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Game-Based Learning for IoT: The Tiles Inventor Toolkit

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Abstract. This paper presents a Game-Based Learning Design Pattern for designing Internet of Things (IoT) applications, as well as an instance of this particular pattern, namely the 'Tiles inventor game'. This educational game has been validated in various educational contexts aiming to understand IoT fundamentals. Due to lack of topics on IoT in the STEM curricula today as well as due to the lack of game-based learning design patterns, we propose these two artifacts, the pattern of designing IoT applications and the description of the Tiles inventor game, as a means of communicating best practice and contributing to bridging the gap between educational theory and informal practice in such a niche domain.

Keywords: Internet of Things · STEM innovative scenario Game-Based Learning · Prototyping · Design · Programming

1 Introduction

Game-Based Learning (GBL) has a long tradition in education, although it was introduced to the Technology Enhanced Learning community at the beginning of the second millennium by Prensky (2001). GBL is part of entertainment education, which refers to any attempt to make learning enjoyable (Breuer and Bente 2010). It can be media-based, mediated or classroom-based and can include the use of any type of games for educational purposes (ibid): board games, card games, digital games, exergames and so on. The purpose of the Tiles inventor scenario presented in this paper is to engage upper high school students in designing a technology-augmented solution that relates to Internet of Things (IoT) through GBL. The development of the solution exposes students to aspects of four different scientific areas: human-device interaction, Internet of Things, design and programming.

We describe the Tiles game-based learning application as a case of a Game-Based Learning Design Pattern, as an 'intermediary form of knowledge'. Such forms of knowledge which are more concrete than generalized theories, but more general than a single instance (Prieto et al. 2017) are much needed to bridge the gap between theory and practice. Design patterns typically consist of (Huynh-Kim-Bang et al. 2010): the name/title, the context, the problem, conflicting interests (called "forces") that intervene in the problem, and a generic or canonical solution. Design Patterns are embraced by various domains, including education. Examples include:

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- the Design Principles Database (DPD, http://www.edu-design-principles.org/dp/designPatterns.php), an online repository of design principles and design patterns on the use of technologies for education (Kali 2006), and
- the "Empowering the School infrastructures for the Implementation of Sustainable Instructional Patterns" project (eSIT4SIP, http://www.esit4sip.eu/), which has provided a knowledge base of instructional patterns that consider the existing ICT school infrastructure and other local specificities of the school reality (Mavroudi et al. 2016). Game-based Learning Design Patterns (GBLDPs) is a valid way of collecting, documenting and disseminating best practice in educational games and in GBL (Ecker et al. 2011). In Sect. 3, we provide the GBLDP of the Tiles inventor game.

2 The Tiles Game-Based Learning Scenario

The Tiles scenario consists of four main phases, the first one being an introduction both to the design challenge and to the programming and prototyping challenge:

- the introductory activities
- the design challenge (i.e. create an IoT-infused design solution)
- the transition from design to programming/prototyping
- the programing/prototyping challenge (i.e. implement a design solution).

During the design challenge, students work collaboratively in small groups to create an IoT-infused design solution. As a result, this phase generates a number of product ideas of IoT ecologies for a specific domain. In the design challenge, students do not use any technological tools, but instead they make use of design storyboards and cards, while the guidance they receive from the facilitator(s) is minimal. The students initiate the ideation phase using two boards, namely, "users" and "contexts traces", that help them to frame their idea by selecting target audience and set the context for their design solution. That is, the domain and the context of the problem are given to the participant students as a set of different pre-defined options about scenarios and personas. Next, students are supported by a set of 110 ideation cards (Mora et al. 2017) used for the design thinking activities such as idea storyboarding and idea pitching. The cards (Fig. 1) display elements from both the physical and the digital domains, including everyday things, user interface metaphors, and online services. Important to this phase are also the criteria cards. Those constitute a set of critical lenses that enable participants to reflect on the ideas generated at the end of the design phase. An example of a criteria card is "Utility: How useful and practical to use is the IoT concept? Does the concept solve a real problem for their users? Can you see it being used every day?". The criteria cards add constraints to the ideation process that might foster creativity. At the end of this phase, they pitch their idea while presenting their design solution to their peers and the facilitator(s)/tutor(s).

