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### **Exploring Internet of Things, Mobile Computing and Ubiquitous Computing in Computer Science Education: A Systematic Mapping Study**

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# Exploring Internet of Things, Mobile Computing and Ubiquitous Computing in Computer Science Education: A Systematic Mapping Study

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## Abstract

Ubiquitous computing, mobile computing and the Internet of Things (UMI) have been widely used in several application areas. To date, methods and techniques for the application of these technologies in real life situations have continued to emerge; however, their use in education settings focusing on existing practices remain largely underexplored. A systematic mapping study (SMS) method was herein used to map initially identified 395 articles with the aims of systematically analyzing and presenting the evidence from the literature on the topic, and to identify important gaps as well as promising research directions. An appropriate methodological protocol has been adopted from the literature for the analysis, filtering, evaluation and report of the evidence. As a result, twenty-five studies have been selected and analyzed. The axes of analyzing systematically the literature were inspired by an existing UMI learning ecology. The analysis revealed important characteristics of existing UMI related educational practices in all levels of education, including contexts and actors involved, methods and digital tools used, affordances and learning approaches important for achieving effective learning in IoT, Mobile and Ubiquitous Computing domain.

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## Introduction

Internet of Things has emerged as a new, powerful, umbrella term that involves the use of smart objects as well as their control, monitoring and identification through internet (Ramakrishnan, Preuveneers, Berbers, 2014; Vermesan et al, 2014). Some authors suggested that technologies such as the Internet of Things and mobile computing can bring the next technological revolution (Feki, Kawsar, Boussard, & Trappeniers, 2013; Soyata, Ba, Heinzelman, Kwon & Shi, 2015), while others believe that already these technologies are the manifestation of the new paradigm which revolutionizes computing (Gómez, Huete, Hoyos, Perez, & Grigori, 2013). Smart cities, smart and economical agriculture, factory automation, e-health, vehicle safety, assisted living and other applications are often mentioned in the recent literature as recent developments of either mobile computing (MC hereafter) or Internet of Things (IoT); see for example, Whitmore, Agarwal & Da Xu (2015).

Despite the advances of Information and Communication Technologies (ICT) for making IoT a reality, this paradigm has a variety of open issues that require further research and development methods (Rose, Eldridge, Chapin, 2015). One of them refers to the actual use of IoT infrastructures and concepts for education purposes. In this context, challenges arise in terms of collecting, analyzing, managing the educational environment using IoT, Mobile Computing and Ubiquitous computing applications (Stankovic, 2014; Borgia, 2014; Wang, Bi, Xu, 2014). There are two distinctively different points of view on that, namely, the use of these technologies *as educational means or as educational ends* (Mavroudi, Giannakos, Divitini, Jaccheri, 2016). The former refers to using technology as support mechanism with the aim of enhancing the learning experience in any subject matter, whereas the latter refers to exploiting it as part of a modern computing education curriculum. Using the aforementioned technologies as educational means has contributed to the advances of Technology Enhanced Learning (TEL), especially of ubiquitous and contextual learning with encouraging learning gains (see for example, Looi, Wong & Milrad, 2015); relevant reviews can be found in the literature in several domains, like higher education (Pimmer, Mateescu, Gröhhbie, 2016), or mobile and contextual learning (Wei, Chen & Kinshuk, 2012), (Wong, 2015). On the other hand, using these technologies *as educational ends* is closely related to educating the new generation, empowering it with the knowledge and skills needed in developing these IoT applications that can be ubiquitous, mobile or context-aware. With respect to this viewpoint, not much research has been conducted to review in a systematic way the relevant recent literature on the use of Internet of Things, Mobile and Ubiquitous Computing in educational settings. To provide relevant content appealing but also useful to professionals and practitioners in both education and technology field, a systematic mapping study (SMS) has been performed so as to obtain a comprehensive overview of the described research topic, identify research gaps and collect evidences to commission future research but also trace, existing effective practices

(Ibukun and Daramola, 2015). The advent of Internet of Things and Ubiquitous computing since 2002, has brought forward important aspects of addressing these kind of technologies in modern education curricula, and thus pose a problem of significant value to computing education and instructional design.

