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RESEARCH

Design Concepts, Principles and Patterns in the Curriculum of the New Computing Education Era

Anna Mavroudi[*], Olga Fragou[†] and Christos Goumopoulos[‡]

Ubiquitous Computing, Mobile Computing and the Internet of Things (collectively referred to as UMI herein) involve recent advances in technology areas such as low-cost and miniaturized processing and sensing technologies, high-bandwidth wireless networking and so on. UMI technologies can also support the recent attempts to reform computing education. Yet, to accomplish this potential, relevant UMI learning scenarios are needed. Creating such scenarios can be challenging, since this particular field of computing education is still in its infancy. This paper discusses learning design knowledge which can orientate the future design of UMI learning scenarios. Content analysis was applied on ten quality UMI-oriented learning scenarios. The scenarios were freely accessible in online platforms, and they were designed for middle school education and for the UMI domain. Two different methodological approaches were employed: the first one involved mapping the scenarios to existing predefined learning design elements (i.e. design concepts, design principles, and design patterns). The learning design elements were previously defined in an online database and they involved ubiquitous tools. The second method involved mapping the scenarios to the parameters of a UMI learning ecology. The performed analysis revealed design concepts, principles, patterns and key characteristics underpinning the selected UMI scenarios: they cater for students' active learning and engage them in interdisciplinary projects in which students are learning across contexts in groups and solve meaningful problems that exploit the functionalities of the UMI technologies. Several recommendations concerning the creation of quality UMI learning scenarios are suggested, such as: striking a balance between conceptual understanding and 21st century lifelong learning skills, highlighting how students' collaboration is expected to happen in a UMI scenario, providing many opportunities for instructional scaffolding and explicitly mentioning spatiotemporal aspects of the UMI scenarios. These findings could be of interest to computing education researchers, tutors, and curriculum designers who wish to design UMI oriented educational scenarios.

Keywords: Ubiquitous computing; mobile computing; Internet of Things; computing education curriculum; learning design tools

1. Introduction

The many-connected-device world, the Internet of Things (IoT), and the cloud paradigm are examples of major advances in computing that have significant implications for the computing profession and the society, as a whole (Reed, Larus & Gannon, 2012; Burd et al., 2017). These advances in computing aligned with major educational and training advances such as the cultivation of the 21st century skills, reinforce the importance of state-of-the-art technology such as Ubiquitous computing, Mobile computing technologies and IoT applications (UMI) in teaching practice-oriented subjects, especially in computing education and engineering (Toh et al., 2016). Although computing education might entail different connotations for stakeholders of different countries, herein it involves STEM-related curricula with a focus on computer science (Delistavrou & Kameas, 2017).

Through the networking of digital objects and the use of embedded sensors, UMI technologies create new and diverse opportunities for students to learn and for teachers to inform the design of their lessons and the assessment of their students (Mershad & Wakim, 2018). Computer science educators have already started teaching students how to develop and maintain IoT-based applications and technologies and this poses big challenges and opportunities for curriculum designers and computer science educators alike (Burd et al., 2017; Goumopoulos et al., 2017). Proposing learning design approaches that could support the development of educational material for UMI technologies is an important contribution in modern computer science education which is making a passage from the exploitation of the Internet and Web technologies to leveraging of the Internet of Things technologies.

* Norwegian University of Science and Technology, NO

† Helenic Open University, GR

‡ University of Aegean, GR

Corresponding author: Anna Mavroudi (anna.mavroudi@ntnu.no)

The contribution of the paper is further supported by the fact that it has recently been suggested that such intermediate-level learning design knowledge is scarce but needed in technology-enhanced learning generally in all its sub-domains (Prieto, Alavi & Verma, 2017); let alone in this niche domain that revolves around the exploitation of UMI technologies in the learning processes. Intermediate-level design knowledge refers to forms of design knowledge, that in terms of abstraction, are less abstract than theoretical frameworks and more abstract than the instances of these frameworks in practice which are typically constructed via empirical research (Höök & Löwgren, 2012): narratives, patterns, principles and so on. To the best of the authors' knowledge, there is no other similar attempt in the recent literature of computing education that synthesises and concludes on learning design knowledge about the UMI as a learning domain. Yet, this design knowledge is useful for learning designers and computing educators alike. Conclusions that touch upon learning design aspects can help stakeholders to orientate their own learning designs and the development of their own UMI learning activities or learning scenarios. As such, the paper has the potential of advancing the quality of computing education in the UMI era. Finally, an additional motivation for looking into learning design is "to identify a set of learning designs' properties that can be considered as reference when assessing learning design's effectiveness" (Campos, Alvarez-Gonzalez & Livingstone, 2012, p. 53).

This work is using well-established learning design work with the aim of extracting intermediate-level learning design knowledge from existing quality UMI learning scenarios. The research question addressed herein is: what are the most important concepts, principles, patterns and characteristics (e.g. enabling contexts, main processes) that underpin high quality UMI learning scenarios?

2. Background: learning about UMI

2.1. UMI in computing education

Broadly speaking, there are two distinctively different ways of using UMI in educational settings: as educational means or as educational ends (Viberg & Mavroudi, 2018; Mavroudi, Giannakos, Divitini & Jaccheri, 2016). The former involves learning *with* UMI technologies and has been frequently associated with the exploitation of UMI technologies as support mechanisms of the learning process; a characteristic paradigm involves mobile and contextual learning (Looi, Wong & Milrad, 2015). The latter involves learning *about* UMI technologies and involves computing education; or, more recently, interdisciplinary approaches in computing education (Mavroudi, Giannakos, Divitini & Jaccheri, 2016).

