Arenas for Innovative STEM Education: Scenarios from the Norwegian University of Science and Technology

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Abstract *Although promoting the uptake of STEM subjects is considered a priority in today's knowledge-based economy, attracting students' interest in these subjects has proved challenging. To this end, the paper proposes a series of educational scenarios that on the one hand incorporate ubiquitous computing, mobile computing and the Internet of Things, and on the other hand are designed in a way that attracts creative students which might not be particularly interested in STEM. The paper concludes with some generalised principles of these scenarios and future work. It is specifically addressed to STEM educators since it provides insights in curriculum development that does not treat the STEM subjects in isolation.*

Keywords: ubiquitous computing, mobile computing, Internet of Things, educational scenarios, 21st century skills

1. Introduction

There is a growing body of research about emerging technologies, such as, ubiquitous computing, mobile computing and the Internet of Things (IoT). The proliferation of these niche technologies may offer a wide range of unprecedented learning opportunities, which currently remain unexplored. In parallel, there is a growing market need for jobs that fall within this professional domain and it has been suggested ([3], [8]) that recent developments in research, technology and policy support this need for the development of ubiquitous open-source hardware and software, and low-cost digital fabrication tools/products. Yet, a question raised is: where the developers of these technologies and related products will come from, what skills will they need and how will they be trained [5]. To compensate for this problematic situation, this paper seeks to shed some light into the training aspect by presenting a small number of educational scenarios that incorporate these technologies (collectively mentioned as UMI), cultivate relevant competences and are addressed to upper high school students.

2. Background

In an effort to keep up with the complexities of today's world, there is a shift evident in education and training from the fragmented subject matter knowledge to a more holistic approach which embraces transversal competences and is more interdisciplinary. This shift is lately documented both in educational research and in educational policy and practice worldwide. For example, there is a pledge from Finnish policymakers nowadays to remove school subjects from the national curricula in order to enable students studying in an interdisciplinary format which serves better the needs of the citizen of the 21st century. In parallel, a growing body of researchers agree that, also within the STEM domain, the borders of subject matter knowledge are becoming blurred. For example, Blikstein [3] suggests that teaching programming in isolation does not add much in terms of learning gains, compared to teaching it in tandem with engineering and design. In addition, he points out that “there are calls everywhere for educational approaches that foster creativity and inventiveness” (p. 2). This section presents research projects and initiatives that cater for such kind of learning in the context of school education.

2.1. The UMI-Sci-Ed project

The purpose of the UMI-Sci-Ed (Exploiting Ubiquitous Computing, Mobile Computing and the Internet of Things to promote Science Education, http://umi-sci-ed.eu/) European project is to exploit state-of-the-art technologies to promote science education among youngsters aged 14-16 years old. In the context of this project, UMI technologies emerge both as educational means but, most importantly, as support mechanisms for developing careers in pervasive, mobile computing and Internet of Things (IoT). Regarding the latter, the orientation of the project is entrepreneurial and multidisciplinary in an effort to raise young boys’ and girls’ motivation in UMI science education.

The project is funded by the European Union (under the Horizon2020 program) and will be completed on May 2019. Technological institutions, academic organizations and Communities of Practice active in formal or semi-formal learning activities that revolve around UMI form the network of participants and partners in the project. Its core objectives are the following:

- Novel educational services - develop and evaluate a training mechanism for UMI to help students acquiring relevant competences
- Career consultancy services - develop and sustain Communities of Practice for UMI and materials to motivate students pursuing a career in related domains
- Supporting software tools through the project online platform
- Supporting hardware tools through the delivery of a dedicated hardware kit

The supporting software tools will be organised in a platform which will include, among others, a set of educational scenarios (including the necessary hardware and software tools) that will convey both technological and pedagogical approach to future users. In the next section, we present a small sample of such scenarios developed and supported by the researchers of the Department of Computer and Information Science at the Norwegian University of Science and Technology (NTNU).

