Entrepreneurial Education Based on Physical Computing and Game Development

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Abstract. This paper presents a pilot evaluation study, focusing on a variety of mechanisms to successfully integrate the learning of physical computing, entrepreneurship and game development. First, we introduce a workshop design framework developed as part of the European project DOIT (Entrepreneurial skills for young social innovators in an open digital world). We then reflect on the implementation of the workshops over the course of two months, including a group of 24 youths between 15 and 16 years old. The workshops are evaluated by measuring students' changing self-efficacy in a pre-post design. The interpretation of these changes is further complemented by interviewing the workshop facilitators. While we can find a small increase in students' self-efficacy, our findings also show the importance of facilitating students' ability to thrive in a project-based workshop setting, where part of their learning experience hinges on their ability to establish their own learning goals and making design decisions in the face of uncertain outcomes.

Keywords: Physical Computing, Entrepreneurship, Game Development, Entrepreneurial Learning, Self-Efficacy, Games with a Purpose.

1 Introduction

According to the annual Horizon report, forecasting trends in education, experiential learning facilitated through making and hands-on projects will gain in importance over the coming years [1]. In this paper we investigate how students' self-efficacy changes when learning about game development and making prototypes [2], involving open source hardware. Maker education, just as making [3] combines a huge variety of technologies such as low-tech tools (hot glue, cardboard or rubber bands) and more advanced components such as programmable micro-boards, sensors capturing changes in the environment (noise, temperature, air particles, etc.).

This short enumeration of possible components for a prototype already reflects the inherent complexity due to the sheer number of technologies and their possible combinations. One strategy is to teach basic skills first and prepare learners systematically for more complex tasks [4]. The 'basics first' approach relies on the hope that learners will fill in the gaps more easily when having a broader overview of related materials. Alternatively, rather than having dedicated courses for physical computation, there is the suggestion to integrate this knowledge in established subjects such as computer science [5]. In this paper we propose that physical computing could also be integrated with art or entrepreneurship subjects and combine our argument with the analysis of a pilot and the resulting evaluation of a workshop series for learners (15 to 16 years old) in a higher vocational-technical school, specializing in business and commerce. The pilot we present is part of the European project DOIT (Entrepreneurial skills for young social innovators in an open digital world). This project runs for 3 years until October 2020 and includes 13 partner organizations from 11 countries.

The overall objective of the DOIT project is to develop and test a program framework for early entrepreneurial education. Hence on a pilot level we designed a series of workshops to develop an entrepreneurial project addressing a societal challenge related to either healthy lifestyles, better living conditions or environmental protection. These umbrella topics were derived from the UN sustainable development goals (SDGs) with a particular emphasis on turning comprehensive SDGs into concrete actions [6]. Entrepreneurship education has many objectives including the development of a diverse set of skills, attitudes and knowledge ranging from increased self-efficacy, self-awareness, resilience in face of uncertainty as well as creativity [7]. There is little doubt about the worthiness of pursuing these objectives, however, many facets of educational systems such as highly structured and packed curricula, reliance on grades as ultima ratio for enticing sufficient effort on students side, the message that failure is a loss of time rather than a necessary part of learning or the focus on individual performance rather than team results make it difficult to foster an entrepreneurial spirit among youths [8]. However, there are already many formats such as problem or project-based learning in 'maker education' [9, 10] that can serve as a starting point for combining physical computing and other subject matters. The pilot presented in this paper combines open source hardware programming, game development and an entrepreneurial project, planning for the transformation of the prototype into an actual product. Technologically, the prototypes developed by the students involved a system on the chip (SoC), sensors for environmental data and user interface elements indicating the status of the gadget (LEDs and a small displays 3 x 2 cm).

2 Related Work: Entrepreneurship Learning, Game Development and Physical Computing

For our research we conceptualized learning as a self-regulated, project- and problem-driven activity [10]. Based on this understanding, we aim to analyse learning activities triggered by the needs of students' projects, being interdisciplinary and collaborative in nature [11–13]. Figure 1 (left) displays how the context of an entrepreneurial project defines roles and activities for developing a game as a product, which is then implemented as a first prototype using physical computing. Hence, learning about hardware becomes a means to an end, embedded in prototyping an entrepreneurial game. Overall, we find that combining different areas of expertise is also a way to engage youths with different interests, degrees of previous knowledge as well as different support structures at home [14], an important aspect if learning technologies are to be inclusive.

