Introducing IoT Competencies to First-Year University Students With The Tiles Toolkit

SIMONE MORA, Department of Computer Science
NTNU
FRANCESCO GIANNI, Department of Computer Science
NTNU
STEFANO NICHELE, Department of Computer Science
Oslo Metropolitan University
MONICA DIVITINI, Department of Computer Science
NTNU

Advances in the field of Internet of Things (IoT) are introducing innovations in multiple domains including smart cities, healthcare and transportation. An increasing number of jobs today require IoT competences that university courses need to be prepared to deliver. Yet, teaching IoT topics is a challenging task due to complexity and unstructured nature of the IoT. It requires to deliver skills in multiple domains including design, hardware and software engineering and it is often hard to find an entry point to the field. In this paper we explore using the Tiles ideation toolkit as a way to teach bachelor students in IT topics IoT fundamentals. Tiles is composed by a set of 150 cards and a workshop procedure for collaborative ideation. We performed a user study with 60 computer science students to investigate how Tiles can be used as an experiential learning tool to develop basic knowledge in IoT and to train design thinking skills. Results show the tool was accepted as useful and fun to play with. Nearly all students managed to develop a simple IoT idea during the three-hours workshop. Learning outcomes were observed in about half of participants, although time constraints and high stress levels impacted the participants' experience.

CCS Concepts: • **Social and professional topics → Computer engineering education**.

Additional Key Words and Phrases: Internet of Things, Experiential Learning, Computer Science Education

ACM Reference Format:
Simone Mora, Francesco Gianni, Stefano Nichele, and Monica Divitini. 2018. Introducing IoT Competencies to First-Year University Students With The Tiles Toolkit. 1, 1 (March 2018), 15 pages. https://doi.org/10.1145/3289406.3289410

1 INTRODUCTION

The Internet of Things (IoT) is rapidly gaining interest as an infrastructure technology for the future. Although several definitions of IoT are available, see [23] for an exhaustive list, we envision IoT systems as an ecology of technology-augmented and interconnected everyday things that are somehow more useful, engaging or playful then their ordinary selves. IoT is expected to impact the lives of many; addressing problems in multiple domains such as smart cities, health-care and transportation.

Authors' addresses: Simone Mora, Department of Computer Science
NTNU, , Trondheim, Norway, 7034, simone.mora@ntnu.no; Francesco Gianni, Department of Computer Science
NTNU, , Trondheim, Norway, 7034, francesco.gianni@ntnu.no; Stefano Nichele, Department of Computer Science
Oslo Metropolitan University, Oslo, Norway, 7491, stefano.nichele@oslomet.no; Monica Divitini, Department of Computer Science
NTNU, , Trondheim, Norway, 7034, monica.divitini@ntnu.no.

2018. Manuscript submitted to ACM

© Authors | ACM 2018. This is the authors' version of the work. It is posted here for your personal use. Not for redistribution. The definitive Version of Record was published in Proceedings of the 7th Computer Science Education Research Conference, http://dx.doi.org/10.1145/3289406.3289410.

An increasing number of jobs are today related to the IoT. Universities around the globe are therefore catching up delivering compelling courses to allow students to be prepared to today and future need of IoT competences.

In [4] several motivations for teaching IoT concepts in information and computer science courses are provided. Among those, the interdisciplinary of IoT allows for new forms of participation in computing; while applicability of IoT inventions to solve problems that are common in students' daily lives might facilitates students' motivations in taking the subject.

On the other side, teaching IoT topics is a challenging task for professors and educators because of the complexity and unstructured nature of the IoT. IoT requires skills in multiple domains including design, hardware and software engineering, HCI, privacy and security. To add, it is hard to define an entry-point for students to allow them to have an overview of topics and skills and perhaps allow them to decide on what aspect of IoT decide to focus later on in their study.

In [24] we presented an ideation toolkit, Tiles IoT Toolkit. The toolkit is composed by a set of ideation cards and a workshop methodology that enable participants to rapidly develop an idea to solve a given societal problem using IoT technology. Participants are not required to have any pre-existing knowledge in IoT, design or programming topics; meaning that we target, for example, students, makers and artists. Using Tiles Cards (Figure 1) and Tiles Generator Board (Figure 2), participants in teams of 4-6, fast-pace through a set of 6 design thinking activities to collaboratively converge towards an IoT concept.

In this paper we investigate how the Tiles Toolkit can be used to teach IoT fundamentals to bachelor students in IT.

Tiles toolkit has not been explicitly developed as an educational tool. Yet, due to its informational nature, we expect that the cards and the ideation workshop could be used as experiential learning tool; combined with traditional classroom activities.

To this end we ran a user study with sixty 1st-year computer science students in a large Norwegian university which has recently started to provide courses about IoT and its application domains. The study consisted in two phases: workshop and idea contest, unfolded over the 2017 spring term. During the study, the Tiles Toolkit was adopted to develop an IoT concept to improve the lives of fellow citizens, as part of a course mandatory assignment.

We aim at investigating (i) what role Tiles plays in informing students about different components of IoT systems as well as related HCI concepts (ii) how Tiles could be used to help students developing basic design thinking skills.

Further, we direct at understanding what characteristics of the Tiles Toolkit make it a useful tool for learning and what learning goals can be achieved.