This study aims to explore existing practices in all levels of education which make use of Internet of Things, Mobile and Ubiquitous Computing applications, describing: the underlying context, important actors involved, methods and affordances that shape the essence of these practices. The remainder of this paper is structured as follows: Section 2 provides the background on issues regarding the SMS. Section 3 describes and documents the systematic mapping study (SMS) methodology, research questions, search strategy, selection criteria and data extraction method. Section 4 reports on the results of the SMS. Section 5 presents the discussion regarding the presented results, threats of validity as well as implications for future research. Section 6 contains concluding remarks.

## Background

### Internet of Things in Education: Contexts and Practices

The idea of IoT evolves over time and has undergone succeeding transformations which will predictably still continue over the next years with the advent of new enabling technologies (Atzori, Iera & Morabito, 2016) and the arising consequence of preparing young generations for these changes. By definition, IoT connects a) people to people, b) people to machine / things and c) Things /machine to things /machine, interacting through internet (Patel and Patel, 2016). Though enabling technologies for the Internet of Things exhibit a variety in applications, they can be grouped into three categories: (1) technologies that enable “things” to acquire contextual information, (2) technologies that enable “things” to process contextual information, and (3) technologies to improve security and privacy (Rose, Eldridge & Chapin, 2015). In education, "craft-like" creative practices supported by IoT have already been recognized among highly skilled professional artist-engineers (Woolford, Blackwell, Norman & Chevalier 2010), (Blackwell, Aaron & Drury, 2014). Recent popular movements such as the *Code Club* and *Computing at Schools Consortium* involve technologies that bridge professional artists and hobby/enthusiasts, for example, under the banner of the "maker movement" (Blackwell, Aaron & Drury, 2014). In that context, programming is becoming “*a creative material competence rather than simply an intellectual and scientific pursuit*” (Blackwell, Aaron & Drury, 2014: p 77).

Applied in education, IoT technologies have been used to collect and use data to enhance the learning experience, to support the learning goals, or improve the overall school operations and alter school or college life (Burd et al, 2018). IoT and Ambient Intelligence (AI) based courses currently run in major colleges or University Institutions in Higher Education (Corno and De Russis, 2016), and this could imply an adaptation of curriculum development in Computer Engineering (CE). In the IoT paradigm, the co-existence of hardware, software, networks, and the mix of programming languages requires a systems-level view, difficult to reach in vertically oriented courses (Hwang , Kim & Im, 2017]. Under this context, interdisciplinary work is needed in CE field curriculum development, bringing forward as a goal to outline the multidisciplinary nature of IoT and Mobile Computing design and to provide a strong set of respective competencies (Hwang , Kim & Im, 2017). Teaching IoT may include topics on “algorithm, programming skill, distribution and collaboration, creative design, collaborative design, ethical issues, and computing in society” (Wei, Chen, Kinshuk, 2012 : p.92). In terms of pedagogical approaches, problem solving and the constructivism are popular for supporting IoT and Mobile computing courses (Corno and De Russis, 2016) .

### Related Studies

Regarding the scope of this paper, we have traced similar work dealing with designing an IoT curriculum, such as the work of Voas and Laplante (2016), and Kortuem, Bandara, Smith, Richards, Petre, (2012). The most similar piece of research work that the authors identified in the recent literature is a systematic review of research publication between 2006 and 2014 on the trends of mobile learning in computing education (Anohah, Oyelere, Suhonen, 2017). To date, the educational affordances of mobile and ubiquitous learning have been examined in a number of settings: in formal education settings inside and outside the classroom (e.g . Wassan, Nawaz, Syed, Arfeen, Naseem, Noor, 2015), in the workplace (e.g., Pimmer and Pachler, 2014), and in the context of lifelong learning (e.g., Ramakrishnan, Preuveneers, Berbers 2014). There also seems to be a predominance of mobile learning in higher education settings (Filali, Retbi, Idrissi & Benammi, 2014), (Moreira, Ferreira, Joao, Pereira, Durão, 2016), (Kearney, Schuck, Burden, Aubusson, 2012), (Ning and Hu,

2012). Keengwe & Bhargava (2014) as well as Mac Callum, Jeffrey, Kinshuk (2014) reported that higher education students were the most often researched target group for mobile learning studies. In these reviews, UMI technologies have been examined as educational means to support the learning process, exploring different forms, practices, outcomes of mobile learning and the actual use of Internet of Things and their theoretical underpinnings, in the sense of enabling contexts, tools, practices and methodology (learning theory) supporting their use.