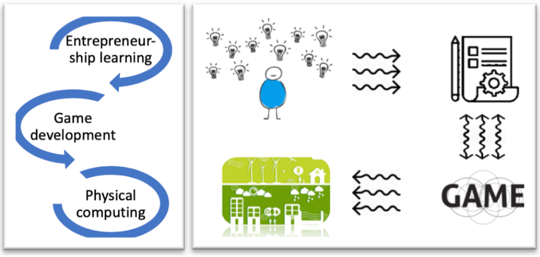

Fig. 1. Knowledge domains required (left) and flow of activities (right)

The right side of the figure presents the more dynamic aspect of the learning process, where there is a continuous back and forth between new ideas, game concept, technical feasibility and economic considerations. Making development decisions subject to economic considerations is important since entrepreneurship in itself is based on explorative value creation, opposed to routine value creation [7]. Hence it is not always foreseeable how much investment needs to go into materials and development time. Once more, this highlights the multifaceted range of skills future entrepreneurs develop when facing the uncertainty inherent to messy problems.

2.1 Entrepreneurship Learning

There are different ways of conceptualizing entrepreneurship education, emphasizing either entrepreneurial attitudes or entrepreneurial knowledge. Combining both, Lackeus [15] suggests a progression from experiential learning (i.e. *going through* an entrepreneurial learning process), to more cognitively oriented learning about entrepreneurship (e.g. *learning about* business canvas, risk management, pricing strategies) and finally, specializing in a particular task (e.g. *learning for* project controlling, innovation management etc.). In our pilot we were mostly interested in changing skills and attitudes but found it necessary to outline concrete task areas for the students, such as working on game ideas, the technical implementation of the game, elaborating a business and marketing plan. In some teams 'product packaging' emerged as an additional area due to the related effort in terms of time for designing and crafting the product representation.

2.2 Learning through Game Development

The importance of gaming for learning or problem solving has been widely reflected in the literature on serious games and games with a purpose (GWAPs) [16, 17]. Gaming and game development helped to make computer science more accessible to a diversity of learners [18] who would otherwise perceive programming as a rather dry content. GWAPs combine the appeal of game interfaces with the power of human interpretations to accomplish that have no automatic solution yet, e.g. image recognition or capturing subjective perceptions of noise or air quality. GWAPs are also increasingly used for environmental data collection tasks as envisioned in our pilot.

Time spent in games has been steadily on the raise. In 2019 mobile devices have been the primary gaming device and the average gamer played about seven hours per week [19]. The question is whether this time can, at least partially, include learning components. However, the idea that gaming can be repurposed for learning needs has to be taken with caution, since most people engage in GWAPs because they wish to be entertained and not so much because they desire to solve problems or improve the availability of data [ibid.]. Hence, it is necessary that game mechanics prompt players to test their knowledge or to reflect upon their actions, while still preserving an entertaining experience. Gros [16] lists 15 game mechanics and their equivalent learning mechanisms. For example, typical game strategies can be based on role playing, collection of tokens, answering riddles, managing resources or striving for the next level or a higher status. Finally, evaluation studies have shown that game development contributes to several literacy competencies (e.g. computer, media and information literacies) or skills such as creativity, self-confidence and empathy [20].