Examples of learning with UMI technologies abide in the educational research literature. For instance, technologies such as UMI technologies have been linked to the improvement of secondary school students' abilities and skills in problem solving, and collaboration (Varney et al., 2012; Hong et al., 2011). Also, they have been used in several domains as support mechanisms towards enhanced understanding of the subject matter; for instance, science concepts and sequencing skills (Highfield, 2010). Other examples of the exploitation of IoT in education as a means of supporting the learning process include the use of smart whiteboards and other interactive digital media, but also enhancing collaborative learning and management tasks (Charachristos, Goumopoulos & Kameas, 2014).

Learning *about* UMI technologies has a shorter history in education and it is more focused on computing education learning objectives, such as the cultivation of Computational Thinking (CT), which can be broadly defined as "the ability to engage in problem solving, designing systems, and understanding human behavior" (Wing, 2006, p. 6). Early attempts to introduce UMI-related learning objectives with a focus on CT revolved around the affordances of educational robotics. Educational robots have already offered a substantial set of tried and tested materials that can help CT theory becoming a successful practice in schools (Toh et al., 2016). An associated challenge is that, in order to act effectively in their roles, teachers need training on appropriate student-centered pedagogies for tackling aspects of computing education that relate to the development of programming and CT skills, among others (Sentence & Csizmadia, 2015; Burd et al., 2017). It has been suggested that the cultivation of programming and CT skills in tandem with transferable skills that can be applied in a variety of real-life problems probably constitutes a best practice (Resnick, 2013). Learning about UMI technologies is also aligned with the European Council directive that has explicitly put forward key competences for 2020 and has set priorities accordingly. One of these key competences, which is particularly relevant with learning about UMI, involves "strengthening the confident and critical use of digital technology, including coding and programming, safety and citizenship related aspects" (European Commission, 2018, p. 2).

It should be noted that UMI is an emerging but a not well-established domain in computing education yet. Currently, the educational community recognises that UMI technologies can be utilised to improve the quality and effectiveness of education, while accepting that challenges exist when it comes to indicating ways that would lead to deep and meaningful learning about UMI technologies (Magdalinou & Papadakis, 2017). Another motivation on learning *about* UMI is derived from the added value of IoT education, which has been documented in the recent literature. For example, Burd et al. (2017) argue on the importance of teaching about IoT in the context of post-secondary education; IoT is an inherently interdisciplinary field which involves significant aspects of contemporary computing and provides opportunities to engage students with applications that can be part of their everyday lives.

2.2. UMI learning scenarios

With respect to learning scenarios, the UMI-Sci-Ed European project[1] developed several UMI learning scenarios suitable for the context of school education; some of them are described by Mavroudi, Giannakos, Divitini & Jaccheri (2016) and Goumopoulos et al. (2018). The Umi-Sci-Ed ("Exploiting Ubiquitous Computing, Mobile

Computing and the Internet of Things to promote Science Education") project focuses on the creation of educational scenarios that incorporate UMI technologies in order to cultivate relevant competences among high school students (Goumopoulos et al., 2018). Furthermore, a small number of UMI learning scenarios can be found available online in the AESOP platform[2] ("Advanced Electronic Scenarios Operating Platform"). The platform hosts "high quality teaching digital material, scientifically and pedagogically accredited by the responsible scientific authority for educational issues of the primary and secondary education in Greece" (Grammenos, Tsanakas & Pavlatou, 2017, p. 4863). Both the UMI-Sci-Ed and the AESOP platforms offer UMI learning scenarios as Open Educational Resources (OERs).

Three other projects offering such OERs in their respective online platforms are the "Open Discovery Space" (ODS) project[3] in conjunction with the "Open Schools for Open Societies" (OSOS) project, and the Open Educational Resources Commons" (OER Commons) project[4]. The OSOS project is an ongoing project funded by the European Commission via the Horizon2020 research and innovation program. It engages a number of schools, teachers and students with innovative STEM learning activities and scenarios (Doran, Saraiva & Tyszka, 2018). The ODS portal provides a gateway to learning scenarios and learning activities for a great variety of subject matters. Using the ODS portal, teachers can search for learning materials, create and upload their own materials (Athanasiadis, Sotiriou, Zervas & Sampson, 2014). The OSOS project scenarios are also hosted by the ODS online platform. Similarly, OER Commons is an online platform where users can find, rate, review, and share learning materials (Petrides, Jimes, Middleton-Detzner & Howell, 2010). These initiatives also created arenas for scenarios design and implementation in which UMI-related knowledge and skills are treated as educational ends i.e. the learning objectives of the scenarios fall within the UMI domain.

With respect to relevant empirical research in schools, interestingly the recent literature can showcase several examples of learning about UMI in the context of high school education. In India, a group of researchers used a block-based programming software tool in combination with microcontrollers to effectively introduce high school students to logic programming, electronics concepts and software-hardware interfacing (Gupta, Tejovanth & Murthy, 2012). Another group of researchers (Herger & Bodarky, 2015) discusses their efforts on creating a number of IoT projects that were attractive for and customized to high school students. These projects were created as part of a "National Engineers Week" program in the USA that seeks to expose and attract students to several engineering career paths. The projects used open source technologies and microcontrollers.

2.3. Learning design structures: scenarios, principles and ecologies

Learning scenarios frameworks can support the creation of educational materials and the orchestration of associated learning processes in a structured and formalised way. According to Lejeune & Pernin (2004) a learning scenario is a description of a learning situation at a given level. They typically include components such as: goals, pedagogical approach, content and structure, learning methods and strategies (Georgoutsou et al., 2012; Athanasiadis, Sotiriou, Zervas & Sampson, 2014). They can be enacted inside the classroom in formal learning settings or they can be combined with non-formal settings, such as museums and field trips (Athanasiadis, Sotiriou, Zervas & Sampson, 2014).