Crucial to the success of the Tiles workshop is the intermediate (third) phase that facilitates the transition from design to programming. In this phase, the themes cards are important. They describe provocative design missions, centered on human behaviors and desires. Example of themes are: "Sixth-Sense: Create an IoT concept that

Fig. 1. Tiles ideation cards used in workshop setting

gives its owner some kind of superpower, like new types of senses, perceiving new information, etc." and "Trojan Horse: Create an IoT concept that seemingly does one thing, but where the intention is to produce another, deeper effect."

Prototyping complements idea generation with a set of technical tasks that allow participants to hands-on experience the ideas generated, by using making as a process to both evaluate ideas feasibility and to find input to iterate on concepts. Prototyping is supported by electronic bricks (Fig. 2) that connect to online data sources and third-party IoT devices; they can be programmed with a simple textual language via a companion software toolkit described in (Mora et al. 2016). Prototyping allow participants to play with code and electronics in order to implement creatively the idea generated in hybrid physical/digital artefacts.

To that end, the electronics bricks (Fig. 2) provided by Tiles allow participants to focus on exploring the combination of simple pre-implemented functionalities with a simple JavaScript-based language. Especially for the programming part of the prototyping phase, the workshop facilitator supports students while they make use of the Tiles toolkit (explained in the next section), physical artifacts and javascript templates to program and test the design solution. Usually, the same IoT-infused design solution is exploited in the design challenge phase, but it could also be a pre-defined mission from the themes cards.

Resources and Materials Needed for the Tiles Game-Based Learning Scenario
The completion of the scenario requires core (i.e. obligatory) and secondary (i.e. subsidiary) hardware. The former involves a PC connected to the internet, a projector, and IoT squares. Examples of IoT squares are the TILES squares (http://tilestoolkit.io/), and micro:bit (http://www.microbit.org/). Tiles is an inventor toolbox that supports the

Fig. 2. Tiles prototyping tools

design and making of interactive objects for learning and playing. It allows non-experts to create complex and distributed physical interfaces. Similarly, BBC micro:bit is a pocket-sized computer that users can interact with, code, customise and control to bring their ideas and applications to life. With respect to secondary hardware, it depends on the specific ready-made IoT scenarios that the instructor wishes to demonstrate or that the students wish to attempt. Examples include a 3D printer, a laser cutter, drones, and so on. Regarding software, the scenario requires a programming environment that supports the development of the javascript code snippets. In addition, in order to play the game, the Tiles generator idea board is needed, since it supports the ideation and design process step-by-step. The Tiles primitive design cards and the Tiles generator idea board used to play the game and overcome the design challenge are available online under Creative commons license in the 'Tiles IoT cards' repository (https://github.com/simonem/tiles-IoTcards).

3 Tiles Inventor Game and Skills Cultivation

This section outlines the student competences that can be developed with the Tiles inventor game by suggesting conceptual mappings with the game-based learning skill framework that emerged from a comprehensive review conducted by Mishra and Foster (2007). The definitions of the skills are in line with this framework. In doing that, we explain from the game designer viewpoint the intended skills cultivation, focusing on how and why it happens using the Tiles inventor game. Also, we explain how students can be assessed with respect to these skills in the context of the game.

Practical skills refer to learning which aims at the cultivation of skills that are applicable to the real world or to authentic settings. Good games afford expertise development, innovativeness, creativity and other skills needed for the 21st century workforce. From this theme, we identified the following skills:

- Digital/technological literacy – this involves the IoT knowledge acquired, as well as the prototyping and programming skills cultivation.
- Innovative/creativity/design skills – intended as sparking design thinking and idea generation. In a previous empirical evaluation conducted by the authors (Mora et al. 2017), most of the student participants stated that they had put forward ideas they

would not have had without the cards and that the themes cards helped them to be creative. A collaboration rubric, like the rubric suggested in (Mokhtar et al. 2010), may be used for self-assessment or for peer feedback. It assesses domain-general views of creativity across three axes: novelty, resolution and style. The whole Tiles scenario focuses on design, which involves how students "make use of the materials and resources that are available to them at a particular moment to create their representation" (Sanders and Albers 2010, p. 8).

- Multirepresentional understanding and multimodal literacy/processing – this involves engaging students with multimodal representations: auditory, textual, visual and interactive. For example: the introductory PowerPoint presentation, the boards and the cards in the design phase in order to overcome the design challenge, the code snippets in the programming phase in order to create a prototype, the storyboard creation, the idea pitch, and so on.

