ]	When a given answer was wrong, the displayed message helped me to find the correct answer.
(f) [ ]	Every mini-game was easy to navigate.
(g) [ ]	After an action, it was easy to understand what to do next.
Q7	Did you face any problem when using the game (e.g., small mobile screen, interactions with the touch screen, structure of learning activities, etc)? If yes, please describe it shortly.
Q8	How much do you agree with the following statements regarding the game? (check all the appropriate boxes)
(a) [ ]	It was very funny to learn while playing the game.
(b) [ ]	I liked that the game has a short amount of reading material and more action.
(c) [ ]	I would like to play the game again in my classroom.
(d) [ ]	I would like to play the game again outside the classroom in my free time.
(e) [ ]	I became familiar with what is required for a personal device to be protected against basic online attacks from the Web.
(f) [ ]	I realized the importance of privacy in the Internet age.
(g) [ ]	I will recommend it to my friends.
Q9	Do you expect anything else from the game? if so, please describe it shortly.

Appendix B

Structure of log files

B.0.1 selection1ScreenStats.json - (CyberTechs - Game1)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
// (The Date stamp that shows when the activity started.
// It is null if never started.),
#3 "activityendtime": "HH:MM:SS",
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "wrongtimeattempts":["HH:MM:SS", "HH:MM:SS",....],
// (List of time stamps that show when the user gave a wrong answer.,
//  It is empty [] if no any wrong answer is given.),
#8 "infowrongpagetimespent":[X,X],
// (This is a list of questions, in which the learner gave a wrong answer.
//  This is associated with the values stored in the wrongtimeattempts,
//  and wrongattemptscounter fields.,
//  It is empty [] if no any wrong answer is given.)
#9 "attemptscounter":X,
// (Total number of wrong answers before a challenge successfully finishes.
```

```
//  This value is associated to the values stored in the
//  infowrongpagetimespent field.
//  It is 0 if no any wrong answer is given.)
```

B.0.2 selection1Next2ScreenStats.json - (CyberTechs - Game2)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
// (The Date stamp that shows when the activity started.
// It is null if never started.),
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "wrongtimeattempts":["HH:MM:SS", "HH:MM:SS",....],
// (List of time stamps that show when the user gave a wrong answer.,
//  It is empty [] if no any wrong answer is given.),
#8 "infowrongpagetimespent":[X,X],
// (This is a list of questions, in which the learner gave a wrong answer.
//  This is associated with the values stored in the wrongtimeattempts,
//  and wrongattemptscounter fields.,
//  It is empty [] if no any wrong answer is given.)
#9 "attemptscounter":X,
// (Total number of wrong answers before a challenge successfully finishes.
//  This value is associated to the values stored in the
//  infowrongpagetimespent field.
//  It is 0 if no any wrong answer is given.)
```

B.0.3 selection2ScreenStats.json - (Keep Strong - Game3)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
```

```
// (The Date stamp that shows when the activity started.
// It is null if never started.),
#3 "activityendtime": "HH:MM:SS",
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "questionnumber":[X,..,..],
// (A list with the number of questions that made an attempt the user,
//  during the current phase.
//  This number is associated with the relevant number stored in the LCMS.)
#8 "correctquestionnumber":X,
// (This is the number of questions that are remaining to be answered)
#9 "questionsinfo"[{"questiondescription":"Question1","suggested1description":
   "Description1","suggested2description":"Description2","suggested3description":
   "Description3"},{}, ....],
// (This is a list of questions in which the user tried to answer.),
#10 "wrongattemptscounter":[X,X,X,X],
// (Total number of wrong attempts for each question.
//  The value is associated to the values stored in the
//  field wrongtimeattempts.
//  This is 0 when no any wrong answer is given.),
#11 "wrongtimeattempts":["HH:MM:SS", "HH:MM:SS",....],
//  (List of time stamps after a wrong attempt.
//  This value is empty [], if there is no any wrong answer.),
#12 "infowrongpagetimespent":[X,X],
// (This is a list of questions, in which the learner gave a wrong choice.
//  This is associated with the values stored in the wrongtimeattempts,
//  and wrongattemptscounter fields.,
//  It is empty [] if no any wrong answer is given.)
```

B.0.4 gameArenaUserStatistics.json - (Security Arena - Game4)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
// (The Date stamp that shows when the activity started.
// It is null if never started.),
```

```
#3 "activityendtime": "HH:MM:SS",
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "score":X,
// (This is the total score.),
#8 "timestartedfrom":X,
// (This is the time duration of the current game in seconds.),
#9 "remainingtime":X,
// (This is the time that elapsed before finishing the game.),
#10 "addpointstartedfrom":X,
// (Show the points that the user gains after a successful choice.),
#11 "negativepointstartedfrom":0,
// (Shows the points that the user loses after an unsuccessful choice.),
#12 "scanpressed":0,
// (It counts the times that the scan button is activated by the user.),
#13 "scanremainedopen":[],
// (This list of values holds the time in seconds each time the scan button is activated),
#14 "scenarios":
   {"scenariodescr":["Description1", ...], //Holds the description of the scenarios
    "correctcollectorscenario":[X,...],    //Holds the correct answer for each scenario
    "wrongattempts":[X, ...],              //Holds the wrong answers for each scenario
    "wrongcollectorscenarios":[X,X, ...}   //Holds the number of questions in which the
                                           //user gave a wrong answer (it is associated
                                           //with the key number stored in the database
                                           //of the LCMS).)
```

