STEM education post-graduate students' training in the eCraft2Learn ecosystem

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Abstract. *The eCraft2Learn research project aims to introduce digital fabrication and maker movement in formal and informal education settings. In the context of the eCraft2Learn pilots we organised during the academic year 2017-18 two experimental sessions of six hours each in the eCraft2Learn lab for student-teachers who attend the post-graduate course STEM Education. This paper reports the educational methodology and the technologies used in the experimental sessions, the projects that trainees first observed being developed by the young students and then realised by themselves, and finally the evaluation of this intervention through trainees' reports and the "homework" assigned to them.*

Keywords*: STEM Education, Educational Robotics, Teacher Training*

1. Introduction: The eCraft2Learn ecosystem

The eCraft2Learn research project (H2020, 2017-18, https://project.ecraft2learn.eu/) aims to introduce digital fabrication in formal and informal education settings and to support a paradigm shift in educational robotics and STEAM education from "black box" and silo products to the "white box" paradigm where learners become "makers" of transparent computer-supported artefacts.

In the context of the eCraft2Learn project, the Constructivist "learning by making" methodology (Papert&Harel, 1991) is strongly related to the "do-it-yourself" (DIY) philosophy and is the driving force behind the eCraft2Learn pedagogywhich argues for an education that goes beyond knowledge acquisition and aims to introduce the "maker movement"(Blikstein 2013) in education. The maker movement has emerged recently in education with the great promise to democratize access to opportunities for learning by making and the 21st century digital making technologies (Alimisis et al. 2017).

The eCraft2Learn project recognises a learning potential in digital fabrication and DIY technologies assuming they are coupled with proper learning methodologies such as learning by making. Hence, the 21st century learning ecosystem should be designed in a way that can actively engage students with learning tasks, hands-on activities and with each other and finally provide learning experiences that promote young people's creativity, critical thinking, teamwork, and problem solving; skills that are essential in the workplace of the 21st century (Schon et al, 2014).

In the framework of the eCraft2learn project local labs are established and run project pilots in Athens and Joensuu (Finland) in formal and informal education settings. In addition to student pilots, the eCraft2Learn labs are used for training teachers who act later as coaches in student pilots. Usually, teacher training takes place in classes and labs established and run in universities and training centres in a rather academic way. The eCraft2Learn labs may offer two advantages: first, an authentic environment for STEAM teachers to train in a "FabLab" that provides opportunities for personal fabrications (Gershenfeld, 2007) and second, can allow the trainees to experience a direct observation and an immediate contact with young students while they are doing their projects in the lab.

Having these potential advantages in mind, we organised during the academic year 2017-18 two experimental sessions of six hours each in the eCraft2Learn lab for student-teachers who attend the post-graduate course STEM Education (run in cooperation between the Universities of Patras and Athens, http://stemeducation.upatras.gr). This paper reports the educational methodology and the technologies used in the experimental sessions, the projects that trainees first observed being developed by the young students and then realised by themselves, and finally the evaluation of this intervention through trainees' reports and the "homework" assigned to them.

2. The eCraft2Learn educational methodology

The eCraft2learn methodology includes five stages: imagine, plan, create, program, share. Students in small groups of 3-4 persons ideate about the project they wish to develop, plan their projects, create their robotic artefactsworking collaboratively, program their artefacts using visual programming environments and finally share their projects. Sharing takes place in the lab through presentations made by one student from each group in the end of each pilot session. Students are provided also opportunities to present their projects in public events (i.e. the Athens Science Festival 2018) and if possible with online communities (i.e. Thinginverse (https://www.thingiverse.com/).

However, the methodology is not recommended to be followed in a serial way; students often while programming come back to creation for improving their artefact and continue again with programming; or while creating their artefact come back to planning making new choices and altering their initial plan and so on. More importantly, the eCraft2learn methodology of the 5 stages should not be conceived as a "cook recipe" but rather as a tool to foster students' imagination, creativity, problem solving and sharing. The projects that are addressed to the students integrate aspects of real, relevant and meaningful learning, provide links to different subject/cognitive areas and the real world, authentic contexts and interdisciplinary scenarios that can create opportunities for engaging learning experiences (Alimisis, 2013).

3. The eCraft2Learn Technologies

Whereas software has already become increasingly more accessible to a broader audience, this is not always the case for hardware, where complexity and high costs of materials have been considerable barriers to learning. The selection of the hardware components has been done to minimize the cost, the size, the power consumption and maximize the reusability of materials and electronics. The hardware core of the eCraft2Learn ecosystem includes:

- A set of card-sized microcontrollers (Raspberry Pi 3, ASUS Tinkerboards) serving as experimental development computers (workstation units) for the students. These units are equipped with TFT screens and keyboard-mouse sets.
- Arduino boards connected with a variety of electronic components and/or the Raspberry Pi 3 units. The Arduino boards are the core module inside the majority of the designed artefacts.
- Various DIY electronic components (e.g. photoresistors, potentiometers, servomotors, LEDs) that are used in conjunction with the RPi3 and the Arduino units.
- Various DIY modified parts brought from home during a recycling process, like broken toys, plastic bottles, pieces of paperboard, computer fans, speakers, etc.
- A 3D printer used for preparing customised physical components of the artefacts.