2.3 Physical Computing and Learning

Similar to digital game development, designing and programming physical computing systems has been mainly researched in the context of engineering or computer science education [5]. There is a huge variety in how physical computing can be understood, ranging from programmable bricks in the 1980s (e.g. LEGO/Logo) to more sophisticated systems such as the Lilypad, Arduino kits for e-textiles or Computer on a Board products such as the RaspberryPi. This trajectory has been analyzed by Blikstein [21], the author highlighted a number of important developments in how learning with and through physical computing was approached over the last 40 years. First, understanding the 'medium' was always part of learning the 'message' in that choosing a medium would inherently enhance learners' expression in some ways while limiting them in others [22]. For example, programming on a PC is limited to the peripheral devices of that PC; keyboard, mouse, camera etc., whereas the programming experience of microboards is more readily enhanced by connected sensors, LEDs or motors. Blikstein [ibid.] makes the point that physical computing provides learners with a new way of expressing themselves; learners design their own devices. Katterfeld et al. [23] argue that digital fabrication and physical computing contribute strongly to the development of self-efficacy, creativity and the experiential unity of body and mind, much like we need to ride a bike rather than hear about riding a bike. Similar to Blikstein, these authors emphasize the facilitating nature of an 'object-to-think-with'.

3 Research Objectives and Methodology

In line with our focus on integrating various field of knowledge (entrepreneurship, making and game development), our research objective was to explore the effects of multidisciplinary project work on entrepreneurial skills and attitudes. Our project looked into eight evaluative dimensions: self-efficacy, creativity, teamwork and collaboration skills, dealing with uncertainty, perseverance, empathy with others and their needs, motivation and sense of initiative and planning and management skills. The first two were assessed quantitatively following a pre-post data collection design and the remaining six were evaluated qualitatively. Similar dimensions are also assessed within the entrepreneurship competence framework [24].

Since reporting on all dimension would go beyond the space available in this publication, we focus on the analysis of self-efficacy, measured before and after the workshop series through a survey. For the complementary analysis of changes in learning processes over time we used the transcripts of facilitator interviews.

The *survey* was constructed based on published scales [25–28] with adaptations on the item level. Self-efficacy was conceptualized as students' judgements of their own capabilities, their problem-solving capacities and how they saw themselves in comparison to others.

The *interviews* took about 45 min and focused, among other things, on how well the overall workshop structure (presented in the next section) supported the elaboration of a socially relevant problem statement providing the foundation for prototyping a solution. These interviews provide valuable insights on workshop dynamics ('How would you describe the motivation over the course of the workshops?', 'How would you describe teamwork among students? Or 'How well did students deal with roadblocks and persevered in their efforts to overcome them?' etc.).

Overall, we followed a case study evaluation method, where a single site provides the data as described above. Case studies are suitable methods when the phenomenon to be researched, is complex and the number of potentially relevant variables is prohibitive for an experimental design or when there is value in obtaining a more fine-grained understanding of the phenomenon under research [29]. Next we describe shortly the design and implementation of the workshop series and present then our findings evaluating changes in self-efficacy as well as related qualitative remarks.

4 Designing the Workshop Series

Physical computing education has been researched in a variety of contexts; one distinction often made, is the degree of embeddedness and interdisciplinary perspectives taken when learning through physical computing [30]. This distinction has also framed the design of our workshop series, combining entrepreneurship, game development and physical computing. Since most youths have an emotional link with playing games, making a game was a suitable context to present workshops involving entrepreneurship, environmental thinking and physical computing in a compelling way. The entrepreneurship dimension of the workshops was already a relatable topic for them, since they were attending a school with an orientation on commercial subjects, so that product design and marketing were tasks where they could benefit from skills they already had gained. As outlined in section 2.1, our workshops are based on Lackeus' [7] model of early entrepreneurial education, adapted in Table 1. The table presents each step by step its objectives and some example activities, specific to our pilot study.

Table 1. Program elements of early entrepreneurial education (EEE), based on [9]