In general, design principles refer to characteristics of a learning design or its procedure and can take various forms, such as heuristic statements, criteria of particular learning environments types, or advice on how others might benefit from the findings of a particular research development or endeavour (Herrington, Herrington & Mantei, 2009). A relevant example from the recent literature includes the creation of three learning design principles suggested by Andersen & Munksby (2018) that can be applicable when introducing student-generated digital multimodal representations in a science classroom: 1) to organise activities among students that promote awareness concerning the affordances of the different representation modes, 2) to organise practical experiments which help students to use data representations, and 3) to encourage students' production of digital multimodal representations as means of expressions of learning, reflection and self-evaluation.

Similarly, the "Design Principles Database (DPD)[5]" (Kali, 2006) provides an online environment that captures, synthesises, and disseminates learning design ideas with a focus on Technology Enhanced Learning (TEL) in science education. The added value of DPD is based on the exploration of critical elements in learning environments that systematically have a positive effect on learning. These learning design elements are organised in three formats: design meta-principles (i.e. concepts), design principles, and design patterns. The principles are generated inductively from prior interventions of successful empirical design research endeavours with educational software tools. Each principle is connected to one or two meta-principles (i.e. concepts) via the DPD. Each design concept constitutes an abstraction of the constituent design principles. That is, one design concept is typically associated to several design principles. Additionally, the design concepts of the DPD are organised into themes (e.g. ubiquitous computing tools) and a search mechanism is provided so that the users of the online database can search themes that are relevant to them (Kali, 2006). Currently, the DPD contains 34 design principles grouped into four design concepts; it also contains 10 design patterns.

Finally, a learning ecology is another type of a learning design structure which emulates continual learning (Siemens, 2005; Fragou et al., 2017), while it fosters and supports the creation of learning communities (Siemens, 2007). It has been associated to the theory of connectivism (Siemens, 2005, 2007), both as a learning design structure and as an analytic tool that could be appropriate when studying distributed learning environments. A learning ecology may function as an autonomous system, comprised of the interaction and interrelations of individuals and devices that set distinct cognitive territories. It forms a self-regulating system developed and alive through consuming resources, actors' interaction and time evolvement. Yet, spatiotemporal aspects of a learning ecology can also refer to limitations and restrictions. In general, it has been suggested that schools are not responding effectively to the lives of the 21st century students, in the sense that they are not flexible enough while promoting disconnected knowledge (Kumpulainen & Sefton-Green, 2014). For instance, time needed to complete an interdisciplinary project and learning spaces that can be configured even outside the walls of the classroom are more relevant parameters of a learning situation compared to numbers of didactic periods needed to teach a specific subject matter within the classroom in the context of a teacher-oriented classroom orchestration (Kumpulainen & Sefton-Green, 2014).

A learning ecology as a system which collectively and individually "thinks" about itself, is highlighted in the Cognitive Flexibility Theory (CFT) (Yang & Koszalka, 2016) advocating that for deep learning, learners are required to engage with new content from multiple perspectives and in flexible ways of thinking. Also, CFT proposes engaging learners with multiple content representations in different situations that involve complex learning. Important principles of CFT are that: a) knowledge is "context dependent", b) knowledge cannot be oversimplified, c) knowledge is constructed, and d) knowledge is interconnected.

3. Materials and methods

3.1. Design concepts and principles

One of the themes of the DPD involves the design concepts and the design principles that are associated specifically to ubiquitous computing tools in the context of science education. This is one of the main reasons why this database was selected. In addition, although the DPD was created years ago, it is still being used as a point of reference by researchers interested in learning design or design research in education- see for example Sasson (2019), Banerjee and Murthy (2018). According to its creators, over the years, the DPD was useful to a large number of (learning) design researchers (Kidron & Kali, 2017).

In particular, the DPD identifies 17 design principles grouped into four design concepts, which are shown in **Table 1**. It should be noted that the intended pedagogical usage of the ubiquitous computing technologies in the DPD mostly refers to them in the context of science education in general and not in the context of computing education, in particular.

Table 1: Design principles and meta-principles linked to the use of ubiquitous computing tools from the DPD (Design Principles Database website, n.d.).

Principles	Meta-principles/concepts
Build on student ideas Connect to personally relevant contexts Engage learners in complex projects Create a clear and engaging flow of activities Provide students with templates to help reasoning Reduce visual complexity to help learners recognize salient information	Make contents accessible
Create a clear and engaging flow of activities Enable manipulation of factors in models and simulations Enable virtual navigation for exploring complex physical systems Model scientific thinking Provide knowledge representation and organisation tools Provide students with templates to help reasoning Reduce visual complexity to help learners recognize salient information Scaffold the process of generating explanations Support student-initiated modelling of complex science Use multiple representations	Make student thinking visible
Encourage reflection Engage learners as critics Establish a generalized inquiry process Engage learners in complex projects	Promote autonomous lifelong learning
Promote productive interactions Scaffold the process of generating explanations	Help students learn from each other

3.2. A UMI learning ecology

Recently, a theoretical framework that caters for the UMI domain in education was proposed by Fragou, Kameas and Zaharakis (2017). The framework is expressed as a learning ecology which makes it unique and relevant when it comes to serve as a basis of describing UMI learning materials and interactions involved in UMI-based educational environments. The rationale of studying and analysing UMI learning materials through a learning ecology touches upon the fact it is linked to the ideas of distributed learning environments and Cognitive Flexibility Theory (Yang & Koszalka, 2016).