### **The Need for a Systematic Mapping Study**

There is a variety of approaches in using Internet of Things, Mobile Computing and Ubiquitous Computing in real life settings, practices in education which make use of these technologies vary in terms of context, learning objectives, tools used, important actors involved, and methods and practices applied. We have looked closely at Ubiquitous Computing, Mobile Computing and Internet of Things (UMI) based practices in computing education on the basis of three axes: a) description of actual and enabling contexts that provide learning opportunities, b) description of learning objectives, digital tools and affordances created by these interventions, c) description of associated actors and learning processes involved. These axes were adopted from the learning ecology framework for using UMI technologies (Fragou, Kameas, Zacharakis 2017). The motivation for conducting this systematic mapping study has been based in the need to advance our knowledge regarding the existing uses of UMI in computing education and what characterizes associated practices. The practical dimension has also been important in the sense of highlighting gaps in the literature in using these technologies in various levels of education but also potentials for further exploitation of these technologies.

In order to shape a clear structure of the research domain (Petersen, Vakkalanka, Kuzniarz, 2015) we have been inspired that a systematic mapping study would allow us to indicate what methods and practices, in which contexts have been used in modern education and to what extent based on a carefully identified sample from the literature. The benefits of study as such are the following: a) provision of a comprehensive overview of state of the art on the topic at stake, b) identification of relevant gaps in the literature and collection of evidence to commission further research, c) systematically analyzing all available evidence in the literature and answering the research questions (Nunes and Albuquerque, 2016), (Petersen, Vakkalanka, Kuzniarz, 2015), (Rose, Eldridge, Chapin, 2015), (Soua, Mazo, Salinesi, Comyn-Wattiau, 2016).

## **Methodology**

### **Research Questions**

The research questions of the systematic mapping study have been the following:

- *Which are the contexts (actual and enabling) that provide opportunities for learning about these technologies?*
- *What are the learning objectives addressed in these learning interventions?*
- *What are the digital tools used and their affordances?*
- *Which are the associated actors and learning processes involved (orchestration methods & practices)?*

### **Search Strategy**

The search strategy is in line with the guidelines of the mapping study protocol prescribed in the Durham template ([www.dur.ac.uk/ebse/resources/templates/MappingStudyTemplate.pdf](http://www.dur.ac.uk/ebse/resources/templates/MappingStudyTemplate.pdf)) for conducting mapping studies, originally suggested by Petersen, Vakkalanka and Kuzniarz (2015). It involves the following: bringing forward the need and relevance of the SMS, defining objectives and questions important for the scope of the study, deciding upon a search strategy, conducting manual and database search, setting inclusion and exclusion criteria, resolving disagreements among participant researchers, consulting experts when needed, specifying a paper test-set, and discussing threats.

A mixed search strategy was adopted implementing both manual and automated search so as to have a holistic picture of the data collected and to balance the authors' human judgement with the functionalities of the information retrieval technology. The three main terms used for the automated search were "Internet of Things", "Ubiquitous Computing" and "Mobile Computing" as well as equivalent terms. The equivalent terms were: "internet of everything", "web of things", "machine to machine", "nomadic computing", "mobile networking"

and “distributed computing”. The main priority was to cover all the publishing venues mentioned by the Special Interest Group on Computer Science Education (SIG in CSE) mentioned in their website; accessing the website of leading research groups to identify relevant literature has been proposed as a good practice suggested by the protocol followed herein. Finally, since the Durham protocol suggests taking measures to cope with validity threats, a quality assessment process (Stemler, 2004) was integrated as a separate phase, although inclusion of such a phase is not vital in systematic studies.

### Inclusion and Exclusion Criteria

The inclusion criteria that the authors specified with the intent of filtering the studies were: 1) relevant studies falling within the scope of the research, 2) studies written in English, 3) studies including empirical research, and 4) journal articles or “grey literature” in the form of conference proceedings and book chapters. Since UMI is a relatively new and rapidly developed field, we have chosen to include in our study only primary studies of the last five years from the time that the search strategy was created by the authors (November 2018). In case of duplicate studies, the most recent one was kept. On the opposite, workshop papers, speculative papers and reviews were excluded from the analysis.