Results show the tool was accepted as useful and fun to play with. Nearly all students managed to develop a simple IoT idea during the 2-hours workshop. Learning outcomes were observed in about half of participants although time constraints and high stress levels impacted the participants' experience.

The paper is organised as follows. Section 2 reports relevant work in courses that have adopted a project-based or experiential learning approach to teach IoT skills. Section 3 introduces the Tiles IoT toolkit detailing the different pack of cards and the workshop procedure. Section 4 depicts the user study methodology, procedure and results; while section 5 discusses the results in relation with the research questions. We conclude the paper highlighting future work.

2 RELATED WORK

Teaching IoT competences is not an easy task. In [4] four different strategies for teaching IoT topics were identified, depending whether they provide a general introduction on IoT-related topics or the focus is on application of IoT technology in a specific domain. Choosing a teaching strategy involves identifying the expected audience, their preexisting knowledge and expected learning outcomes. The authors also argue on the complexity of choosing a teaching strategy.

At the same time, project-based tasks are a useful way to deliver learning goals. Students can develop skills by doing and playing with real-world problems and needs; learning through experience [16]. Project-based, experimental learning has been adopted for many years in different learning domains such as software engineering [15], economics and business [5]. This approach heavily relies on collaboration and social interaction among students with different background with the goal of developing competences by solving tasks collaboratively.

In [19] IoT is used for a large scale study involving university students. The goal of the project was to empower students with new concepts and tools, to more effectively convey education about traditional computer science related topics like programming and embedded systems.

In a similar way, Chin and Callaghan [7] envision IoT as a platform for teaching computer science. Their goal is to produce a highly motivating and effective educational environment, where students and staff can learn elementary programming skills.

Dobrilovic et al. [8] explore in their paper a set of IoT enabling technologies oriented to wireless sensor networks, that are simple enough to be deployed in an educational environment. They propose Arduino as a common platform to simplify the prototyping and learning process of such technologies.

The UMI project aims at enhancing the attractiveness of science education and careers for young people, via the use of latest technologies. Innovative learning methods to teach ubiquitous, mobile and IoT are investigated [13].

Besides the abundance of tools and methods for supporting experiential learning of IoT technology concepts by building prototypes interactive artifacts with code and electronics, for a review see [4] and [3]; education tools for more design and HCI IoT topics can be hardly found.

The set of skills required to develop IoT applications can be summarised in three areas: design, engineering and entrepreneurship. Because of the multidisciplinary of the field it is important for students of introductory IoT courses to provide some knowledge in all the three areas.

With Tiles Toolkit we expect to provide 3 goals: (i) describe the basic components that are common for IoT architectures, (ii) describe HCI concepts that can be used to design user interfaces for the IoT (iii) develop design thinking skills. These objectives are supported by the information printed on the playing cards and the activities provided by the Tiles Workshop.

The Tiles toolkit has already been used as an education tool in previous works, but never as part of a university course. In [22] and [10] the toolkit has been used as part of a game-based learning scenario in high schools and primary schools, and in [21] the Tiles workshop has been used to introduce IoT and Smart City concepts in lower-secondary schools. In [12] Tiles has been extended to support the development of IoT applications to promote reflective learning.

3 TILES TOOLKIT

The research that lead to the development of Tiles Toolkit started from addressing today's technology-driven nature of the IoT field and the lack of a human-centred perspective in IoT development [18]. Although several resources to engage multiple stakeholders in developing human-centred applications exist, an exploration of the IoT field from an HCI point of view is still in its infancy [17].

The goal of Tiles Toolkit is to foster human-centred design of novel IoT concepts by providing tools to engage non-experts in ideation and design. With the term non-experts, we refer to individuals without formal training in design or technology; for example makers, students, children and artists. The toolkit design is inspired by a thing-oriented vision of the IoT [2] and adopts object augmentation [20] as a design strategy.

Although several ideation tools exist, for example Know-cards [1], Thingsclash [6] and IoT Service Kit [9]; none of them have a strong focus on supporting non-expert ideation or providing a structured process for doing so. They focus on facilitating design and to our best knowledge have never been explored as educational tools.

Tiles Toolkit is composed by (i) a set of 150 ideation cards, (ii) the Tiles Idea Generator, a cardboard to stage ideation activities via card play; and (iii) an ideation process to be used in workshops with teams of 4-6 participants.

The toolkit is designed to be extensible and adaptable to multiple application domains. Although the tools have been tested with one workshop process, different ideation activities and games that make use of the cards can be developed. New cards can be also created by end-users during the workshops. The toolkit is released under Creative Commons license and available at http://tilestoolkit.io.

In the remaining of this section we describe the different elements of the toolkit. The toolkit was initially presented as a generic ideation tool in [24] and later extended in [11] to target the design of IoT applications for smart cities. In this paper we present the toolkit in its latest iteration which has integrated elements from [11] and brought usability improvements.

3.1 Ideation Cards

The Tiles IoT Cards are a collection of 150 cards grouped in 9 colour-coded packs (Figure 1). In the following we provide a brief explanation of the different pack of cards. For a full description please see [24] and [11].