The UMI learning ecology is comprised of the following dimensions:

1. **Space:** spatial aspects comprising of physical spaces where the affordances of physical objects are augmented with digital capabilities
2. **Time:** temporal aspects such as activity duration
3. **Contexts:** national, organizational, or individual contexts including actors and interactions among them
4. **Processes:** socio cultural, developmental, semiotic or pedagogical processes
5. **Affordance networks:** activities, ideas, methods and tools, practices, commitments or people that can be enlisted towards a particular goal
6. **Action, capability and performance:** real time processes of engagement with emergent solutions to problems in real time, adaptation and transfer of ideas to new contexts, the structure of the environment in which learning resources are created, inter/intra-personal skills to achieve a goal, prioritising numerous tasks and nurturing of relationships (e.g. self-instruction, help seeking)
7. **System:** software, hardware and devices, telecommunication networks.

The learning ecology framework defines important design components for creating workable practices in UMI educational scenario design. For example, considering space and time aspects is important when designing UMI educational scenarios, since UMI technologies lend themselves to spatiotemporal arrangements that might differentiate UMI scenarios from educational scenarios that involve other more generic technology tools (e.g. collaborative tools). Time and space limitations also interplay with the affordances of the technological tools in an educational scenario.

3.3. Analysis approach

The main methodology adopted herein was content analysis (Wesley, 2011; Bowen, 2009) as a systematic procedure for reviewing contents of various formats (Bowen, 2009). The analysis approach started with the identification and the selection of ten educational scenarios which a) were UMI-oriented and b) involved the upper secondary school context. They were retrieved as OERs from the online platforms mentioned in section 2.2. They are diverse in the sense that they differ in a) the number and variety of devices used; b) the learning approaches adopted; c) the volume of the learning materials incorporated in the scenario; and d) the level of detail in the description of the learning process. For example, some educational scenarios have been quite extensive (e.g. The Smart Home, **Table 2**) and could be implemented across several school hours. The educational scenarios selected for the analysis are presented in **Table 2**. In Appendix 1, we present for each scenario: a short description of its topic, its phases or

Table 2: Titles, origins and references of the analyzed UMI learning scenarios.

	Scenario number and title	Origin	URL/Reference
1.	Tiles IoT design workshop	UMI-Sci-Ed project platform	http://umi-sci-ed.eu/
2.	Anyboard	UMI-Sci-Ed project platform	http://umi-sci-ed.eu/
3.	What is a sensor?	OER commons platform	https://www.oercommons.org/courses/what-is-a-sensor/view
4.	Smart chicken coop (in Greek)	ODS project platform &the OSOS project	http://portal.opendiscoveryspace.eu/en/osos_authoring_tool/view/850608/847214
5.	Smart Traffic Lights Leros	ODS project platform & the OSOS project	http://portal.opendiscoveryspace.eu/en/osos_authoring_tool/view/850211/847214
6.	The smart home (in Greek)	UMI-Sci-Ed project platform, University of the Aegean (IoT Samos Group)	http://umi-sci-ed.eu/ (Gaitanis & Kossivas, 2018)
7.	App Inventor: Teaching Programming Developing Mobile Applications (in Greek)	Aesop platform	http://aesop.iep.edu.gr/node/13460
8.	Introduction to Object-Oriented Game Programming: The Case of Greenfoot (in Greek)	Aesop platform	http://aesop.iep.edu.gr/node/15856/4083
9.	Power Sensor Glove (in Greek)	ODS project platform & the OSOS project	https://portal.opendiscoveryspace.eu/en/osos_authoring_tool/view/850185/847214
10.	Happy..hour (In Greek)	ODS project platform & the OSOS project	https://portal.opendiscoveryspace.eu/en/osos_authoring_tool/view/850162/847214

main activities, and its length while also mentioning any accompanying materials included in the scenario.

The selected scenarios are of high quality and relevancy. The relevancy of the scenarios was assessed by the subject-matter being covered: all the selected scenarios fall within computing education and suggest the use of UMI technologies on behalf of the students as a means to solve a problem. Initially, the researchers collected a number of relevant scenarios without judging their quality but focusing on their scope (i.e. UMI-related, designed for school education), resulting in a bigger pool of 16 scenarios. Next, the scenarios included in the analysis were collected by filtering the initial scenarios using quality assessment criteria. The quality of the scenarios was assessed by the following criteria: their description was complete; their contents (i.e. the learning activities along with all the accompanying learning materials, such as presentation files, templates and worksheets) were relevant in the sense that they were appropriately designed to help high school pupils achieving UMI-specific learning goals; they were created as part of research and development projects that have received funding from the European Commission so that it can be safely assumed that a review had already taken place (i.e. the UMI-Sci-Ed project, the OSOS project); or, they were already characterized with respect to their quality (i.e. in the case of the A.E.S.O.P. platform two of the scenarios are characterized as exemplars and the third one as sufficient). Specifically the scenario titled "Tiles IoT design workshop" is directly associated to published research in IoT education that received a best paper award in an engineering education conference (Mavroudi et. al, 2018). Also, the scenario titled "The smart home" is directly associated to a postgraduate thesis on IoT and STEM education which included empirical research using this particular scenario with encouraging empirical results in classroom interventions with high school students. Finally, the scenario that was taken from the OER commons platform was judged by the authors unanimously with respect to its quality (completeness, appropriately designed, following UMI-learning goals that high school students can achieve).

With respect to ethical considerations regarding the use of the scenarios for our analysis: eight scenarios (all scenarios except scenario 3 and scenario 6 in **Table 2**) are freely accessible online as open educational resources in platforms of projects that were funded by the European Commission. The UMI-Sci-Ed project platform explicitly mentions that data and content of this platform are reusable under an open Creative Commons license which provides usage rights for non-commercial usage. The same rule applies for the A.E.S.O.P platform. Scenario 3 is hosted in the OER (Open Educational Resources) Commons platform, and the source of this material is the TeachEngineering digital library collection (at www.TeachEngineering.org, all rights reserved). The terms of use of this library explicitly encourage any kind of use of collection content by academic users. Finally, with respect to scenario 6, the authors requested permission from its creators (see "Acknowledgements" section).