EEE elements	Objectives	Short description
1. Sensitize (Do it because you can)	- build up confidence among youths - showcase possibilities	- learners were shown working prototypes from previous workshops - discuss the use of games outside the entertainment and leisure sector - students analyze existing games in a holistic way (ease of learning the game, target market etc.) - build and test a first open hardware setup on a breadboard, flashing the microcontroller (MCU)
2. Explore (Do what matters)	- explore links between sensor data and social or environmental problems (e.g. noise or air pollution) - explore basic types of games	- brainstorming exercise (e.g. quantity over quality, no criticism, speculations are welcome) - mind map with a problem statement at the center and related keywords and dot points - identify different rules for winning a game (i.e. defining the winning conditions)
3. Work together (Do it together)	- structure the teams' internal collaboration - integrate the knowledge of external experts	- clarifying different possible roles within a team, working on game ideas, technical implementation, business plan and marketing as well as packaging - as external experts we had a professional game designer and a game producer joining some of the workshops
4. Create & Iterate (Start it now)	- make a first prototype and aim for multiple revisions	- at the core of this step is the testing of the game with specific hypotheses in mind (flow, functionalities, engagement, duration etc.)
5. Reflect (Do it better)	- reflect upon experiences - improve future design- and collaboration decisions	- sharing information, i.e. synchronizing the status of the product in its various dimensions (business aspects, new features, marketing etc) at the beginning of each workshop - continuously aligning students' expectations with the time they had left to finish the product
6. Scale up and share it (Inspire others)	- test the assumptions behind the business model	- present final prototypes and associated business plans at the school - collect feedback from potential users, e.g. regarding game idea, features and envisioned price

There were six workshops in total. Steps 1 and 2 were addressed in the first two workshops, steps 3 to 5 (*collaborate*, *iterate*, *reflect*) were simultaneously addressed in workshops 3 to 5 and the last step (*sharing*) was part of a school presentation during the last workshop. Although attempting to scale a solution is an important part of entrepreneurship education, this last step was little addressed due to the limited time available for the workshops. The following two sections provide a more in-depth account of game and gadget development.

4.1 Game Development

Starting point for our game development were mobile and social game concepts [31]. The mobile aspect refers to the wearable nature of the game gadget which allows players to move outside the classroom and the social aspect is given by developing a collaborative game that is played in a group. Furthermore we also opted for 'social play' since the group experience provides a more positive, fun experience, compared to solo-play, where more competitive game concepts dominate [32]. For our purpose we kept all the data on the game device, however sensor data and associated locations could have been shared with a cloud application so that the data as a by-product of gaming could be visualized and interpreted by players. Students were introduced to various game mechanics (cf. section 2.2) and could adopt elements that fitted best their initial game scenarios. Together with the support of a game developer, students discussed how they wanted to go about four game elements:

(1) *Roles*: A role describes a personality within the game that symbolizes a core aspect of the game (e.g. roles associated with light or clean air).
(2) *Behavioral modes:* 'Behaviors' describe possible actions attached to a role. Behaviors included attacking, defending, escaping or changing the status of other players.
(3) *Datafication*: Since the game was to make use of sensors, eventually leading to the collection of environmental data, player activities should generate data or be influenced by data. For example, one group used the amount of solar energy captured by a device to determine the speed of the catcher when playing tag.
(4) *Winning condition:* The ultimate goal of the game is described by the winning condition. For example, in a game of tag the game is over when there is nobody left to be caught.

4.2 Gadget Development

For developing the gadget, we chose a mix between instruction and experimentation: (1) we used two introductory sessions on open source hardware components and the Arduino IDE; and (2) each team had access to a tutor they could approach for specific hard- or software related changes they wanted to make. Additionally, during the first session, students got to play first with fully assembled gadgets (involving distance sensors, microphones and smart LEDs). The purpose of seeing finished gadgets was to set some expectations about what would be possible throughout the workshop series and what not. They then learned about changing code snippets in the Arduino IDE and flashing the gadget, which would show a different behavior as a consequence.

During the second workshop student groups would then assemble their own gadgets in small teams and at this stage they were also introduced to voltages and currents and why some of the components had to be protected by resistors. Later on, the tutors guided student groups in their approaches to specific developments, i.e. if a desired change was unlikely to be finished in one workshop, the team had to decide whether this was worth it and what consequences this delay might have on other tasks to be accomplished. Hence the teams would often attempt to find a simpler approach or drop the desired feature altogether. The facilitators' task was then to moderate that process as part of the entrepreneurial learning experience, i.e. the management of human resources and time as a limited input variable to every entrepreneurial project. However, beyond facilitating entrepreneurial learning, facilitators had also an important role in presenting themselves as partners in a dialogue rather than as a source of authority, cutting short the explorations of youths.