(1) *Personas (10 cards)* – provide examples of user groups one can decide to design for. They do not address only single individuals but also groups or communities, e.g. elderly or construction workers.
(2) *Scenarios (5 cards)* – provide examples of scenarios that tackle societal challenges that affect modern cities. They are inspired from the sustainable development goals adopted by the United Nations in 2015[1].
(3) *Things (42 cards)* - list most common, everyday low-tech objects. These things are to be augmented with IoT technology; for example, to act as physical avatars for digital services.
(4) *Services (27 cards)* - propose a number of popular online, digital services like social networks, data providers and APIs. These provide information that can be accessed from augmented things.
(5) *Human Actions (11 cards)* - suggest a number of user-interaction metaphors people can use to interact to a service via an augmented thing. They focus on physical and embodied interaction rather than screens.
(6) *Feedback (10 cards)* - indicate a set of ways an augmented thing can display information to people.
(7) *Sensors (9 cards)* - are a collection of ways an augmented thing can sense information from the surrounding environment.
(8) *Missions (22 cards)* - are a set of provocative design goals to inspire creative combinations of things, services, human actions, feedback and sensors.
(9) *Criteria (14 cards)* - are a collection of critical lenses to reflect, evaluate and refine the ideas generated.

Decks 1-2 help participants in contextualising the design effort towards a specific user and domain. Decks 3-7 explain the basic ingredients of any IoT product; hiding technicalities, they focus on how people experience the IoT as an ecology of humans, physical objects and digital information. The last two packs of cards provide triggers for creativity and reflection to foster idea generation.

[1] UN Sustainability Goals - http://www.undp.org/content/undp/en/home/sustainable-development-goals.html

Fig. 1. Tiles Ideation Cards.

3.2 Ideation Workshop Technique

To provide guidance for collaborative ideation using the Tiles Cards we provide a workshop technique to be used in sessions with multiple teams of 4-6 participants, facilitated by professionals. The technique reflects the structure of the creative design process defined by Schön [25] and heavily relies on popular design thinking activities.

Working against a given problem domain (described in the Scenario cards), workshop participants use the Tiles Cards to develop an IoT concept to solve a chosen problem for a chosen user. Participants fast-pace through a set of 6 activities: *explore*, *challenge*, *combine*, *sketch*, *refine*; and *pitch* to collaboratively converge towards an IoT invention idea. These activities are formulated by workshop organisers as questions for the users to brainstorm:

(1) *Explore* - Draw a Persona and Scenario card. What specific needs or problem are you trying to solve for them?
(2) *Challenge* - Draw a Mission Card. Challenge your team to think creatively how to accomplish the mission and what values it brings for your Persona.
(3) *Combine* - Draw a card from each technology deck. Think what objects are central to your user and combine services, human actions and triggers to serve the needs you have identified.
(4) *Sketch* - Flesh out your idea! The storyboard is your sandbox to illustrate the idea you are working on.
(5) *Refine* - Look through Criteria cards and discuss how well your concept scores on each. What are strengths and weaknesses of your concept? Can you change your idea to resolve the weaknesses?
(6) *Pitch* - Write down a brief description of your final idea and present it to your public in a 60-seconds elevator pitch. You should convince your audience that this is the greatest idea ever!

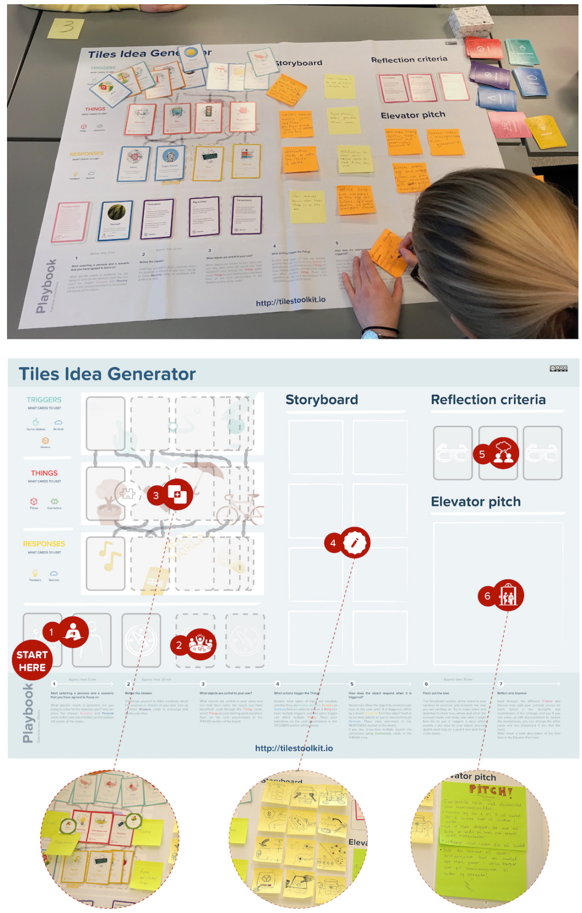

Fig. 2. The Tiles Idea Generator Board and how the board supports the different Ideation Workshop technique steps.

Participants are given a limited amount of time ranging between 5 to 15 minutes to complete each of the six activities, for a total of about 60 minutes.

3.3 Idea Generator Board

To help participants follow the workshop process and limit supervision from organisers we provide participants with a cardboard (Figure 2) used to stage card play. The Tiles Idea Generator Board, enforces and scaffolds the actions of workshop participants by guiding meaningful combinations of Tiles Cards and encouraging production of design artefacts. Further, the board features a detailed playbook to guide participants throughout the different activities. The use of a cardboard recreates a social context similar to board games, a familiar and fun setting for many.