– The necessary power supply equipment like power banks, small solar panels, electricity mains.

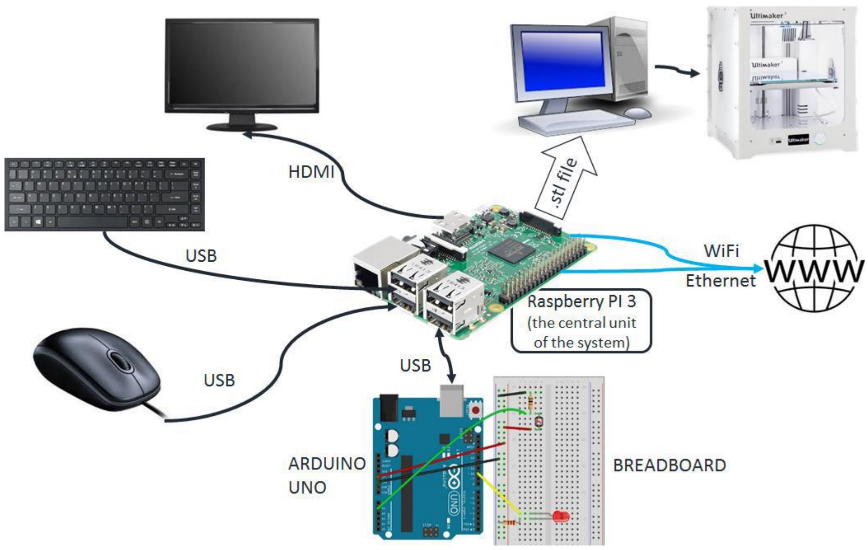

Figure 1. The hardware core of the eCraft2Learn ecosystem

The adoption of this solution, amongst the other benefits, it tackles the problems related with the vast software and hardware diversity characterizing a typical school lab and reduces the overall energy consumption of the lab.
The software tools selected for the eCraft2Learn ecosystem meet most of the following characteristics:

– pedagogically meaningful;
– runnable on the above-mentioned hardware environment;
– reduced need for installation/update of software elements;
– friendly user interface;
– easy integration with the external hardware;
– open source,
– free or at least low cost.

A unified user interface (UUI) has been designed to bring together the proposed software tools that the eCraft2Learn ecosystem builds upon.

The basic software tools are described in the list below:

– The visual programming toolSnap! and its extension Snap4Arduino (http://snap4arduino.rocks/), that allows RPi3 - Arduino interoperation, custom visual block creation, provides easily exportable/importable .xml code, cooperates with many web-based tools for useful data exchange and can offer child-friendly programming interfaces to Artificial Intelligence cloud services like speech and image recognition (Kahn & Winters 2017).
– Visual Tools like the MIT Scratch (https://scratch.mit.edu/) and additional components such as the Scratch GPIO for using the General Purpose Input/Output pins (GPIO) that the RPi3 natively has or the Scratch4Arduino (http://s4a.cat/).
– The Ardublock tool that works as a component of the Arduino SDK (http://blog.ardublock.com/engetting-started-ardublockzhardublock) and offers the capability of visual programming of an Arduino unit in a stand-alone way.

Ardublock offers a mature and stable set of blocks for visual programming the Arduino in a stand-alone way.

- The “native” Arduino SDK (IDE, compiler and library). Although it's true that software tools seem to privilege a block-based orientation, considered more suitable for rapid prototyping and in terms of usability, the Arduino SDK (and the wiring language it is using) is somehow the basis of Arduino programming and in many cases a prerequisite software package for many other visual programming tools.
- Visual programming capabilities of Pocket Code and/or MIT App Inventor (http://appinventor.mit.edu/explore/) tools should be usedto program tablets and/or smart phones to interact with Arduino or RPi3 units, via Bluetooth or WiFi interfaces.
- 3D printing software allowing the design of models to be printed like the web based Tinkercad (https://www.tinkercad.com/).
- 3D printing software for the machine acting as manager of the printer like the Cura (https://ultimaker.com/en/products/cura-software) or the lightweight linux platform based OctoPrint (https://octoprint.org/)

4. STEM education post-graduate students join the eCraft2Learn pilots

According to the project plans, during the academic year 2017-18 each of the four eCraft2Learn ecosystem pilot sites (two in Finland and two in Greece) trained about 25 young students aged from 13 to 17 years old. The topics to be covered and the artefacts to be created were selected in a way to encourage girls and not only boys to get involved, and, in general, students of different characteristics and skills. More specifically, the ecosystem tends to promote the link between science, technology, engineering and math with arts, to encourage the inclusive participation of students with all levels of technical skills and also to reduce the technology-triggered gender divide, hence attracting more girls to the technical arena in all areas. The overall approach is intended to lead to the demystification of robotic technologies and free the creative capacities of the learners (Alimisis 2013).