The scenario analysis involved mapping their learning design elements to the UMI learning design frameworks mentioned in sections 3.1 and 3.2 separately. The reason for selecting these two particular frameworks in order to capture learning design knowledge about UMI is that a) they cater for UMI in education, and b) they incorporate different and complementary epistemological perspectives about learning design knowledge. The first framework (section 3.1.) incorporates a design-based epistemology about learning design, whereas the second framework (section 3.3) incorporates an epistemological stance close to connectivism according to which learning occurs in distributed learning environments (Siemens 2005, 2007). Yet, both frameworks provided a solid basis for the content analysis i.e. they provided some initial predefined codes that were used to analyse the scenarios. The scenarios were analyzed individually by the authors with respect to these codes; and, at a second stage, the results of the individual scenarios analysis were aggregated with the aim of answering the research question. The scenario analysis method was based on two different techniques: a) mapping the scenarios characteristics against the DPD design concepts, principles, meta-principles and patterns described in section 3.1., and b) categorising the scenarios by mapping them against the ecology parameters described in section 3.2.

Regarding (a), initially the authors studied the contents of DPD, especially focusing on the description of design meta-principles, principles, and patterns which were used as initial predefined codes. The authors read and then mapped the scenarios against the descriptions of the DPD elements. Some of the selected UMI scenarios incorporated more than one design principles. However, in each scenario, only three design principles and three design patterns were selected and reported (those that the researchers concluded that are the most prominent). Following quantitative analysis was possible, as the scenarios were mapped against each design element (i.e. concepts, principles and patterns) of the DPD: occurrences of these design elements were identified and respective frequencies across the educational scenarios were calculated.

The second technique (point b) involved a content analysis method based on how the UMI learning ecology parameters are instantiated in the scenarios. In this analysis, the learning scenarios were coded against the seven predefined categories of the UMI learning ecology and emerging themes were identified. For example, in the Anyboard scenario the parameter "time" is well-defined and included the indicative duration of the scenario, and whether it can be repeated (see Appendix 2), whereas in the "Power Sensor Glove" there was no indication concerning temporal aspects.

4. Results

4.1. Design concepts, principles and patterns for UMI in education

The quantitative analysis of learning design elements is the product of mapping the selected scenarios against the predefined DPD design elements. An example of how this was conducted in the level of the individual scenario is illustrated in Appendix 2. **Tables 3** and **4** depict the results of mapping the selected educational scenarios against design concepts/meta-principles and design principles for ubiquitous computing, respectively. **Figure 1** depicts the results of mapping the selected scenarios against design patterns.

The most frequently met learning design concept refers to "making contents accessible", closely followed by the concept of "making student thinking visible". With respect to the former, it reflects that the majority of the scenarios engaged the students to complex and interesting learning activities that were related to their everyday lives. For example, in the "Power sensor glove" scenario it is mentioned explicitly that the final physical artefact that was created by the students (i.e. the "smart" glove) compensates for the loss of human touch which can happen in some elderlies. It is mentioned in the scenario that the students' motivation was to help with their IoT solution a family member of a student from their group who suffered from that particular problem, as well as to help the elderlies of their local community, in general. The latter design concept reflects the fact that most of the scenarios were using visual aids to scaffold students' reasoning, to help them obtain systemic thinking e.g. to visualise how the changes that they make in the code affect the observable behavior of the physical artefact of the resulting IoT solution.

Table 3: Frequencies of design concepts/meta-principles in the selected scenarios.

Design meta-principles (concepts)	Frequency
Make contents accessible	13
Make thinking visible	12
Promote autonomous lifelong learning	8
Help students learn from each other	5

Table 4: Frequencies of design principles in the selected scenarios.

Number	Design principles	Frequency	Appearance in scenarios
1	Connect to personally relevant contexts	6	3, 4, 5, 6, 9, 10
2	Scaffold the process of generating explanations	5	3, 6, 7, 8, 9
3	Engage learners in complex projects	4	1, 2, 4, 5
4	Enable manipulation of factors in models and simulations	4	5, 6, 7, 8
5	Establish a generalized inquiry process	2	3, 9
6	Provide knowledge representation and organisation tools	2	1, 2
7	Encourage reflection	1	1
8	Promote productive interactions	1	2
9	Model scientific thinking	1	7
10	Build on student ideas	1	4
11	Create a clear and engaging flow of activities	1	8