### Papers’ Selection

At the beginning of the search process, the search strategy was pilot-tested by both analysts. Afterwards the search was performed over the selected electronic databases by searching for all studies that have matched the adapted search strings and inclusion criteria. The selection of the studies initially involved reading the Title, Abstract and Keywords (TAK) of the studies retrieved from the electronic databases. Through this process, 395 articles were identified. Not all these papers satisfied all five inclusion criteria at this phase of automated search; in particular, some of them didn’t satisfy criterion 1 or criterion 3 (i.e. studies within the scope of the search and including empirical research). Further filtering of these articles has been performed on the basis of human judgement by studying the TAK of the articles. The purpose was to read the TAK and to judge whether an article was satisfying all the inclusion criteria. Whenever this could not be inferred from the TAK, the paper was still included in the next phase. The end of this phase limited the number of papers to 35. The third phase involved full-text reading and revisiting papers for which is has been ambivalent whether they actually satisfy all criteria, especially criterion 1 or 3. The authors conducted a consensus meeting to discuss and negotiate about the final paper selection. Finally, 25 papers were included in the analysis. Figure 1 below depicts the selection process of the studies included in the analysis.



Figure 1. The Papers’ Selection Process

### Data Extraction

For our data extraction process, the authors developed two templates and used online spreadsheets. In particular, one template for the papers' selection and filtering, and another one for the analysis of the papers included in the SMS. Regarding the former, the columns of the spreadsheet corresponded to the different phases of the filtering process across the 395 papers. To reduce researcher bias, one researcher extracted the data and another was reviewing the initial extraction (Pimmer, Mateescu, Gröhbbe, 2016). Regarding the second template, the spreadsheet columns corresponded to relevant data categories (e.g. learning objectives, orchestration) across the 25 papers included in the SMS. The categorization schema used to create these categories was inspired by the learning ecology schema in UMI education (Fragou, Kameas, Zacharakis, 2017) as described in section 3.1. The data extraction process was pilot-tested by the two researchers working with a small number of papers. The result of the pilot test was to finalize the headings (i.e. the titles) of the columns of the second spreadsheet and agree upon their semantics. For example, in its initial version the spreadsheet included three columns for the different levels of learning objectives (knowledge, skills, attitudes). In the final version of the spreadsheet, these three columns were grouped in one column titled “learning objectives” with a mutual understanding among the researchers about its semantics. Each of the 25 papers included in the analysis was analyzed twice by the two

analysts/authors working independently and reporting individually. The final results presented herein mostly correspond to aggregated views (i.e. a synthesis) of what the analysts were reporting individually.

### **Quality Assessment Procedure**

Two analysts evaluated the selected papers against five quality criteria that addressed “study planning, execution, results, and conclusion” (da Silva et al, 2014 p.64]. In particular, the criteria were inspired by two different literature sources (Petersen, 2011), (Steinmacher, Chaves, Gerosa, 2013) and involved: 1) the research problem, 2) the context description, 3) the data collection, 4) the analysis of the collected data, and 5) the process of reporting the results, respectively. Based on these criteria, each paper received a score in a 5-point scale and from these scores the interrater agreement (Stemler, 2004) has been calculated so as to validate the quality of the selected papers as proposed by the Durham protocol in the Methodology section.

### **Results**

With respect to the quality of the papers included in the review, the average scores assigned by the two raters were 3.92 (S.D.= 0.76) and 3.72 (S.D.= 0.89) respectively, indicating that the majority of the papers had a relatively high-quality standard. Cohen's  $\kappa$  was run to determine if there was agreement between two raters' judgement on the papers' quality. There was good inter-rater agreement,  $\kappa = .703$ ,  $p < .001$ .

### **Enabling and Actual Contexts for Education Using UMI Technologies**

With respect to the *actual context*, the vast majority of the papers included in the review involved university education and formal learning settings. Only 4 papers (16%) involved either school education or semi-formal learning settings. Not surprisingly, in terms of the domains associated to the UMI education, computer science was the most dominant. Example of topics include: pervasive computing, mobile computing, IoT, Big Data Analytics, programming, systems security, Ambient intelligence and visualization.