3.4 From Ideas to Prototypes

After having developed an idea, participants of the Tiles workshops can build a prototype using popular toolkits like Arduino, Raspberry Pi or Micro::bits. The way the Tiles Idea Generator process arranges cards as groups of triggers and responses makes it easy to build prototypes with code and electronics. Further, participants develop a storyboard and an elevator pitch script, useful to effectively communicate their idea to a broader audience.

4 USER STUDY

During the first half of 2017 we experimented using the Tiles Toolkit as an experiential learning tool with 1st year bachelor students in computer science.

The intervention took place as part of a university course in IoT topics provided by a large Norwegian university. The course is part of the study program in Applied Computer Technology.

In this course, students acquire an understanding of some of the most important principles of the IoT, become familiar with IoT architectures and intelligent algorithms, earn a comprehensive understanding of IoT from a technical point of view; and evaluate the consequences for society (e.g. privacy, security) when billions (or trillions) of units communicate in the cloud. The course runs in the spring semester and builds on previous introductory IT courses. The explicit learning outcomes for the course, as stated on its webpage[2], are:

- Basic technical understanding of Internet and computer networks;
- Overview of the most important principles of Pervasive Computing and IoT including Wearable Devices, Context Aware Computing, Health Monitoring, Smart Houses, Crowd-sensing, Smart Grids and Ambient Intelligence;
- Basic principles of various algorithms for autonomous control in IoT;
- understanding of how IoT and Pervasive Computing affects the security and privacy in our society;
- Solid knowledge of how science and technology has evolved to enable Internet of Things;
- Conceptualisation of architectures for solutions based on IoT and Pervasive Computing.

The course includes three mandatory assignments. Each assignment corresponds to 30 hours of work. The second assignment has been the object of our user study.

In the second assignment the students were asked to perform a project-based exercise consisting in the development of an IoT system within the smart city domain. They had to deliver two artifacts: a description of the idea in the form of an elevator pitch plus a software prototype, and finally attend an idea contest event.

The Tiles toolkit has been adopted to facilitate development of students' IoT concepts for the assignment. First, we ran a workshop engaging students with the activities described in Section 3.2 to help students quick-start their assignment projects. In this phase Tiles acted as an inspirational and design tool to help students quickly converge on an idea. After 30 days from the workshop, students presented their elevator pitches in front of a jury of experts who eventually gave grades to the students.

Following, student teams had 30 days to build a simple software prototype. During this phase, Tiles cards were available as a source of inspiration to help students extend or modify their initial ideas. For the prototyping, students had free access to the IBM Bluemix IoT platform[3]. Teaching assistants were present in weekly lab sessions with the students.

The study focused on investigating the following research questions:

- **RQ1** How Tiles helps informing students about different components of IoT systems such as sensors, actuators, data sources and networks;

[2]http://www.hioa.no/eng/Studies/TKD/Bachelor/Applied-Computer-Technology/Programplan-for-Bachelorstudium-i-anvendt-datateknologi-2017/ADSE1310-Internet-of-Things-2017
[3]IBM Bluemix https://www.ibm.com/cloud/

- **RQ2** How Tiles helps informing students about HCI concepts such as tangible interfaces, user inputs and system feedback suitable to build User Experiences for IoT systems;
- **RQ3** How Tiles helps students in developing basic design thinking skills like sketching, storyboarding; and to present their idea in front of an audience.

4.1 Participants

Sixty students aged between 19 and 27 years old participated in the trial. Students were divided in sixteen teams, with an average number of student per team of four. The formation of groups was facilitated by the teaching staff, although students were free to form groups on their own.

The students were surveyed about previous experience as designers and programmers and asked to self-assess choosing between: no experience, little experience and professional. The majority of participants reported no experience (54%(d)/57%(p)) or little experience (44%(d)/43%(p)) both as (d)esigners or (p)rogrammers. One participant rated herself as professional designer.

Background information from participants was surveyed to make sure that our users could be considered as non-experts and lie in the anticipated target group of the Tiles Toolkit.

4.2 Procedure

The study consisted in two phases: workshop and idea contest. Between the two activities the students had four weeks to work in team to develop ideas before presenting them to the jury during the idea contest.

4.2.1 Phase 1 – Ideation. During this phase students participated in the Tiles Ideation workshop. The goal of the workshop was to help the teams to develop an initial idea of the IoT application that will be further developed as part of the assignment. The workshop lasted about two hours and proceeded with the following structure.

First organisers gave a presentation about the workshop. A definition of the IoT was given to the students and examples of applications of the IoT in different domains were showcased. Following, a brief introduction about the different decks of cards (Section 3.1) and activities to be done (Section 3.2) was given. This part lasted for a total of 15 minutes and was supported by the PowerPoint slides available at http://tilestoolkit.io.

Following, each team was given a deck of Tiles Cards, one Idea Generator Board, some Post-It and markers. Teams were asked to start browsing the cards following the ideation process as indicated on the playbook printed on the board. Circa 45 minutes later, the ideation process was stopped by the organisers and participants were asked to get ready to present their idea. After a short break each team gave a 60-seconds elevator pitch of their idea (final step of the ideation workshop technique).

During the activities, workshop organisers were acting as observers although they were also able to intervene to support the participants if they were in need or asking for help. The course's teaching assistants were also present as facilitators.

4.2.2 Phase 2 – Idea Contest. This phase started right after the Tiles workshop and lasted for four weeks. It culminated with an idea contest event.