2.2. Other related projects and initiatives

There is a growing interest among researchers and practitioners on digital fabrication and the ‘maker movement’ in education. They are both rooted in constructionism and have the potential of developing students’ 21st century skills [11]. In fact, there is an analogy that exemplifies their potential of acting as ‘disruptive technologies’, especially in learning and teaching programming. The analogy involves the Logo computer language which also acted as a catalyst of change by making computer coding a means for the creation of powerful ideas in mathematics, engineering, and science ([3], [16]).

Kodeløypa (http://www.ntnu.no/skolelab/kodeloypa) is one of six established science frameworks at NTNU. Together with the other frameworks (Mathematics, Energy, Physics, Chemistry, Biology), the Computer Science Framework Kodeløypa is an outreach program to all 10th years grade classes in the region of Trondheim, Norway. It is sponsored by Norwegian industry and public administration actors, such as Trondheim Municipality, and the association of Norwegian Engineers (TEKNA). In its activities, Kodeløypa uses Scratch, as a visual programming environment for kids or Scratch for Arduino (S4A). The latter is an extension to Scratch, and provides functionality to control the behaviour of physical artefacts, like robots or art installations. As a hardware platform, Arduino is used due to its smooth operation with Scratch [15]. The first scenario presented in the next section is devoted to Kodeløypa.

Open Discovery Space (ODS, http://opendiscoveryspace.eu/) was a project aiming to engage teachers from more than 2000 European schools, parents of schoolchildren, instructional designers, and educational policy makers in web-based communities ([1], [18]). In these communities, stakeholders can access, create, share, and rate educational resources and scenarios. That is, the scenarios are available online in the community as demonstrators and are populated with relevant educational resources [18]. Within this context, a number of exemplar interdisciplinary and innovative scenarios were created, focusing on technology, entrepreneurship and innovation.

Make World (http://www.makeworld.eu/) is an Erasmus+ project providing tools and methodologies for STEM primary education. A focus is placed in digital literacy along with skills such as computational thinking, interpersonal communication and teamwork. The main components of 'Make world' are: 1) a digital platform integrating modules for the creation of educational resources, learning analytics visualisation and social network, 2) educational resources to develop and assess computational thinking and ICT competences in the classroom and 3) guides for participating teachers and parents.

2.3. Educational context in Norway

Norwegian students spend three years in lower secondary school (13-15 years old) and three years in upper secondary school (aged over 16 years old) where they can choose to follow a general education path or a vocational education path. Regarding programming in Norwegian schools, it is quite limited across the different stages of education. In lower secondary schools, an elective course related to coding is taught since fall 2016 in a limited number of schools. In upper secondary schools there are more options for a specialisation on programming and computing.

A large survey called 'the Lilly study' was conducted on 2011 among upper secondary pupils in Norway (general education path) concerning the factors that actually matter on their science choices [4]. The findings of the 'Lilly study' indicate, among others, that many science students expect interesting and personally meaningful lessons and that there is a challenge to meet this expectation. Also, it concludes that school science is not able to make students interested in the wide range of applied science careers available. Finally, the 'Lilly study' stresses the importance of continuously introducing students to interesting topics and career opportunities.

3. Scenarios

This section briefly describes four UMI-Sci-Ed scenarios. The first two scenarios are described in terms their rationale and main phases, and their added pedagogical value, including a justification on how the scenarios can support CoPs [19] that revolve around UMI-Si-Ed. These fields are inspired by a scenario template which was created for the purposes of the project by its coordinator, who is the Computer Technology Institute and Press "Diophantus" in Greece (http://www.cti.gr/en/). The last two are emerging scenarios, and, consequently, are described more loosely. Regarding the scenario design methodology, the scenarios are based on constructionism [17]. They are real world scenarios designed to encourage collaboration and knowledge sharing as well as practice for achieving skills competence.

3.1. Scenario 1: "Joyful Engagement and Creativity in Learning Science"

Rationale and main phases: The task of programming a game is an archetypical example of complex problem solving. Instructors ask the students to produce interactive installations that tell a story about a theme that is important for the students themselves. For example, some groups could focus on pets, or television shows. Students should make the installations interactive, have concrete outcome, and include tangible interactive experiences like sensors, motors and actuators, as research has found that providing students with guidelines in a discovery learning endeavor can improve the quality of outcome [7]. Throughout the process, students are guided and assisted by an artist, a STEM educator, a game developer, an expert in creative reuse of artifacts, as well as by a senior researcher in instructional technology.