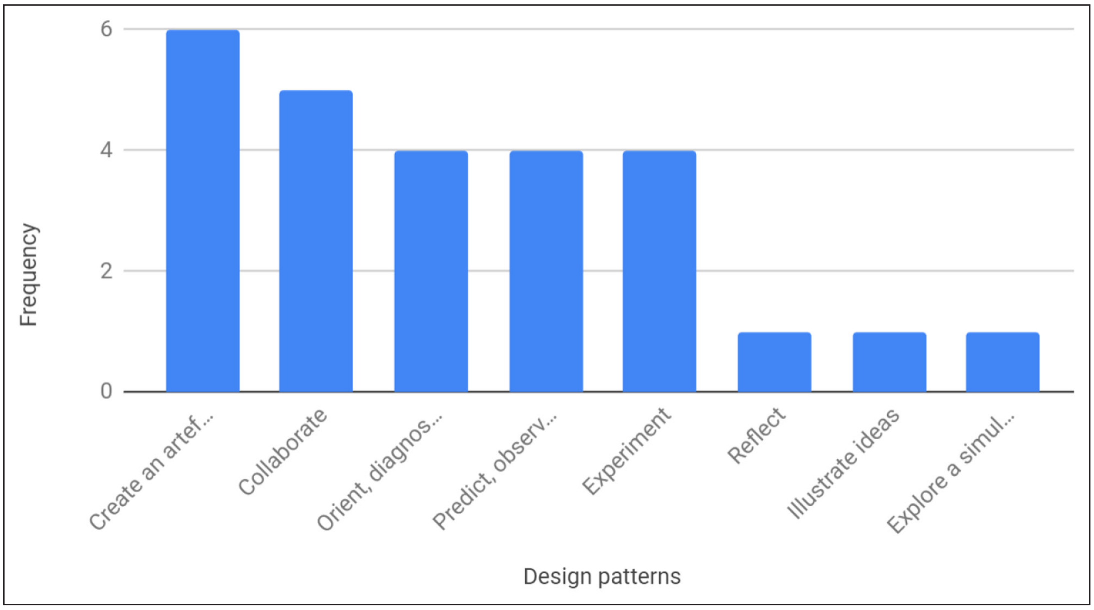

Figure 1: Frequencies of design patterns in the selected scenarios.

Following, the design concept of "promoting lifelong learning" is met with a considerably smaller frequency across the selected scenarios and finally the concept of "helping students learn from each other" has a small number of occurrences in the selected scenarios. It could be argued that these two meta-principles combined revolve around the social learning capital aspect, which mostly touches upon social capital and lifelong learning (Baker, 2006). In general, based on the frequencies observed in **Table 3**, it seems that the design of educational scenarios focuses more on scaffolding students' learning experience in order to acquire knowledge and subject-specific skills, and to master important subject-specific aspects, like UMI-specific knowledge and processes. Thus, the selected scenarios target more at promoting students' conceptual or procedural understanding rather than the social learning dimension and the respective lifelong learning skills.

The design principles mainly involve (see **Table 4**):

- authentic and relevant project-based learning activities (principle 1, principle 3)
- moving the locus of control of the learning process to the students by enabling manipulation (principle 4)
- instructional scaffolding methods (principle 2, principle 6)
- promoting student inquiry (principle 5)

In the selected scenarios, engaging learners in complex projects entailed making connections between various ideas of central topics to develop an integrated understanding about STEM, and to be prepared for future learning STEM endeavours. Also, connecting to personally relevant contexts involved seeking examples that resonate with student experiences and interests. These might depend on individual, cultural and contextual factors which might be difficult to predict.

The cultivation of higher order thinking skills in tandem with the manipulation of factors in models or simulations has also been an important design principle in the scenarios. An example of such a learning situation can be seen in most of the selected UMI learning scenarios that incorporated the combined use of basic physical computing components (i.e. microcontrollers, sensors, actuators) along with some physical artefact which is controlled by some code and embeds sensors. In such a learning situation, the students can program and directly control the behavior of the artefact and, by changing the values of the associated variables, they can observe the immediate result of their actions through the change provoked in the behavior of the artifact.

Complex learning processes were supported by the use of effective instructional scaffolding aiming to lead students to higher levels of thinking and learning; thus, the importance of providing scaffolds for generating explanations has also emerged as an important design principle. Furthermore, in terms of instructional scaffolding, providing tools and principles for knowledge representation to UMI students has emerged as one of the most important design principles herein.

With respect to design patterns, **Figure 1** indicates that the scenarios cater for collaboration and creation of artifacts, as well as for active learning approaches, inquiry-based learning and experiential learning. The collaboration dimension involved students planning and managing their projects and actively engaging in problem-solving, experimenting, exchanging knowledge and providing experience or guidance to peers. By inspecting **Figure 1** also emerged that students' active "hands-on" experimentation with the learning materials and resources outweighed in importance students' reflection of the learning situation: it was very common in the scenarios to encourage students to actively use UMI devices, manipulate models and build simulations that work, engage in teamwork and projects with tangible outcomes, such as student products, UMI artifacts and UMI applications. "Prediction, observation and explanation" emerged as an important inquiry-based design pattern: this underpins the students' ability to understand, explain the science and use state-of-the-art technology to produce UMI applications. Finally 1) the ability to reflect, 2) to explore simulations and 3) to present ideas in a clear manner that other students can understand, also emerged in the analysis, although not frequently mentioned.

4.2. The UMI learning ecology mappings

An example of how the conceptual analysis was conducted in the level of the individual scenario is presented in the Appendix 2. The aggregated results of the conceptual analysis in the form of mappings of the educational scenarios with the learning ecology framework could be summarized as follows:

- The **Space** aspect in all the scenarios involved mainly the affordances of the arrangement of the physical space where the students are working on, e.g. the classroom, the school lab or some personal space. Examples included promoting group-work and facilitating learning across contexts. Secondarily, it involved the affordances of the technological space and the orchestration of state-of-the-art technologies used, e.g. a microcontroller in the case of an UMI educational scenario. In some scenarios the place where the students' IoT solution is intended to be used is mentioned or its actual usage is illustrated via an online video (scenarios 4, 5, 9, 10). For example, in the "happy hour" scenario (scenario 9) the students explain in the video how their solution is intended to be used by elderlies in their homes and in the "Smart chicken coop" scenario they show in a video how their solution is used by a professional (scenario 4).
- The **Time** aspect involved: a) the indicative duration of the scenario (scenarios 1, 2, 5, 7, 9), b) the phases of the scenario and whether it can be partly or gradually implemented (scenarios 1, 2, 7, 8, 9, 10), and c) whether it can be repeated with the same students using possible variations whenever there is no model answer (scenarios 1, 2, 6, 7, 8).
- The **Context** aspect involved how the scenario can be initiated, its learning goal(s) and any explicit alignment with already existing educational standards. For

example, the scenario titled "What is a sensor?" is aligned with three different taxonomies of the U.S.A. national K-12 STEM educational standards. In half of the scenarios (scenarios 4, 5, 6, 9, 10), the context aspect particularly involved learning across contexts while bridging formal and informal learning e.g. taking measurements or testing an idea in the field while designing or developing the design solution in the school computer lab. Regarding learning goals, some scenarios have a clear practical goal which is useful in a context that is personally relevant for the students (scenarios 4, 5, 9, 10).