In some cases, the UMI education aspect was incorporated in already existing courses (16%), or it was embedded in interdisciplinary courses (8%). This approach (i.e. integrating IoT into existing courses) is mentioned as one of the four main course approaches in the state-of-practice presented in (Burd et al, 2018). Especially Computer Science courses, or Embedded Systems Design and Robotics, Mobile Applications' Development are important contexts for using these types of applications. Ambient Intelligence is also an important context for using IoT and mobile applications. With respect to the enabling context (whenever aspects of it were mentioned or could be easily inferred) it mostly entailed receiving financial support and funding grants (12%).

### **Learning Objectives and Education Using UMI Technology Interventions**

Surprisingly, almost half of the papers (48%) do not explicitly mentioned any *learning objectives* associated with the UMI education interventions or endeavors discussed in their works. The remaining papers describe learning objectives, which in general address students' higher order thinking skills, since in their majority correspond to higher levels of the hierarchy of learning objectives proposed by Anderson et al. (2001). Examples of such learning objectives include: application techniques (e.g. programming), creation (e.g. applications), design (e.g. prototypes). At a lesser extent, lower level thinking skills have been also addressed via learning objectives that involve students describing (e.g. protocols), explaining (e.g. architectures), and using (e.g. services). Some papers focus on competencies rather than learning objectives, since students' attitudes or 21st skills have been also addressed in parallel.

### **Digital Tools Used and Respective Affordances**

With respect to the digital tools involved in developing IoT and mobile computing applications, Raspberry Pi and Arduino Uno have been used as the most popular microcontroller platforms, Arduino and Raspberry Pi are the most popular platforms for IoT development applications as revealed from literature (Stankovic, 2014) . This has also emerged from the mapping study: 24 % of the reviewed papers included the use of these specific

platforms, whereas App Inventor has been used in one paper. Java Micro Edition has been used for mobile game development, Java GUI widget classes, and Java Eclipse for Android. Sketchup and TinkerCAD have been used for graphics design and Scratch Game Creator for game development. All these technologies were mentioned in different papers, but only each of them was mentioned in one paper. Cloud-based C/C++ compilers for software development and breadboards in the context of laboratory projects to rapidly build prototypes of robots and embedded devices have been also used in two papers. The 15.1 % of the reviewed papers have targeted the use of Android platform which has been quite popular in papers on IoT and mobile applications focusing at security aspects. Apart from these used tools, the reviewed papers revealed some extra technology tools, most of them being open source software products such as mobile development platforms, cloud or collaborative applications. For example Appcelerator Titanium as a mobile development platform has been used to develop cross platform mobile applications in higher education context (one paper). Advanced graphic design for supporting mobile and IoT applications has also emerged a quite important parameter since technologies as such impose complex situations, problems and processes; under this scope tools to safely perform graphical operations such as TSGL (the Thread Safe Graphics Library) seem to enhance the development processes of UMI applications (one paper). Versatile and quite easy to use software tools such as the Twilio cloud application with which students can create their own IoT application (one paper) or , SONIC Pi, (an environment for creating live-coded music at a level of complexity that is suited to first-language teaching) seem to support the designed educational practices as retrieved from data analysis . Smart lightbulbs, smart thermostats , home cameras have also been used in the context of smart objects in two papers, whereas collaborative tools such as wiki (one paper) and GIT/GitHub have also been used peripherally (one paper) .

With respect to the *affordances* involved, reinforcing programming topics such as loops, classes, arrays through game development has emerged important in the context of one paper. Algorithmic thinking via a) 3D animation & storytelling, b) through coding music & graphical user interface, c) creating 2D visualizations has not been quite popular in existing practices as the analyzed data revealed, since only one paper focused on that. Applying sprite graphics, tile base playfield maps, finite state machines & path finding, prototyping and software testing via 2D interactive games have emerged as important in one paper. Sensors for automatic measurement and graph sunlight exposure, ground temperature, soil moisture, and soil fertility in real time and over time as important devices for developing IoT applications have also emerged from the study (two papers). Arduino and Raspberry Pi emerged as popular platforms for developing UMI applications. The selection of Arduino in the respective two papers has been linked with the a) low cost, b) flexibility, c) the ease of programming, d) enabling connectivity to virtually any possible sensors, actuators, or networking interfaces, e) fully supporting for the sensing and networking architectural. The selection of Raspberry Pi, in one paper, has been grounded to its Linux –based operating system as well as its equipment for programming in C making it an excellent fit for teaching all Systems Programming concepts. Google’s Web Toolkit has been used in the context of providing students with experience in designing and implementing user interfaces for mobile and web applications (one paper). The Java-based app development use by incorporating Javascript, CSS, HTML even in cross-platform development environments such as Appcelerator Titanium has been related to imposing a short learning curve (five papers). Only in one paper, transitioning from object-oriented to event-driven Java programming involved coverage of Model-View-Controller pattern; this meant using design iterations, matrixes, probe software. Internet accessibility “affords “ opportunities for accessing information which is a popular practice in IoT and Mobile computing applications development; however, what seems to be challenge is to elaborate on how these affordances could be relevant to the learner or a practitioner (Laurillard, Stratfold, Luckin, Plowman, Taylor, 2000).