In the first phase, students are supported by the artist to create the physical characters (see Figure 1, i). Then, the game developer offers a Scratch tutorial, which includes sprite animation, change costume, movement, sound and graphic effect. Following, students compose a storyboard and start creating scenes in Scratch. The story written by the students is now programmed in Scratch. Sensors are used to establish interactivity between the audience and the created characters (see Figure 1, ii). Next, the game developer continues with a second part of Scratch tutorial which includes change scenes, synchronization (broadcast and when-receive), check the value of a variable, actions from sensors.

Students use Scratch to bring their stories alive (see Figure 1, iii) with the assistance of the artist, the STEM educator and the game developer. The conceptual connections from the digital environment of Scratch to the physical world by means of light, sound, and touch sensors are implemented by homemade sensors connected to the PC by Arduino boards. At the final stage, students complete their artworks, and they decorate a room for installing and presenting their work (see Figure 1, iv). The instructors assist students whenever they ask for help. The researcher records children's activities through photographs, interviews and observation reports in order to assess the effectiveness of the learning scenario.

Figure 1 Kodeløypa scenario in action

Added pedagogical value: Digital artifacts have the potential to make the symbolic and abstract manipulations involved in creative procedures more concrete and manageable for youngsters ([6], [9]). In our approach, we chose open source software, namely 'Scratch' and 'Scratch for Arduino' to illustrate both collaborative and creative learning. Both software are media-rich programming languages that allow youth to design and share programs in the form of stories and games. Regarding the creation of CoPs that revolve around this scenario, each pilot site will include students from one or more schools, around which a broader community will be built encompassing local (e.g., teachers, parents, public bodies and organizations), but also remote (i.e., connected through the Internet) participants (e.g., experts, creators, other schools). The scenario can foster partnerships between different groups of stakeholders through: 1) the exchange of ideas and combinations of different areas of expertise, 2) the exchange of know -how in UMI technologies in conjunction with teaching and learning competences, and 3) the dissemination of best practices.

3.2. Scenario 2: DesignAthon - "Apply Rapid Design Ideation to Broaden Participation in Computing"

Rationale and main phases: Hackathons have become a popular activity for ideation, design and development in a variety of STEM domains, like technology and manufacturing to mention few. One of the most common qualities of a hackathon is software development and common application areas are social good and social entrepreneurship. Hackathon empowers, excites and engages students due to the competitive nature and intrinsic motivation that promotes [13]. The DesignAthon leverages them by assigning a design challenge that solves a real-world problem; in a team-based challenge, with time pressure, using rapid design ideation methods, with tangible rewards, among and against valued peers, and with a live audience.

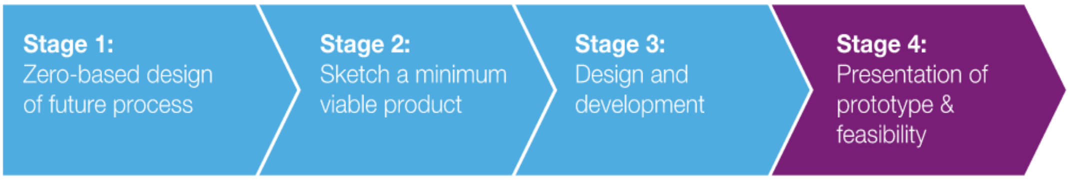

Figure 2 Stages of the DesignAthon

Added pedagogical value: The term hackathon is a portmanteau of "hack" and "marathon," originating as an exploratory exercise in software development that extends over a period of time to address an innovation challenge using a variety of teams. Hackathons have received enormous attention during the last years, since they present both social and professional opportunities to young students, who are tasked with making a functional prototype to pitch to investors for a prize, working on it for one or two days. Hosted within corporate, academic, or community-based settings. Many of these hackathons are organized spontaneously, attracting a hundred or so hobbyists whereas others, such as the student-organized hackathon, attract thousands of school or college students. Hackathons with their come-one-come-all ethos, have emerged as the new forum for networking, learning, and engaging. Hence this type of activity was selected, due to its: a) social and professional aspects, b) flexibility, in terms of its duration and implementation, and c) empowering innovation and entrepreneurial behavior.