- The **Processes** aspect involved primarily the kind of learning that is promoted in the scenario and how student understanding is facilitated. The main processes that were present in the examined scenarios were collaboration and problem solving. Examples of other processes adopted in some of the scenarios are: experiential learning (scenario 4), multimodal learning i.e. working with multimodal representations (scenarios 1, 2), and critical thinking (scenarios 5, 6). Another relevant element is that some of the scenarios comprised of phases which are following a specific learning model, such as: the "feel/emphathise-imagine-create-share" model (scenarios 5, 6, 9, 10), and the generic IoT application development process (idea generation, design, prototyping, 3D print and assembly) in scenario 1. Interestingly, both models are based on design thinking (Doran, Saraiva & Tyszka, 2018; Mavroudi, Divitini, Gianni, Mora & Kvittem, 2018).
- The **Affordance networks** aspect revolved around the added value of the scenario by enlisting its goals and its intended impact, its main ideas and its main actors as well as how these actors engage in the scenario activities. Also, the specific aspect touched upon instructional scaffolding methods: in some scenarios (scenarios 1, 2, 8) this involved the creation of computer or hybrid games as a means of learning programming (impact); in all scenarios students were actively engaged in using state-of-the-art technology to create automations by exploiting the microcontroller functionalities in real world settings (goal); some scenarios (scenarios 4, 5, 9, 10) engaged students in problem solving processes along with a person from the local community (main actors); most scenarios (scenarios 2, 4, 5, 6, 7, 8, 9, 10) catered for providing support to students that have to collect data, change variables, handle data and components to develop an application (scaffolding).
- The **Action, capability and performance** aspects covered the rationale concerning the evaluation criteria, student assessment strategies, and the role of the tutor in order to improve student performance. Examples included: student assessment criteria involving students' perception on their performance, perceived easiness of using the IoT components, and learner satisfaction (rationale of the evaluation strategy; scenarios 1 and 2), pre/post student tests (assessment strategy; scenarios 1 and 4), and instructors acting as facilitators throughout the learning process while providing relevant feedback and scaffolds (tutor's role in all scenarios).
- The **System** aspect included primarily a description of the software and the hardware used in the teaching-learning process and their pedagogical affordances. Examples included: students that can "watch" sound waves while using microphones connected to computers running the Audacity® software (in scenario 3); students that are using templates in JavaScript (scenarios 1, 2, 4, 7); the use of LEDs, sensors and actuators (in all scenarios except 3).

It should be noted that not all educational scenarios catered for spatiotemporal aspects (e.g. duration of the scenario), whereas most of them covered the remaining five aspects of the learning ecology. For example, in three scenarios (scenarios 3, 9, 10) there was no reference about any time-related aspects.

5. Discussion

The contribution of this work touches upon the European Council priority that caters for the critical use of technology along with the development of programming and coding skills, since it provides insights onto constructing a good UMI learning scenario for school education. Regarding the research question on the most important concepts, principles, patterns and characteristics, it strongly emerged from both analyses that the UMI oriented educational scenarios employ active learning methods. Some elements of constructivism coupled with problem solving methods were eminent, such as the locus of control, authentic and relevant learning activities, promoting student inquiry and collaboration (Nanjappa & Grant, 2003). This was expected in the sense that the focus of the scenarios was on the active construction of knowledge on students' behalf: students interact, experiment, construct their own artifacts, design and manage their own projects. Also, the best practice suggested by Resnick (2013) about introducing computing education concepts while cultivating 21st century skills is by and large adopted in the selected scenarios. The same applies for the generic guidelines suggested by Burd et al. (2017): engaging in interdisciplinary projects, working with real-life IoT applications.

The most important design concept/meta-principle was to make learning content accessible to the students. According to the DPD, this involves knowledge integration by building on what students know. A recommendation for instructors would be to 1) design materials that connect to students' ideas and encourage students to revisit their existing ideas, 2) ensure that students connect ideas such that they are prepared to revisit UMI in everyday life rather than isolate the UMI domain education, 3) help students to solve UMI problems in authentic settings. This finding is verified using the second technique which revealed that learning across contexts was prevalent in the scenarios, which was often coupled with the exploitation of microcontrollers' functionalities in real-world settings. For instance, in the "Smart chicken coop scenario", the students had to solve a real-world problem for a breeder who was not able to visit the coop frequently.

Another important concept is making student thinking visible, which adds new perspectives to the mix considered in the knowledge integration process and makes explicit the interpretive process of combining perspectives to form more coherent knowledge webs: in the scenarios selected the students are called to make progress in learning environments designed for the UMI school education while working with a variety of learning contents and technologies (e.g. educational resources, coding manuals, half-baked scripts, sensors and educational microcontrollers, project management guidelines). Consequently, the importance of making student thinking visible becomes crucial for the successful implementation of an UMI-oriented educational scenario. Combining the findings of the two analyses, it becomes evident that making students thinking visible can be achieved via proper instructional scaffolding that unleashes the potential of the pedagogical affordances of the UMI technology tools used (e.g. students could "see" sound waves, they were using templates in JavaScript).

Promoting autonomous lifelong learning is another important learning design concept that UMI oriented educational scenarios need to convey: providing appropriate guidelines, stimuli, and technology so as young learners become familiarized and accustomed to a scientist's philosophy for life. To become autonomous lifelong learners, students have to engage in sustained project work so they can connect personally relevant problems to class topics, and reflect on their experience using powerful UMI learning processes in diverse contexts.