5 Evaluation Results: Self-efficacy and Learning Experience

Our workshop series included 6 events over the course of 2 months. 25 students participated (38% male and 62% female) and 24 students gave their consent to use their data for research purposes. The workshops took close to 3 hours with the exception of the fifth workshop dedicated to testing and iterating the game, which took 5 hours. All workshops were supported by three to four facilitators. The self-efficacy survey (cf. section three) was handed to the students during the first and last workshop in order to measure any changes in the perception of their self-efficacy. The result was a very moderate increase by 0.95 of the sum of means and a decrease of the standard deviation by 0.95. A paired sample t-test showed that the difference of pre- and post means was not at a significant level. Figure 2 shows the individual means of the items asked in the self-efficacy survey. Numbers 1 to 5 on the y-axis indicate the level of (dis-)approval with the statements listed on the x-axis. The '3' indicates the 'undecided level', everything above means approval and every value below implies disapproval.

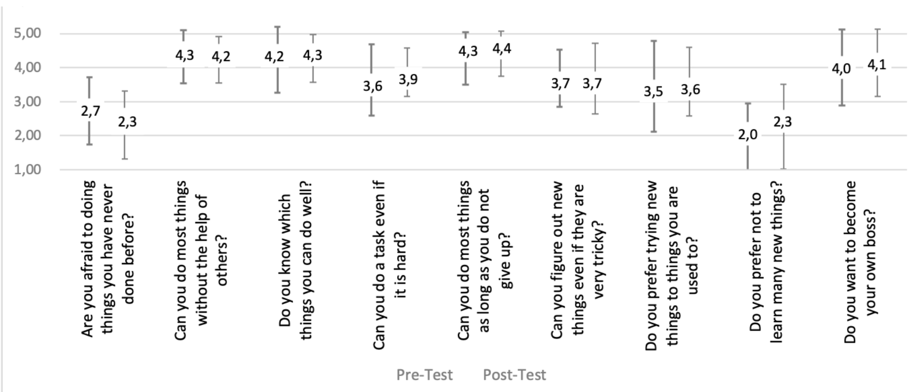

Fig. 2. Items on the self-efficacy questionnaire (N=22)

The small changes are also reflected on the item level. The largest changes of 0.4 and 0.3 can be observed for the first and the penultimate item, referring to a decrease in 'not being afraid of new things' and a less pronounced disapproval of 'rather not having to learn many new things'. Although these are positive developments as they go in the right direction of becoming a self-confident, skilled entrepreneur, we would have hoped for a more distinct showing of differences. Further analysis is needed to better understand the multitude of influencing factors. One hypothesis we have is related to the number of successful experiences students have had, i.e. actually mastering the challenge of the workshop in a way they felt satisfied with.

5.1 Facilitators' Critical Reflection on Student's Self-efficacy

Both facilitator interviews were transcribed, and their content was analyzed according to a set of emerging categories such as 'Prototyping', 'Embracing new things', 'Perseverance' or 'Collaboration' and 'Co-design'.

Embracing New Things. Although students had experience with board games or playing catch in general, none of them had previous knowledge with the Arduino IDE, MCUs or systematic game development. Still, with support, they made amendments to their game gadgets and produced their own game accompanying play cards (Figure 3). However, in light of the results on self-efficacy in figure 2, open source hardware and game development can be complex so that students might have perceived their work as small contributions compared to what experts could do.

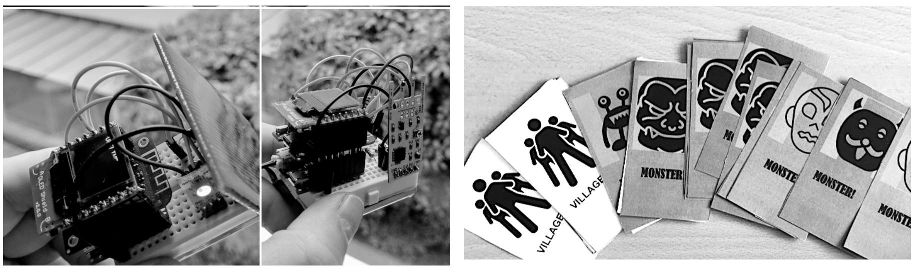

Fig. 3. Game gadget with solar shield (left), gadget with wind sensor (middle) and game cards (left)

So, in some instances the facilitators needed to stop ongoing work on one component (e.g. game design) so that there was enough time left for actually testing the game and get a first affective feedback. The students were continuously seeing things they could improve further, however, the facilitators stressed that the actual testing of their game prototypes, even though still very raw, would help them to prioritize which shortcomings had to be addressed and which ones could be postponed.