The scenario serves the vision of the UMI-Sci-Ed project to form around students CoPs that will foster STEM education by developing real solutions for real problems. The envisioned CoPs comprising parents, teachers, experts, and other stakeholders will form a supportive environment for young innovators. Eventually it is intended that the scenario and the CoP that will revolve around it will foster students' idea generation and construction abilities, and help them to apply STEM skills in important real-life challenges.

3.3. Scenario 3: "Foster the transition from design to programming through IoT"

The proposed solution integrates IoT components to control the behavior of physical objects. The scenario has two parts and each part has certain stages. The first part is associated with the design challenge (design an IoT-infused design solution), whereas the second part is associated with the programming challenge (implement the design solution). It is facilitated by two instructors, one focusing on the design aspects and one focusing on the programming aspects. The rationale is that the students are exposed to diverse aspects associated with both fields and cultivate 21st century skills while they follow the whole life-cycle of an IoT-infused solution, from ideation up to its evaluation. The structure of the scenario is briefly presented below:

- Part I: Design about IoT
    - Phase 1: Welcome session
    - Phase 2: Introduction to IoT mostly through examples from everyday life
    - Phase 3: Introduction to the design challenge
    - Phase 4: Student group-work to design the IoT-infused scenario of use
    - Phase 5: Student groups present their design solution
- Part II: Programming about IoT
    - Phase 6: Transition from design to programming
    - Phase 7: Hands-on activity to run a programming task (using basic predefined scenarios)
    - Phase 8: Students flesh out their scenarios

The scenario is making use of the TILES inventor toolkit for interactive objects which is described in [14].

3.4. Scenario 4: Summer school on UMI-Sci-Ed

The purpose of this summer school is in line with the goal of the UMI-Sci-Ed project and it is twofold: to engage youngster with what the UMI-Sci domain has to offer and to inspire them to follow a career path within this particular domain. Consequently, it will incorporate a wide range of educational activities that expose participants to the diverse aspects of this niche domain, are entrepreneurial and multidisciplinary. In addition, during the summer school the students will have the opportunity to receive career consultancy that will advise them in terms of professional orientation. The latter will involve understanding the profile of professionals that work currently within the domain of pervasive, mobile computing and IoT; but also to present future professional possibilities. This is crucial because, since the domain is still in its infancy, the identification of the professions that are closely related to this domain can be difficult, especially when projections in the future need to be made. Finally, the activities of the summer school will try to compensate for the fact that women are underrepresented in STEM professions [2].

4. Conclusions and future work

In this paper, we have exemplified how ubiquitous technologies can promote student engagement and provide opportunities for novel and creative interactions within STEM

[10]. Systems and artefacts support students in their UMI activities, mediate and transform the interactions with the physical world. The scenarios presented in this paper encourage systems thinking, since they enable students to see the (conceptual) connections between the systems and the artefacts that interact to form a whole. In addition, the suggested scenarios embrace digital citizenship by incorporating design, engineering and programming aspects interweaved with the development of transversal skills (creative thinking, collaboration, co-creation, reflection). The scenarios activities, as designed, do not presuppose prior programming knowledge and skills. Also, programming skills are not developed in isolation but rather in the context of other scientific domains. These underlying principles have the potential of transforming the way we teach and learn programming in the classrooms. Today's children are digital natives and it is easier to prepare them for the next wave of computing, by helping them to relate programming to other scientific domains and co-create at an early stage. In turn, the suggested approach can motivate them in becoming computing entrepreneurs.

Due to its highly-innovative nature, evaluating the learning effectiveness of such endeavour in a systematic way is challenging. Regarding future work, we need a proper evaluation framework that will assess the impact of such activities in terms of learning gains. In addition, we need to take into account the knowledge that has been already accumulated in the Communities of Practice that are active in the UMI-Sci-Ed domain. Preliminary results from the stakeholders' analysis show that they operate mostly in semi-formal learning settings and less in the context of formal, school education. There is a lack of empirical studies that actually show how CoPs work and are sustained in the educational community ([12], [18]), let alone in semi-formal learning settings.