Cognitive skills in most game environments are cultivated by a learning-by-doing approach, where knowledge and hands-on experiences are inextricably linked. The review reports that the proponents of GBL report immediate feedback, cooperation and collaboration, scaffolds, problem solving, exploration and curiosity in a risk-free environment and transfer of knowledge to new situations as the main game affordances. From this theme, we identified the following skills:

- Deductive/inductive reasoning: while themes cards foster divergent thinking, criteria support refining ideas toward converging on a concept that satisfies one or more criterion.
- Systemic thinking: the Tiles scenario provides a 'lightweight' simulation environment of IoT ecosystems where students can inquire, problem solve, test hypotheses and apply their ideas.
- Causal/complex/iterative relations: the students use the themes cards to find ways to challenge one's idea, then go back and refine the storyboard contents. This provides triggers to diverge by iteratively modifying and expanding previous ideas.

Social skills can be cultivated when players collaborate with each other or when they learn to work with others in gaming situations. This theme focuses on the development of interpersonal skills, cooperation and the development of identities. From this theme, the Tiles scenario focuses on the cultivation of communication and collaboration skills. During the Tiles scenario, the student groups work together towards the creation of their IoT-infused scenario of use. Students are using all the materials ('users' board, 'context traces' board, 'Tiles idea generator' board, Tiles primitive design cards) and co-operate in order to design their own scenario of use. The criteria embedded in the game design act as triggers for collaborative reflection. During the programming phase, each student group also co-operates with their instructor in order to program the behavior of the physical artifacts by writing the java script code. To assess student communication and collaboration, we can consider assessment of collaborative projects with collective outcomes using formative assessment mechanisms. As an example, the collaboration rubric mentioned above, originally suggested by Mokhtar et al. (2010), can be used in conjunction with students' peer feedback after the ideas pitch.

Motivation pertains to the affordances of game environments to cultivate the intrinsic learner motivation. In turn, this revolves around the motivational design principles (e.g. grant power, autonomy, and adjusted challenge levels). From this theme, we identified the following skills:

- Immediate feedback/scaffolds- the materials are intended to guide students to succeed in the design and the prototyping challenge and the instructors act as facilitators throughout the learning process. Their role is to scaffold the learning experience by using different techniques, like explaining, providing examples, demonstrating, discussing, using metaphors, and encouraging the students. At the end of the design phase the student assessment on subject matter aspects can take place via a knowledge quiz. The questions can be integrated in a classroom response system, like kahoot!, which gives automated feedback to all participants after the time limit in each of the multiple questions. This can facilitate immediate feedback and reflection, student monitoring, and in-class discussion in tandem with game-like features (like competition, rewards and so on). The Kahoot! knowledge quiz is available online at https://play.kahoot.it/#/k/36df1589-fcff-4c5f-a03c-8d8190bfeecc.
- Control/choice/autonomy/clear goals- at the beginning of the scenario, the students go through the Tiles cards in order to check that they have understood their meaning and purpose of use in the game. Then, the instructor facilitates the process by providing feedback on an as-needed basis; in this case explaining to the students the meaning of those cards that they do not know or understand (probably due to lack of background knowledge). The problem is open ended, and the students are bounded only by the procedural rules of the game, there is no expert solution.

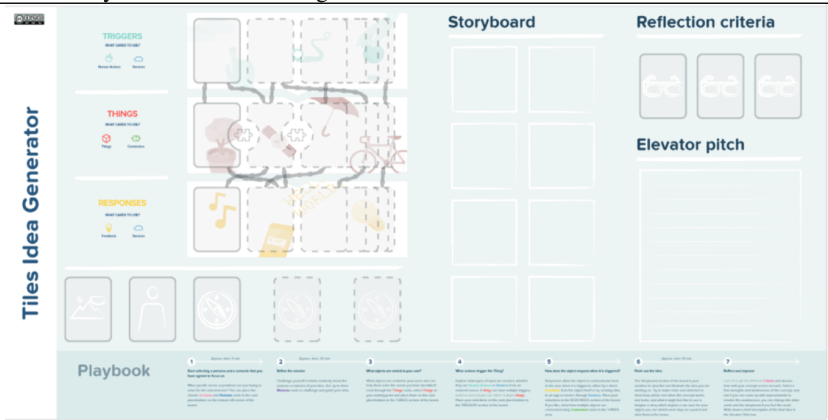
4 The Tiles Game-Based Learning Design Pattern

This section presents the design part of the Tiles Inventor game using the generic pattern template and the specific case study template, which are recommended by Ecker et al. (2011) particularly for GBLDPs. That is, the Tiles Inventor Game is manifested as a case study of the generic underlying GBLDP proposed. The basic structural elements of the pattern template are:

1. Formal aspects, which capture information about the pattern's history, contact details of the pattern creator(s), and so on; all this information aim to help readers, among others, advancing the pattern in a responsible way
2. Aspects of content, which involve crucial characteristics the learning situation
3. Conceptual aspects, which aim to externalize important background information of the learning experience
4. Examples and references to better understand the pattern.