### **Associated Actors and Learning Processes Involved**

In the vast majority of the papers the main *actors* involved are university students (88%). In half of these papers, the role of tutors (university teachers, teaching assistants or professors) is also discussed in terms of providing guidance in laboratory contexts or supporting the development of IoT and mobile applications. Two papers involve school pupils and two papers involve adults as trainees. Though IoT and mobile computing development and respective topics seem to be quite popular in Higher Education, there have been also some efforts in disseminating IoT and mobile computing development in school context.

With respect to addressing (or not) *gender issues* in Computer Science education, the vast majority of papers included in the review did not address gender issues. Only 11,1% of the papers clearly and specifically addressed the aspect of gender whereas there have been others (2) which have introduced gender aspects in an implicit manner, for example balancing gender participation in comparison and Hackathon group or balancing gender participation in research sample , achieving an homogenous research sample. The (3) papers who

explicitly dealt with gender issues focused on performance issues for example explore women's average grades in CS courses using game design, or explore women's preferences on specific IoT based degree (CITA degree) in respect of level of attraction, retainment and graduation on this degree. Motivating women in CS education, proves quite important from literature because as it has been related to drop out from CS courses (Pappas, Giannakos, Jaccheri, 2016). Studies in the area have investigated the difference in the behavior of male and female CS students (Krieger, Allen, Rawn, 2015); the reasons that women are underrepresented in CS courses indicate that it is not a matter of ability but further work is needed to identify factors that can help reducing gender differences (Byrne, O Sullivan, Sullivan, 2017; Pappas, Giannakos, Jaccheri, 2016; Beyer, 2014).

With respect to the *learning approaches* used on the reviewed papers, 11,1% have focused on the constructionism and social constructivist approaches, whereas 14,1% of the papers have focused on project-based learning and collaborative learning. Two papers have used design-based learning whereas quite popular has been learning with programming, applied and described in three papers, followed by problem-based learning (2 papers). Important approaches have also been laboratory-based learning and motivational learning through labs' use (employed in 2 papers) as well as experiential learning and real-world problem solving (employed also in 2 papers). Creative learning and design first approach respectively have been used in one paper each; this provides ground for future implementation of learning approaches as such in teaching complex subjects such as UMI in computer education. Motivating young students through triggering their creativity and reflective thinking on applying taught material in everyday practice has been the goal of various attempts to introduce creativity to CS teaching in literature; most of these approaches have been applied to CS freshmen courses with documented success (Giannakos, Jacheri, Proto, 2013; Blackwell 2013). Problem solving has been acknowledged as an important learning approach over the recent years; however, as graduates even have difficulty in applying theory in practice, it is important to teach it in the sense of leveraging higher order thinking skills and critical thinking (Wells, 2013; Yu, Lin, Fan, 2015; Chen, 2012).

In respect with *orchestration methods and practices*, the analysis of the selected papers revealed a popular pattern, which is addressing the understanding of fundamental concepts via lecture-based methods and then augment the learning experience with lab experiments or hands-on sessions. Variations of this orchestration pattern are explicitly mentioned in nine papers (36%). The lecture-based part includes mainly presentations conducted by the facilitators and whole-classroom discussions. The hands-on activities involve mainly students' supervised groupwork while they intensify their interaction with the UMI technology. Interestingly, four papers (16%) imply the adoption of a spiral curriculum model (Kortuem, Bandara, Smith, Richards, Petre, 2012), in which students have plenty opportunities of revisiting a topic and applying the newly-acquired knowledge, while they progress their understanding of the subject matter moving from simplistic ideas to complicated ideas. With respect to orchestration practices, the reviewed papers showed that a variety of practices have been used, from modules teaching IoT and mobile computing to quiz activities, resources, developer's logs. Only one paper focuses on the use of IoT and mobile computing for STEM disciplines, which means that there is ground for implementing in the future respective practices targeting at STEM. Popular resources have been presentations, notes, wikis supporting lab assignments, or even some evaluation tools such a rubric.