Perseverance. There were several points in the development of the gadget where we realized that a change was needed. For example, they only found out in practice that the air quality sensor did not work reliably if moved or that the noise sensor had only a very limited range within which noise levels could be captured meaningfully. As a consequence, we replaced the air quality sensor with a wind sensor and the team working with the noise sensor had to keep in mind that their game should only make use of close range sources of noise (e.g. a motor, speakers in front of a shop or air conditioning units) rather than aiming at ambient or background noise. Figure 4 (left) shows two students taking notes on the energy absorption of the solar shield under different light conditions. According to the amount of energy caught by the device, players were allowed to switch from walking to running and hence be more efficient catchers. However, finding suitable thresholds took a number of iterations: updating and testing the new game modalities (Figure 4, right).

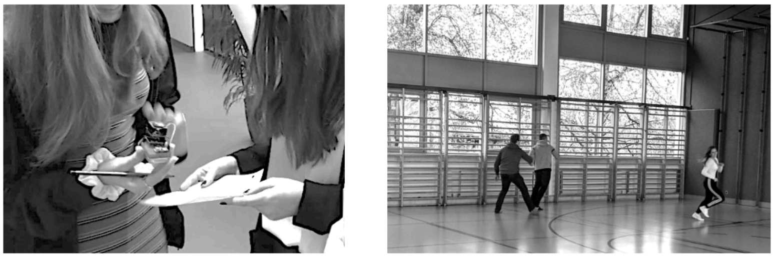

Fig. 4. Exploring the solar gadget (left) and testing game modalities (right)

Entrepreneurship and Management Skills. During the first workshop students started with drawing a mind map in order to catch the 'every day meaning' of the data they were collecting with the device. For example, in the case of sunlight, the mind map resulted in the following concepts: sun supports the generation of vitamin D, light is a precondition for oxygen production via plants, sun lets evaporate water and causes rain, too much sun can cause skin cancer or solar cells transform sun light into electrical energy. These thoughts had an immediate impact on the emerging game structure, with students postulating (1) monsters thrive in dark places such as parking houses, tunnels, subways or narrow alleys; (2) monsters' power growths or shrinks according to exposure to light, (3) the equivalent of exposure to light is the sun light captured by the game gadget, only available to hunters of monsters.

From the facilitators' point of view, it was important that students also became aware of using games not just for entertainment but also as a vehicle to create social awareness of a societal challenge. They also recognized that game development is a whole industry and that some of the business skills they had learned at school could be applied there. Towards the end they also understood various ways in how data can be valuable in themselves, as a side-product of the game.

6 Conclusion

With this paper we emphasized the importance of embedding even simple things such as the basics of electronics or programming in a meaning-providing framework such as an entrepreneurial project or developing a game with a purpose. We started our paper arguing that if 21st century skills (critical thinking, creativity, communication and collaboration) and an entrepreneurial spirit are core objectives of today's education, then this needs to be reflected in the way education is conceived and facilitated. This is not necessarily something new, since project-based learning has heralded interdisciplinarity and a focus on practice since its beginning. Our experiences confirmed that the bigger picture of a project is more motivational than an isolated skill or fact. However, in practice this bears the cost of losing a useful structuring mechanism when a systematic introduction to the foundations of a technology would be a natural scaffold for teaching physical computing. Implicit to changing the way we introduce youth to new technologies is the need to support learners in using their own evolving problem understanding as a guide to self-organize their learning.

For future work we are looking into further optimizing the workshop experience by experimenting with what Blikstein [21] calls 'selective exposure', i.e. consciously deciding which aspects of a technology to show or to hide and thereby managing the growing complexity of multi-level systems such as physical computing gadgets.

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