GBLDP: design your IoT solution	
Formal aspects	
Author(s)	Mora S., Divitini M. and Gianni F. (2016)
Version	1.0
Date	12 September 2017
Aspects of content	
Basic problem	It is an open ended design problem on IoT applications. The pattern is: (1) Initiate the game, (2) Ideate your IoT solution, (3) Design your IoT solution iteratively
Approach	It covers the first two steps of the IoT application development process: (1) idea generation, (2) design, (3) prototyping, and (4) 3D print and assembly
General description	Game–based learning and learning by design
Conceptual aspects	
Educational concept	The pattern includes a series of design thinking and reflection activities performed collaboratively in a workshop setting. It aims at co-creating IoT–related concepts that are validated against several criteria, like creativity and feasibility, while a number of learning outcomes among workshop participants are facilitated
Learning objectives	The students will be able to: (a) define in their own words the concept of IoT (b) recognise IoT applications (c) summarise the basic elements associated with the concept of IoT (d) design an IoT-infused solution (e) judge the efficiency of their solution based on specified criteria (f) reflect on their progress
Activated cognitive skills	This pattern links with the Revised Bloom Taxonomy (Anderson et al. 2001): understand factual knowledge, create procedural knowledge, evaluate procedural knowledge, and evaluate metacognitive knowledge
Requirements	It requires an introductory activity to IoT and to the design challenge
Potential problems in using	Students might have misconceptions about IoT
Advise on the application	For the students' group formation, it is advisable that the students within one group have complementary skills
Examples and References	
Related patterns	'Create an artifact', 'Collaborate', 'Reflect' from the DMP, http://www.edu-design-principles.org/dp/designPatterns.php
Application sample(s)	Makerfairs, Hackathons, Designathons etc.
References	Divitini et al. 2017

The ensuing case study which is based on the proposed pattern is shown below.

Case study: The Tiles IoT design Game	
	
(Available online at: https://github.com/simonem/tiles-IoTcards/blob/master/release/workshop-addons/Tiles%20board%20generic.pdf)	
Summary	The basic steps are described in the ‘Playbook’: (1) Initiate the game - start selecting a persona and a scenario that you have agreed to focus on, (2) Ideate your IoT solution (2a) What is your mission? (2b) What objects are central to your mission? (2c) What human actions trigger the objects? (2d) How do the objects respond when they are triggered? (3) Design your IoT solution iteratively (3a) Flesh out your idea (3b) Reflect and improve
Authors	Simone Mora, Francesco Gianni, Monica Divitini, Anna Mavroudi
Task	The main tasks involve: (1) the Tiles idea generator, (2) the storyboard, (3) the reflection criteria and (4) the elevator pitch
Action	The final student product is the IoT-infused scenario of use, including the storyboard and the idea pitch
Conclusion	Enable the design of affordances for interactive objects without being limited by form factor of the technology used for prototyping
Lessons learnt	Students might find challenging to work using the learning by doing approach, especially at the beginning

5 Method

The Tiles scenario was implemented with 12 freshmen working collaboratively in groups in the classroom. The groups were created randomly. The students are studying Computer Science at the Norwegian University of Science and Technology, but they were not familiarized with IoT-related aspects. The duration of the learning endeavor was three hours approximately. To analyse the Tiles scenario learning impact, we used the artefact analysis of students' design solutions created in the main phase of the scenario. To collect the data for the artefact analysis we used photographical observations (i.e. photos of the students' final solutions). They were analysed against a dedicated assessment rubric, which was validated by two researchers. The rubric assigns a score from 0 to 5 in each of the following criterion:

1. Data exchange/online services: does the idea make use of them?
2. Use of scenario: does the idea cover all the aspects and address all the challenges proposed in the scenario?
3. Persona use: is the idea actually targeting the chosen persona? Is it too generic or too restrictive in terms of target group?
4. Implementation with Tiles design element: how is the idea using the required functionalities in terms of services, sensors, human actions, feedback etc.?
5. Participation: is the idea promoting participation and collaboration between the actors of the scenario?