During the four weeks, the students elaborated the idea generated with the Tiles toolkit, with particular focus towards the three reflection criteria cards selected at the end of Phase 1. They were given support by the teaching staff for two hours weekly, otherwise the groups were free to meet in the lab or other places of their choice. They had access to the card deck if needed, as well as photos of their board taken at the end of Phase 1.

In this phase the ideas were developed and validated against the state of the art. They focused on communicating the idea to an audience and preparing the presentation and the pitch. Yet students were free to discard the idea created in phase 1 and start over.

This phase represents a new and extended version of step 6 of the workshop. Teams pitched their ideas in front of a jury of experts. Experts were selected and invited by the teaching staff, and included experts from the industry (IBM, Telia, Startup Lab). The event was organised as a sort of startup investor event, where each group had a given "virtual" budget to invest into other ideas and projects. The experts and the teaching staff had a larger budget. At the end of the idea presentations, some time was allowed for the investments to take place. The project that received more investments was declared as winner and received a free access to the Startup Lab infrastructure to take the winning idea further and explore market potential. The students enjoyed the format of the event.

4.3 Data Collection

Both quantitative and qualitative data about the acceptance and usage of the Tiles Toolkit was collected. Consent forms for the use of data for research purposes were signed by all participants. Every attendant compiled two likert-scale questionnaires, one after phase 1, focused on acceptance and usability; and one after phase 2 focused on delayed perception of tool usability and support given during phase 2 (prototyping). After phase 1, pictures of the board, storyboard and cards were collected. Both during phase 1 and 3, videos of the elevator pitches were taken. At least one of the authors was present during all the phases, acting as observer. Questionnaires were anonymous and handed out on paper.

5 RESULTS

5.1 Ideas Generated

Sixteen ideas have been created by the teams. Table 1 presents a short summary of the concepts that have been developed to exemplify scope and complexity. The idea description have been formulated based on the pitch given by students during the idea contest event described in Section 4.2.2.

5.2 Analysis of Ideas

First, the ideas generated have been analysed to assess whether they match the criteria for being considered an IoT concept (RQ1).

To this end we looked at five characteristic typical of IoT systems: the presence of a technology-augmented artifacts (**AT**), the presence of an ecology of devices and services (**ECO**), the use of online services and APIs (**SER**), and the use of sensors (**SEN**).

Second, the concepts have been examined to understand what type of user interface they feature (RQ2).

To this end we assessed whether the concepts builds on "traditional" user interaction paradigm such as screen-based (**Screen**) or more IoT-specific approaches like voice-based (**Voice**), tangible interaction [14] (**Tangible**) or ambient/glanceable (**Ambient**) interaction.

Photos of the Idea Generator boards developed by students during *phase 1* and video recordings of elevator pitches gave by the students both in *phase 1* and in *phase 2* have been used for analysis.

Results from the analysis are proposed in the right end of Table 1.

Table 1. Ideas Developed

Idea	Description	IoT	UI
SIA (Smart Integrated Accessibility)	A system to help people with disabilities taking a bus. It works by warning incoming bus drivers of the presence of a person with disability.	ECO	Screen
RobotDog	A social robot to help kids with disabilities in recycling garbage.	-	Screen
TechTrousers	An exoskeleton to facilitate mobility of wheelchair users implemented in a pair of augmented trousers.	AT-SEN	Tangible
Sigrid	A social robot to help elderly access information from public authorities.	SER	Voice
YoWhereMyDoggoAt	An augmented pet collar to help finding missing pets based on crowdsourced data from pet's owners.	AT-ECO-SEN	Screen
Smart-box	An augmented pill dispenser for prescription drugs. It reminds the user to take her medication and automatically re-order drugs.	AT-ECO-SEN	Screen
Abeona Travels	An augmented bus stop shelter that visualises information on the user's trip and service status via a glance-able interface.	AT-ECO-SEN	Ambient
Jømp - bounce to the beat!	An augmented tennis ball to be used as a controller in interactive music games. Comes with multiple play-modes where players have to bounce the ball following specific songs and patterns.	AT-ECO-SEN	Visual, Tangible, Screen
Frablet	An augmented tray that helps keeping track of food stored in the fridge. Data is used to warn the user about expiration dates, to automatically fill in grocery list and produce nutrition statistics for the owner.	AT-ECO-SEN	Screen
WiWater	An automatic watering systems for plants at home.	SEN-ECO	Screen
WorkSafe	A set of wearable sensors for improving safety on construction sites. The system does not allow tools to be operated unless the worker wears all prescribed safety equipment (e.g. helmet, glasses).	SEN-ECO	Tangible
Lightup	An augmented armband to improve safety in kindergartens. It tracks children location and can light up in different colours to allow teacher identify different groups.	AT	Visual
Autotransport	A smartphone app to help people with disabilities to use public transportation services.	ECO-SER	Screen
OpenTaCo (Tangible-Computing)	A platform to engage children in making tangible computing applications for learning.	-	Screen
Assistio	A system that help people with disabilities to find a wheelchair-friendly path to get to a location. The system makes use of data crowdsourced from other sensor-equipped wheelchairs.	AT-ECO-SEN	Screen
iRute	An augmented bus-stop shelter to provide glanceable information about the service.	AT-SEN-SER	Ambient