5. References

[1] Athanasiadis N., Sotiriou, S., Zervas, P., & Sampson, D. G. (2014). The open discovery space portal: A socially-powered and open federated infrastructure. In Digital Systems for Open Access to Formal and Informal Learning (pp. 11-23). Springer International Publishing.

[2] Beede, D. N., Julian, T. A., Langdon, D., McKittrick, G., Khan, B., & Doms, M. E. (2011). Women in STEM: A gender gap to innovation. Economics and Statistics Administration Issue Brief, (04-11).

[3] Blikstein, P. (2013). Digital Fabrication and 'Making' in Education: The Democratization of Invention. In J. Walter-Herrmann & C. Büching (Eds.), FabLabs: Of Machines, Makers and Inventors. Bielefeld: Transcript Publishers.

[4] Bøe, M. V. (2012). Science choices in Norwegian upper secondary school: What matters?. Science Education, 96(1), 1-20.

[5] Callaghan, V. (2012, April). Buzz-boarding; practical support for teaching computing, based on the internet-of-things. In 1st Annual Conference on the Aiming for Excellence in STEM Learning and Teaching, Imperial College, London & The Royal Geographical Society (pp. 12-13).

[6] Cassell, J.: Towards a Model of Technology and Literacy Development: Story Listening Systems, Journal of Applied Developmental Psychology 25(1), 75-105 (2004)

[7] Cohen, E. G., Lotan, R. A., Abram, P. L., Scarloss, B. A., & Schultz, S. E. (2002). Can groups learn?. Teachers College Record, 104(6), 1045-1068.

[8] Gershenfeld, N. (2007). Fab: the coming revolution on your desktop--from personal computers to personal fabrication: Basic Books (AZ).

[9] Giannakos, M. N., Divitini, M., Iversen, O. S., Koulouris, P. (2015). Make2Learn: Fostering Engagement and Creativity in Learning through Making. In Workshop of Making as a Pathway to Foster Joyful Engagement and Creativity in Learning (Make2Learn) (p. 1).

[10] Giannakos, M. N., & Jaccheri, L. (2013, June). What motivates children to become creators of digital enriched artifacts?. In Proceedings of the 9th ACM Conference on Creativity & Cognition (pp. 104-113). ACM.

[11] Kafai, Y., Fields, D., & Searle, K. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. Harvard Educational Review, 84(4), 532-556.

[12] Kirschner, P. A., & Lai, K. W. (2007). Online communities of practice in education. Technology, Pedagogy and Education, 16(2), 127-131.

[13] Lewis, B. A., Parker, J., Cheng, L. W., & Resnick, M. (2015, September). UX Day Design Challenge Hackathon to Apply Rapid Design Ideation to a Practical User Experience Challenge. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 59, No. 1, pp. 304-306).

[14] Mora, S., Divitini, M., & Gianni, F. (2016, June). TILES: an inventor toolkit for interactive objects. In Proceedings of the International Working Conference on Advanced Visual Interfaces (pp. 332-333). ACM.

[15] Papavlasopoulou, S., Giannakos, M. N., & Jaccheri, L. (2016, June). Creative Programming Experiences for Teenagers: Attitudes, Performance and Gender Differences. In Proceedings of the 15th International Conference on Interaction Design and Children (pp. 565-570). ACM.

[16] Papert, S. (1980). Mindstorms: Children, computers, and powerful ideas. Basic Books, Inc.

[17] Papert, S., & Harel, I. (1991). Situating constructionism. Constructionism, 36, 1-11.

[18] Riviou, K., & Sotiriou, S. (2017). Teachers' Professional Development in the Theme of Competence-Based Learning—Impact and Lessons Learnt. In Research on e-Learning and ICT in Education (pp. 283-297). Springer International Publishing.

[19] Wenger, E. (2009). Communities of practice. Communities, 22, 57.