The scores correspond to performance levels described in the generic template for holistic rubrics which was originally suggested by Mertler (2001), as shown in Table 1.

Table 1. Students performance levels description from Mertler (2001)

Score	Description
5	Demonstrates complete understanding of the problem. All requirements of task are included in response
4	Demonstrates considerable understanding of the problem. All requirements of task are included in response
3	Demonstrates partial understanding of the problem. Most requirements of task are included in response
2	Demonstrates little understanding of the problem. Many requirements of task are missing
1	Demonstrates no understanding of the problem
0	No response/task not attempted

6 Results

The idea of the first student group aims at connecting people and making new friends through social media. It describes an IoT-design solution that promotes co-located - yet distributed in the smart city- online communities by using proximity (and other) sensors in tandem with social media outdoors to connect with other people in the smart city. The second idea describes a smart watch that helps children adopt an eco-friendlier behavior indoors. For example, the smart watch vibrates when the persona, who is a six-year-old girl, forgets to turn off the lights whenever she leaves the room. The third idea is targeting Tom, a 43-year-old man who lives on a wheelchair, and it suggests the use of environmental sensors which adapt the wheelchair to the environment conditions. For example, the wheelchair has an autopilot system with GPS. Finally, the fourth student team designed a smart bin which is helping children to recycle better.

Concerning artefact analysis, Table 2 presents the scores of the student solutions against the predefined criteria of the assessment rubric mentioned above.

Table 2. The scores of the student solutions against the predefined performance indicators

Student group	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Total score
1	3	3	3	4	4	68%
2	5	4	4	4	2	76%
3	4	4	3	5	2	72%
4	5	4	5	3	2	76%

7 Conclusions

The paper suggests a GBL paradigm for learning about IoT based on previously validated templates and prior research work. The empirical results of this paper and the results mentioned in (Mora et al. 2017) have shown that the Tiles IoT inventor game can promote an effective teaching methodology for the basic design and development aspects of the IoT applications students. The scores of the artefact analysis, except for the scores of the fifth assessment criterion, are encouraging, considering that the students were not familiarized with IoT. The scores of the fifth criterion corresponding to the social aspect of the design solution of the students' artefacts suggest that it is more difficult to cultivate attitudes of IoT-related issues (such as collaboration and digital citizenship), than skills development (such as design skills) with the Tiles learning scenario.

The Tiles IoT inventor game incorporates attributes that have been identified as important pedagogical affordances of GBL (Kim et al. 2009; Pivec and Dziabenko 2004): (a) it encourages learners to combine knowledge from different areas in order to create their IoT-infused design solution or to make a decision at several points, (b) it promotes open-ended problem solving by enabling learners to test how the game outcome is dependent on their decisions and actions, and (c) it encourages learners within groups to discuss and negotiate subsequent steps and, in turn, cultivate their social skills. There is a growing body of educational environments that make use of Internet of Things, ubiquitous technologies or mobile computing, with very encouraging results. Luckily, the International Conference on Interactive Mobile Communication, Technologies and Learning (ICML) presents numerous such examples every year. Yet, this paper is advancing our views on the topic assuming that the citizens of tomorrow will not only have to make use of the technology, but they will actually design it (Resnick 2002).

The contribution of the paper is twofold. For the practitioners, it presents a generic LD pattern for GBL on IoT (Initiate the game, Ideate your IoT solution, and Design your IoT solution iteratively) that they could use in their respective contexts. In doing that, it identifies and explains the associated student competences, while creating conceptual mappings of students' competences with a dedicated framework for GBL and making use of previously validated templates. Also, practitioners could run the Tiles inventor game with their students by studying this paper and making use of the Tiles inventor game materials which are available online under creative commons license. The contribution of the paper for TEL research pertains to the creation of 'intermediate level design knowledge' on TEL which is much needed nowadays. It has been recently suggested that luckily the field of TEL has reached a maturation point where there exist many successful design instances and also enough theoretical frameworks that can guide our research, but not enough knowledge 'in the middle space', in this case a GBLD pattern (Prieto et al. 2017). This 'intermediate' type of TEL knowledge can evolve to a strong TEL concept provided testing in diverse contexts (Prieto et al. 2017; Sharma et al. 2017), which is in line with our future work.

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