All concepts developed except two (*RobotDoc* and *OpenTaCo*) feature at least one element of IoT technology. Most of the ideas developed consisted in one or more augmented objects (9/16 of the concepts) working in an ecology (10/16 of the concepts), demonstrating the role of Tiles in promoting *augmentation* as a design strategy and a *thing-oriented* perspective on the IoT (see Section 3). Surprisingly only 3 concepts showed visible use of third-party services and APIs,

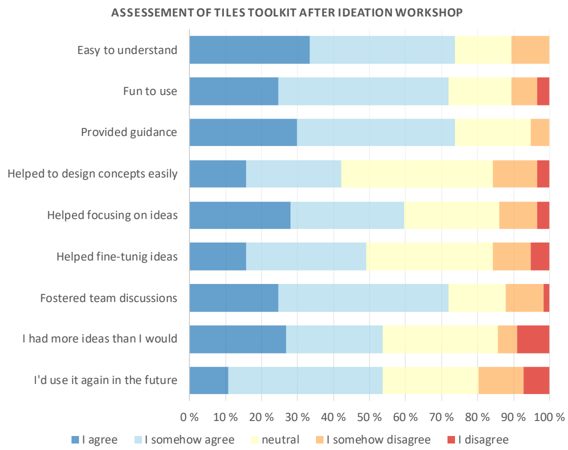

Fig. 3. Students' assessment of the Tiles Toolkit right after the ideation workshop.

suggesting that those components of the IoT were not understood by students or could not be used as "building blocks" for their ideas.

Regarding the type of user interface featured by the prototypes, the majority of the teams (10/16) have designed screen-based interfaces for their concepts. Only a few have considered more novel interaction modality such as voice (1/16), visual (2/16), tangible (3/16) and ambient (2/16). Most of the ideas that rely on screen as UI are based on separate screens such as a smartphone or smartwatch which work in an ecology with the designed augmented objects.

5.3 Analysis Of The Process

The process that led the development of the ideas (Described in Section 3.2) has been primarily evaluated via two surveys. The first questionnaire was administrated right after the Tiles Cards Workshop (*phase 1* of the study). It included questions about acceptance and usefulness of the tool and invited the students to propose improvements. It also explicitly asked the students if they learned anything about IoT using Tiles.

The second survey was handed out after the students presented their final ideas in the idea contest event (*phase 2* of the study), about a month after the Tiles workshop had taken place. The goal of this second enquiry was to ask students a second opinion on the usefulness of the tool, to understand whether they kept using the cards as an aid to develop their idea (although no formal procedure was given to them) or what factors influenced the development of the original idea.

5.3.1 Post Ideation Workshop Assessment. Data from the questionnaires produced in Figure 3 suggests that the Tiles workshop was well accepted among students, although there's a relevant part of the population, ranging between 9% and 24% that considered themselves neutral to the proposed question. Yet more than 70% of the participants considered at least partially the Tiles Toolkit easy to understand and fun to use; meanwhile the Tiles Workshop provided enough guidance and fostered team discussions.

Participants were less positive regarding the outcomes of the workshop, meaning the ideas generated. Roughly only 50% of the students agreed at least partially that the tool helped focusing and fine-tuning the ideas or that they had

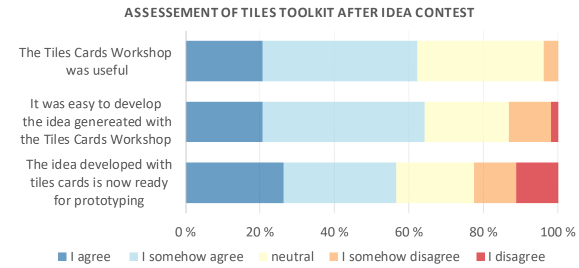

Fig. 4. Students' assessment about the Tiles Toolkit right after the idea contest.

ideas that would not have had otherwise; only 10% of the sample showed strong intention in using the toolkit again in the future.

The open questions featured in the questionnaire: *What was your first reaction to Tiles Toolkit?*, *What was your experience while playing with the cards?*, *What did you like about the workshop?* and *Suggest something you could improve*, helped understanding better such discrepancy in the results.

Twenty-two participants (39% of the sample) answered to at least one open question they felt overwhelmed or stressed by the time-constraints posed by workshop organisers to the different stages of the workshop, characterising their experience with the words: *time pressure*, *stress*, *overwhelming*, *short time.* Participants' feedback were also confirmed by observations from workshop organisers and TAs.

Indeed, due to external constraints imposed by university lessons schedule, the workshop took place during a very limited amount of time. Further, the amount of time reserved for the workshop was reduced even more shortly before its start, accounting for just 2 hours. Yet the stress-factor seemed to have been perceived with either a positive or negative attitude by participants. Asked about their experience, some students reported *"Too small time to come up with a good idea. But with more time it would be more easy"*, *"Stressed out, ended up making a bad idea with too little time"* and *"Limited time forced us to come up with something quickly"*. This might connect participants' lower satisfaction, visible from the data in Figure 3, with the outcome of the workshops and thus willingness to participate again.

On the other side, about half of the participants that felt overwhelmed also showed a positive attitude towards the outcome of the workshop, as confirmed by observations and questionnaires' statements such as *"I was in a rush, but it was fun"* (2 participants), *"Stressing and creative experience!"*, *"Stressful, but fruitful"*.