Hands on and experiential activities have been used in five papers (written quizzes, programming assignments, communication through Fb). The minority of papers focused on the implementation of specific frameworks in educational practices such as the Connected Gardening Design Framework (one paper), or Project Based Learning (applied in two papers); limited have been the cases for implementing Project Based Learning through specific phases such as the "Sketch-Iterate- Explore" cycle (one paper). The aspect of competition, allowing students to be evaluated for their work by subject matter experts, be sponsored and disseminate their work to the public has not yet been quite strong as a trend since only one paper involved this in practice. The use of practice in theme based learning (STEM and zoo settings) has been used in two papers, conclusion which provides ground for further implementation of respective practice.

Four papers involved students in actual programming tasks, whereas two papers focused on the design of IoT applications. In two papers, the intervention has been implemented at the end of the educational program, factor which supports the implementation of such practices at later stages of the courses, when students have grasped important terminology and processes involved. Collaboration, rapid concept prototyping, synthesis and concurrent business analysis (Mac Callum, Jeffrey, Kinshuk, 2014) as important innovative characteristics relate also with understanding design thinking. As it could be deduced from the findings, the systematic use of a synthesis of rich resource types such as lecture notes, videos, audio lectures, assignments, exams, projects, examples, study material, online textbooks, syllabus and interactive demonstrations, is not very usual as in MIT Open Course ware (Dichev, Bhattarai, Clonch, Dicheva, 2011).

## Discussion

In this systematic mapping study we have identified 1) the enabling and actual contexts for teaching IoT , Mobile computing and Ubiquitous computing , 2) the learning objectives, 3) the digital tools used so far in respective courses and their affordances, 4) the pedagogical approaches and associated actors, and 5) the orchestration methods and practices for nice domain in Computing Education, namely, the UMI domain. With respect to the actual context, higher education and formal settings have been dominant in respect with relevant, possible options. There are many possibilities for interdisciplinary approaches and hands-on activities that can be integrated in the UMI education. Also, there is a great potential to explore UMI education in schools as well as in semi-formal settings. Hence, an ensuing recommendation for future research would be to further research these settings which, unfortunately seem to remain currently underexplored .

The study revealed rather inconclusive results with respect to the learning objectives of the UMI education endeavor described in the papers. Surprisingly, almost half of the papers didn't mention learning objectives of the UMI learning activities or educational programs- this is an indication that teaching practices with IoT and Mobile computing need to be expressed also in term of learning design. Hence, it would be highly recommended to explicitly mention clearly stated learning objectives since the learning objectives are the cornerstone of any learning design. In line with the Bologna process, in European institutions the learning objectives should not be content-related, but outcome-based: this actually relates the learning objectives' definition with related student competencies. Under this scope, there has to be a focus on what computer science students should be able to demonstrate or do after the end of the lesson or educational program in general, rather than presenting the content areas included in the computer science lessons or programs, respectively. Such student-learning outcomes are in the heart of the 2018 report created by the ITiCSE (Innovation and Technology in Computer Science Education) IoT working group in which they explored curricula and pedagogy for IoT in undergraduate ICT education (Burd et al, 2018). In the context of this situation, the use of specific frameworks such as the K-12 Computer Science Framework could support the upgrade of the pedagogical methodology of IoT and Mobile learning courses, since they help students critically engage in public discussion for computer science courses, and develop as learners, users and creators of computer science knowledge and artifacts (Milenkovic, Otto, Jovanov, 2006).