B.0.5 selection1PrivacyUserStatistics.json - (Stay Safe - Game5)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
// (The Date stamp that shows when the activity started.
// It is null if never started.),
#3 "activityendtime": "HH:MM:SS",
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
```

```
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "questionnumber":[X,..,..],
// (A list with the number of the questions in which the user made an attempt.
//  This number is the same as stored in the LCMS.)
#8 "statusofquestion":0,
// (Holds the status (correct choice) of the question.
// (1=Private, or 0=Public))
#9 "questionsdescription":["Question1",.....]
// (This is a list of questions that the user participate in the current phase.),
#10 "wrongattemptscounter":[X,X,X,X],
// (Total number of wrong attempts for each question.
//  The value is related to the wrongtimeattempts values.
//  This is 0 when no any wrong answer is given by the user.),
#11 "wrongtimeattempts":["HH:MM:SS", "HH:MM:SS",....],
// (List of time stamps after wrong attempts.
//  This is empty [], if there is no any wrong answer.),
#12 "infowrongpagetimespent":[X,X],
// (This list holds the number of questions in which the learner made a wrong choice.
//  It is associated with the wrongtimeattempts, and wrongattemptscounter values.
//  This value is empty [], if no any wrong answer is given by the user.)
```

B.0.6 selection1PrivacyNext2UserStatistics.json - (Stay Safe - Game6)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
// (The Date stamp that shows when the activity started.
// It is null if never started.),
#3 "activityendtime": "HH:MM:SS",
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
```

```
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "questionnumber":[X,..,..],
// (A list with the number of the questions in which the user made an attempt.
//  This number is the same as stored in the LCMS.)
#8 "statusofquestion":0,
// (Holds the status (correct choice) of the question.
// (1=Private, or 0=Public))
#9 "questionsdescription":["Question1",.....]
// (This is a list of questions that the user tried to answer.),
#10 "wrongattemptscounter":[X,X,X,X],
// (Total number of wrong attempts for each question.
//  The value is related to the wrongtimeattempts values.
//  This is 0 when no any wrong answer is given by the user.),
#11 "wrongtimeattempts":["HH:MM:SS", "HH:MM:SS",....],
// (List of time stamps after wrong attempts.
//  This is empty [], if there is no any wrong answer.),
#12 "infowrongpagetimespent":[X,X],
// (This list holds the number of questions in which the learner made a wrong choice.
//  It is associated with the wrongtimeattempts, and wrongattemptscounter values.
//  This value is empty [], if no any wrong answer is given by the user.)
```

B.0.7 gameprivacyArenaUserStatistics.json - (Privacy Arena - Game7)

```
#1 "activitystarttime":"HH:MM:SS",
// (The Time stamp that shows when the activity started.
// It is null if never started.),
#2 "activitystartdate":"DD/MM/YY",
// (The Date stamp that shows when the activity started.
// It is null if never started.),
#3 "activityendtime": "HH:MM:SS",
// (The Time stamp that shows when the activity successfully finished.
// It is null if not started.),
#4 "activityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity successfully finished.
// It is null if not started.),
#5 "uncompletedactivityendtime":"HH:MM:SS",
// (The time stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#6 "uncompletedactivityenddate":"DD/MM/YY",
// (The Date stamp that shows when the activity unsuccessfully finished.
// It is null if not exists.),
#7 "score":X,
```

```
// (This is the total score),
#8 "timestartedfrom":X,
// (This is the duration of the game in seconds),
#9 "remainingtime":X,
// (This is the time that elapsed for finishing the game),
#10 "addpointstartedfrom":X,
// (Show the points that the user gains after a successful choice.),
#11 "negativepointstartedfrom":0,
// (Shows the points that the user loses after an unsuccessful choice.),
#12 "scanpressed":0,
// (It counts the times that the scan button is activated by the user.),
#13 "scanremainedopen":[],
// (It holds the time, in seconds, that the scan button remains active),
#14 "scenarios":
   {"scenariodescr":["Description1", ...], //Holds the description of the scenarios
    "correctcollectorscenario":[X,...],    //Holds the correct answer for each scenario
    "wrongattempts":[X, ...],              //Holds the wrong answers for each scenario
    "wrongcollectorscenarios":[X,X, ...}   //Holds the number of questions in which the
                                           //user gave a wrong answer (it is associated
                                           //with the key number stored in the database
                                           //of the LCMS).)
```

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