It seems that participants' positive attitudes towards Tiles built during the workshop. Among the fourteen participant (25% of the sample) who reported a negative first impression about the tool, ten changed towards a positive opinion when asked about their experience after having used the tool. For example, a participant reported her first impression as *"this looks complicated"* while post-workshop she rated the experience as *"fun, felt like a game"*.

A few participants reported on issues interacting with group members or in making the elevator pitch: *"it is a bit difficult to communicate with people you just have met"*, *"our group is holding back our ideas"*.

5.3.2 Post Idea Contest Assessment. Data from the questionnaires filled in after four weeks from the ideation workshop shows that more that 60% of the participants considered the ideation workshop to some extent useful. Likewise, the majority of the students claimed that it was easy to further develop the ideas generated during the workshop.

With this second survey we were in particular interested in understanding whether the teams significantly changed the idea developed during the *phase 1* and due to what. Four teams (25% of the sample) converged to a completely new idea during the time between the workshop and the idea contest; meanwhile the other teams only produced minor changes. Asked about what factors drove the redefinition of the initial idea, participants motivated with the need to *reduce complexity* (8 p.), *enable easier prototyping*, focus on a *narrower or different user group*; while others developed a new idea that seemed *more novel, useful or usable* to them (5 p.).

5.4 Perceived Learning Outcomes

Participants were surveyed about their perceived learning outcome, they were asked whether they have learned something, what did they learn or what obstacles obstructed their learning experience.

Over 57 participants, 28 students (49%) answered they learned something while 29 students (51%) did not report any learning outcome.

Among the reported learning outcomes we could identify three main areas: IoT technology, IoT development process and generic soft skills. Eight participants reported to have learned something about IoT technology, for example *"the exercise [Tiles workshop] made me more aware of the possibilities of IoT"*, *"I learned about different inputs and outputs [devices] and the possibilities of IoT"* and *"[The workshop] opened up perspective on triggers and responses/feedback channels"*. Thirteen participants mentioned IoT development process as an outcome, for example: *"I learned how to come up with new ideas, and how to combine multiple ideas later on"*, *"I learned the different things to consider when developing an IoT solution"* and *"I learned an effective way of brainstorming"*. Finally, four participants reported that the tiles workshop improved their soft skills: *"[I learned] how to better communicate my ideas"*, *"[I learned] efficient working"* and *"[I learned] to reflect"*.

Among the twenty-nine participants who did not reported any learning outcome, six students motivated with time constraints, stress and confusion the lack of perceived learning, e.g. *"I was too distracted by trying to figure out the game, time pressure made us rush"*.

6 DISCUSSION

Teaching IoT is not an easy task, due to the diversity and interdisciplinary of the skills involved, both technical as well as non-technical. Three key IoT aspects that are particularly challenging for students have been identified in this paper in connection with the research questions. The first aspect is related to the variety of components of IoT systems, e.g. sensors, actuators, data sources and networks. Tiles allows all the different components to be utilised as inputs, outputs and in combination with each other, directly during the idea creation stage of the IoT concept. Tiles makes it explicit through the cards and the board presenting the different components involved in IoT solutions, and allows combining them into more advanced combinations. In previous iterations of the IoT course object of the study presented in this paper, the students that did not use any facilitation tool to come up with innovative IoT ideas, often did not include all the components of IoT systems, and focused mainly on the more "visible" and tangible aspects, while not considering more "hidden" aspects such as networks, data sources, etc.

The second key aspect that was explicated in the research questions is tangible interfaces, input and feedback systems. Again, the use of Tiles facilitates a more natural and intuitive way to create human interfaces with IoT solutions, both as input as well as output to the users. From our previous experience with the course, the students tend to identify smartphones and tablets as the main interfacing device for IoT applications.

Finally, the third aspect that was targeted in this study was the usage of design thinking skills, that may facilitate the ideation of innovative IoT solutions. This last aspect, while it can be targeted independently through other teaching courses, is particularly relevant in the context of ideation and innovation of IoT solutions. We have therefore utilised it in combination with the two other research questions, in an organic and integrated way. It is our understanding that instruments such as the storyboard and the idea pitch help students focusing on key aspects of their solutions and critically think on their improvements and implementations.

Following the results here presented, the course staff has decided to employ the Tiles workshop also in the coming year.

7 CONCLUSION

In this paper we have proposed to use the Tiles Toolkit as a experiential learning tool to deliver basic IoT competences to first-year bachelor students in IT topics. While the Tiles toolkit has not been originally created as a pedagogic tool, it has proved to be an easy entry-point to IoT basic competences for the majority of the students in our study; via a fun and engaging experience.

Future work points in multiple directions. We aim at changing the workshop structure to avoid time and stress issues that impacted the acceptance of the toolkit in this study, e.g. providing more examples about the activities in the playbook and experimenting with different timing for the activities. We point at repeating the workshop with students from different programs (e.g. design students) to understand how different backgrounds can affect the ideation process and in turn the characteristics of ideas developed. We will collaborate with university professors to extend our toolkit to provide more formal learning goals and define a learning assessment framework. Finally we will combine ideation tasks with prototyping activities to both increase students' engagement (especially in students with technical background) and extend the range of expected learning outcomes.

Acknowledgements. We thank participants of our study and Oslo Metropolitan University TAs and staff for providing support to the workshop.

REFERENCES

[1] Tina Aspiala and Alexandra Deschamps-Sonsino. [n. d.] Know-cards. Learn. Play. Collect. (). http://know-cards.myshopify.com/.