Concerning pedagogical approaches and underpinning learning theories involved, it emerged from the analysis that UMI education lends itself well to constructionism, social constructivism, project-based learning, and social learning. The common denominator of these approaches is active learning and this conclusion is in line with the ITiCSE report (SIG, 2019). Furthermore, herein a predominant learning design pattern emerged from the analysis of the orchestration aspect: addressing the understanding of fundamental concepts via lecture-based methods and then augment the learning experience with lab experiments or other hands-on sessions. Not surprisingly, with respect to the digital tools used, microcontrollers are the most prominent ones followed by Android platforms for mobile applications development. The main affordance of the tools' use is the easiness in programming, which seemingly is still one of the main skills associated with the UMI domain.

## Threats to Validity

Regarding the validity limitation issues we have specified residual validity issues including potential conflicts of interest (i.e. that are inherent in the context of the study, rather than arising from the plan). One of the major ones has been the existence (or not) of relevant studies to validate the specific systematic mapping study. The conducted study and its results may have been affected by some threats to validity. For example the completeness of this systematic mapping may have been affected by missing relevant studies. In order to reduce this threat, we have used electronic databases (such as the IEEE Database) that are among the most relevant available sources in Computer Science and Engineering; however, the selected electronic databases do not represent an exhaustive list of publication sources, so that other databases might also be included. Snowballing has not been performed and therefore, other possibly relevant studies could have been identified and considered in this systematic mapping. To eliminate bias in study selection, we have striven to mitigate the effect of any personal bias or misinterpretation by adopting a multiple-revision strategy. To reduce inaccuracy in data extraction we have clearly defined the data items outlined in the data extraction spreadsheets. In addition, the data items to be extracted in this systematic mapping were discussed among the researchers and agreed upon their meaning. As not all studies sufficiently and clearly describe the details of information to be extracted as data items we have had to infer certain pieces of information regarding data items during data synthesis. In order to minimize the inaccuracy of such inferences, we have conducted discussions aiming at solving any disagreement and clarifying potential ambiguities.

## Implications for Research and Practice

For researchers and educationalists adaption of IoT and Mobile applications in educational settings and developing good practices in employing technologies as such in higher and secondary education, seem important topics for further exploration. In the light of the results of this study, defining exact competencies based on specifically defined learning objectives, seems a key issue in immersing IoT teaching in modern educational settings. Regarding learning theories underpinning the teaching of IoT and Mobile computing, a shift towards creative and interdisciplinary approaches which combine principles of computer engineering, could have positive effects on students' participation in IoT courses. What also seems quite important is develop IoT and mobile courses based on less common platforms such as Arduino and trace theoretical frameworks and instructional methodologies that actually could support the development of good practices in IoT and mobile computing education. There appears to be a lack of focus on how IoT could be implemented in existing educational practices, so this is another topic for further exploration by researchers and practitioners.

## Conclusions

Ubiquitous Computing, Mobile Computing and Internet of Things have been quite dominant in the last decade in computer science, highlighting the importance of applications as such in real life settings and target groups such as transportation, special needs etc in an effort to improve the quality of life. However, there seems to be a lack of focus on how IoT and mobile computing could be implemented in modern education practices, on the emerging challenges out of the use of IoT in education and methods important for teaching effectively IoT as a subject. The contribution of this work revolves around the fact that, to the best of the authors' knowledge, limited efforts on systematic mapping study of Internet of Things' education exist in the literature. This is surprising taking into consideration the impact of UMI technologies in our lives as well as the demand of employees skillful in them.

Four research questions have been raised and mapped with collected literature outlining the IoT practice research landscape in modern education. This study analysed 25 papers, identified from 395 initially retrieved articles through automatic and manual search of digital libraries. Results revealed important issues regarding the use of IoT, mobile computing and ubiquitous computing in education such as the need to motivate more female students in IoT courses, define specific learning objectives for activities and IoT courses developed, include multiple teaching strategies in teaching IoT. Future research could address issues such as the effectiveness of IoT courses according to specific contexts or the methodologies that could be developed for supporting IoT, Mobile Computing and Ubiquitous Computing courses. Limitations of this work pertain to the fact that only studies in English were included in the study, whereas quality research work on the topic at stake could exist in other languages. Another limitation could be related to the publication date of the studies, since it is possible that relevant and good articles exist before 2013.

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### Appendix. List of Papers Included in the Analysis

1. Kurkovsky, S., 2013. Mobile game development: improving student engagement and motivation in introductory computing courses. *Computer Science Education*, 23(2), 138-157.
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