The design concept/meta-principle of peer learning has not been very dominant yet it is important since it can encourage learning. Yet, helping students learn from each other calls for orchestrating social supports; encouraging students to analyse and build on ideas from peers; introducing new perspectives and enabling students to question peers and authorities. Such a connection both with peers and the local authorities is nicely described in the "Smart Traffic Lights" scenario.

An interesting finding of the analysis is that the scenarios describe student collaboration but not in a level of detail that clarifies how students are supposed to learn from each other during their collaboration. This could be a recommendation for creators of future UMI learning scenarios, that is, to highlight how they envision students actually interacting and learning from each other in a collaborative learning setting. Another recommendation would be to create scenarios that involve students in complex projects and connect learning to personal, relevant contexts. That could be part of an effort to change local community life and its quality of life, something that seemed important for the majority of the educational scenarios' selected and analysed (e.g. Smart Home, Smart Traffic Lights).

Furthermore, the use of models to facilitate learning has emerged as an important outcome in both analyses. This was expected since project-based learning and using models as a springboard to cultivate UMI-related knowledge and skills are popular teaching approaches in the respective domain. The use of instructional scaffolding focusing on the provision of representation tools seems also important in the UMI domain which actually shapes a complex learning ecosystem: students have to understand UMI-related concepts, to master the use of digital tools as well as the use of technological infrastructures.

A detailed description with respect to the implementation of the underlying active learning methods seems as a step further that needs to be taken by future educational scenario designers to start mapping specific pedagogical principles with UMI domain educational scenarios. For instance, a question related to the nature of learner-teacher interactions is: *in a UMI oriented educational scenario are all interactions productive and if not, which are the most important features of productive interactions in environments using technology as such?* Guiding also students to model scientific thinking and establishing an effective yet versatile generalized inquiry process are aspects of future UMI oriented educational scenarios that could be further researched and dealt with in upcoming educational research and development efforts.

The learning ecology schema served as a springboard to describe the UMI learning scenarios. The concept of learning ecology per se has been frequently associated with the theory of connectivism. Consequently, a future research recommendation is to consider describing or studying UMI learning activities using the lens of connectivism while viewing these activities as learning ecologies comprised of a distributed learning environment where the humans, the learning processes and the computing technology, both in terms of hardware (e.g. microcontrollers, sensors) and software (e.g. programming scripts), interplay.

Finally, the analysis of the UMI educational scenarios under the learning ecology terms validated the important principles of CFT: a) knowledge is "context dependent", b) knowledge cannot be oversimplified, c) knowledge is constructed, and d) knowledge is interconnected. By being involved in the UMI learning activities and in the UMI learning scenarios (within and outside classrooms), learners have the opportunity to better understand the specific UMI-related ideas at stake because their practical applications are clear to them. For example, in "The Smart Chicken Coop" and the "Traffic Leros Lights" scenarios, students are becoming acquainted to the idea of connecting smart devices and creating a smart environment which is extended in the physical settings of their local community.

6. Limitations

The main limitation of the study involves the small number of scenarios analysed, which has been partially compensated by the combination of techniques as well as from the quality and the diversity of the selected scenarios. Still, the limited generalizability of the results is a major concern herein. Another concern involves the updates of the DPD contents (it seems that the database has not been updated recently). Finally, the authors reached consensus during the selection and analysis of the scenarios by conducting meetings that involved discussions and negotiation. Perhaps scoring the scenarios with respect to the quality criteria at stake using Likert scales and then calculating the inter-rater reliability could entail a more reliable selection and analysis process.

7. Conclusion

This paper aimed to characterize ten existing UMI learning scenarios which are orientated towards the cultivation of student skills in school education by employing two different approaches of content analysis. These scenarios were of high quality and were selected from a greater pool of UMI scenarios. Recommendations on the design of UMI oriented educational scenarios for upper secondary education could be summarised as follows:

- at a first level of design, educational scenario designers have to specify the domain knowledge (UMI-related concepts) and try to relate the design of the educational scenarios with students' relevant context and everyday life
- at later stages of design, educational scenario designers have to specify how collaboration is achieved, specify modes of scaffolding and reflection mechanisms and how scientific inquiry has been conducted through their educational scenario
- the pedagogical schemata (including instructional scaffolding) that the scenarios incorporate have to be elaborated clearly so as to compensate for the UMI domain complexity
- the description of spatiotemporal dimensions in the scenarios' description, could provide a clear and detailed picture to the stakeholders and is related with the clear description of affordances

The prevailing learning design elements (as well as the missing ones) along with the recommendations mentioned above can be useful for learning designers, tutors and researchers of computing education alike since they are extending the learning design knowledge base within the UMI domain in education for which currently we don't know much. More research is needed on how to promote the UMI domain in schools and the role of computing education tutors as designers of UMI learning scenarios or activities.

Notes

1. http://umi-sci-ed.eu/.
2. http://aesop.iep.edu.gr/.
3. https://portal.opendiscoveryspace.eu/en.
4. https://www.oercommons.org.
5. http://www.edu-design-principles.org/dp/viewPrincipleSummary.php.

Additional Files

The additional files for this article can be found as follows:

- **Appendix 1.** Short explanation of the main topic(s) of the selected scenarios. DOI: https://doi.org/10.16993/dfl.140.s1
- **Appendix 2.** An example of a scenario analysed using the second content analysis technique. DOI: https://doi.org/10.16993/dfl.140.s2
- **Appendix 3.** An example of a scenario analysed using the first content analysis technique. DOI: https://doi.org/10.16993/dfl.140.s3

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Competing Interests

The authors have no competing interests to declare.

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