[2] Luigi Atzori, Antonio Iera, and Giacomo Morabito. 2010. The Internet of Things: A survey. *Computer Networks*, 54, 15, 2787–2805.

[3] Paulo Blikstein. 2013. Gears of Our Childhood: Constructionist Toolkits, Robotics, and Physical Computing, Past and Future. *Proceedings of the 12th International Conference on Interaction Design and Children*, 173–182.

[4] Barry Burd, Lecia Barker, Monica Divitini, Felix Armando Fermin Perez, Ingrid Russell, Bill Siever, and Liviana Tudor. 2017. Courses, Content, and Tools for Internet of Things in Computer Science Education. In *the 2017 ITiCSE Conference*. ACM Press, New York, New York, USA, 125–139.

[5] Robert M Capraro, Mary Margaret Capraro, and James R Morgan. 2013. *STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach*. Springer Science {&} Business Media.

[6] Changeist. [n. d.] Thingsclash. *thingclash.com*.

[7] Jeannette Chin and Vic Callaghan. 2013. Educational living labs: a novel internet-of-things based approach to teaching and research. In *Intelligent Environments (IE), 2013 9th International Conference on*. IEEE, 92–99.

[8] Dalibor Dobrilović, Z Čović, Ž Stojanov, and Vladimir Brtka. 2013. Approach in teaching wireless sensor networks and iot enabling technologies in undergraduate university courses. In *Proceedings of the 2nd regional conference Mechatronics in Practice and Education, MechEdu*, 18–22.

[9] Futurice. [n. d.] IoT Service Kit. (). http://iotservicekit.com.

[10] Rosella Gennari, Alessandra Melonio, Mehdi Rizvi, and Andrea Bonani. 2017. Design of IoT Tangibles for Primary Schools: A Case Study. In *Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter*, 26.

[11] Francesco Gianni and Monica Divitini. 2018. Designing IoT Applications for Smart Cities: extending the Tiles Ideation Toolkit. *IxD&A*, 35, 100–116. http://www.mifav.uniroma2.it/inevent/events/idea2010/doc/35_5.pdf.

[12] Francesco Gianni, Lisa Klecha, and Monica Divitini. 2019. Tiles-reflection: designing for reflective learning and change behaviour in the smart city. In *The Interplay of Data, Technology, Place and People for Smart Learning*. Hendrik Knoche, Elvira Popescu, and Antonio Cartelli, (Eds.) Springer International Publishing, Cham, 70–82. isbn: 978-3-319-92022-1.

[13] Dimitrios Glaroudis, Athanasios Iossifides, Natalia Spyropoulou, and Ioannis D. Zaharakis. 2018. Investigating Secondary Students' Stance on IoT Driven Educational Activities. In *Ambient Intelligence*. Achilles Kameas and Kostas Stathis, (Eds.) Springer International Publishing, Cham, 188–203. isbn: 978-3-030-03062-9.

[14] Eva Hornecker and Jacob Buur. 2006. Getting a grip on tangible interaction. In *the SIGCHI Conference*. ACM Press, New York, New York, USA, 437–446.

[15] Letizia Jaccheri and Guttorm Sindre. 2007. Software engineering students meet interdisciplinary project work and art. In *Information Visualization, 2007. IV'07. 11th International Conference*. IEEE, 925–934.

[16] David A Kolb. 2014. *Experiential learning: Experience as the source of learning and development*. FT press.

[17] Treffyn Lynch Koreshoff, Tuck Wah Leong, and Toni Robertson. 2013. *Approaching a human-centred internet of things*. ACM, New York, New York, USA, (Nov. 2013).

[18] Treffyn Lynch Koreshoff, Toni Robertson, and Tuck Wah Leong. 2013. Internet of things: a review of literature and products. *Proceedings of OzCHI*, (Nov. 2013), 335–344.

[19] Gerd Kortuem, Arosha K Bandara, Neil Smith, Mike Richards, and Marian Petre. 2013. Educating the internet-of-things generation. *Computer*, 46, 2, 53–61.

[20] M Kuniavsky. 2010. *Smart Things: Ubiquitous Computing User Experience Design*. Elsevier Science.

[21] A. Mavroudi, M. Divitini, F. Gianni, S. Mora, and D. R. Kvittem. 2018. Designing iot applications in lower secondary schools. In *2018 IEEE Global Engineering Education Conference (EDUCON)*. (Apr. 2018), 1120–1126. DOI: 10.1109/EDUCON.2018.8363355.

[22] Anna Mavroudi, Monica Divitini, Simone Mora, and Francesco Gianni. 2018. Game-based learning for iot: the tiles inventor toolkit. In *Interactive Mobile Communication Technologies and Learning*. Michael E. Auer and Thrasyvoulos Tsiatsos, (Eds.) Springer International Publishing, Cham, 294–305.

[23] Roberto Minerva, Abyi Biru, and Domenico Rotondi. 2015. Towards a definition of the Internet of Things (IoT). *IEEE Internet Initiative*, 1.

[24] Simone Mora, Francesco Gianni, and Monica Divitini. 2017. Tiles: A Card-based Ideation Toolkit for the Internet of Things. *To Appear in Proceedings of Desigining Interactive Systems Conference DIS*, (Apr. 2017), 1–12.

[25] D A Schon. 1987. *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*. Wiley.