The training sessions with the STEM Education post-graduate student-teachers took place in the pilot site at Technopolis City of Athens (informal context). The 1stsession involved 11 student-teachers who were attending the 2nd year of the course in Nov 2017 and the 2nd one 17 student-teachers who were attending the 1st year of the course. Since the two groups visited the lab in different dates, they were involved in two different projects depending on the agenda of the specific pilot site.

More specifically, the first session was concurred with the “lighthouse project” and the second one with the “sensor-driven robotic bug (or pet or car) project”. In both cases the student-teachers were first introduced in the eCraft2Learn concept and methodology, then they were invited to walk around the lab observing the children working on their project and to join a group and work as members of the group. This task lasted for 3 hours and then, after the departure of the young students, they were separated in groups of 3-4 persons and had a 3 hours practice realising the same project from scratch. Thesession was concluded with a plenary discussion summarising experiences and impressions from the whole session.

4.1 *The lighthouse project*

The student-teachers were invited to follow the same methodology they had already observed implemented by the young students in the first part of the session. We present briefly here this methodology:

Ideation stage: student-teachers discuss within their groups questions such as, what is a lighthouse? Why people are making lighthouses? Have you ever visited a lighthouse; in a lighthouse without a keeper how the flashing light is turned on when it is getting dark? How it is turned off in daylight in order to save energy?

Planning stage: students plan within their groups: how can you make a model of a lighthouse? What materials and devices you need? How can you make the lighthouse to blink?

Creation stage: students make a lighthouse miniature with materials and devices available in the lab. They take a photo of their model and upload it to their group folder.

Programming stage: students use Ardublock or Snap4Arduino software to make their lighthouse to blink (a led is alternating from on to off state) every one second. Then, they make it to blink at different rates by modifying the on and off period duration. After that they are helped to make their Arduino board to read and inspect analogue values first from a potentiometer and then from a photoresistor, the latter standing for daylight and darkness conditions. Finally, they are challenged to put all these together and make the lighthouse to blink only at darkness using their hand as curtains to change the light level. When they finish, they are invited to prepare a demo of their project to show to their peers.

4.2 ***The sensor-driven robotic bug project***

Similar methodology with the above 5 stages was followed in the other session with the sensor-driven robotic bug project. Briefly, the project aims at creating autonomous robotic artefacts that can intercept their surrounding environment. The student-teachers were encouraged to investigate how to combine distance sensors (ultrasonic ones – like bats or dolphins) and gear motors with the Arduino board and program simple gesture-controlled behaviours for their robotic artefact. Alternatively, they could try to program it to avoid obstacles. The robotic construction was made of a power bank, an Arduino board, two servomotors and a small breadboard hosting a driving circuit. An Ultrasonic distance sensor was connected to the Arduino board to detect the distance from an obstacle or a target.

Using the Ardublock software the students were invited to program the robot to move back and forth according to its distance from their hand, to keep moving or turn a bit every time it goes close to an obstacle or other similar behaviours they might wish to realise.

During the design and the implementation stages of both hardware and software parts students had the opportunity to tackle with several “real world” issues like: how to make easy-to-inspect physical connections of the components by using wires of proper color, why to use motor driving circuits and not to directly connect the servomotors to the Arduino outputs, why is so necessary to use “if-then-else” blocks to define “behaviours” for both activity and tranquility periods of robot movement, what is the meaning of using composite logic conditions and delays while handling the consecutive distance sensor readings. During this project, students created more than one variant of robot “behaviours” with more or less impressive results.

5. Evaluation

The evaluation of thetraining sessions and their impact on student-teachers was based on the analysis of the “homework” that was assigned to participants in the end of each training session. The assignment required from student-teachers to recall their experiencesfrom the eCraft2learn lab and write a report focused on two topics/questions:

- Evaluate the eCraft2Learn environment: does it contribute and which way to STEM education? Which skills you think it develops for kids?
- Describe the role of the teacher you have seen in the eCraft2Learn lab. Isthisdifferentfromthetraditionalroleofteacher? Whichdifferencesyouhaveseen?

Moreover, they were asked to design their own STEM activity that might be realized in the eCraft2Learn environment. Their work had to include:

- Scenario of the STEM activity,
- learning objectives,
- students’ role,
- teacher role,
- technologies to be used,

Finally, they had to create a simulation of an Arduino-based circuit and relevant code to bring the circuit in life in the frame of their scenario using the simulator Tinkercad Circuits (https://www.tinkercad.com/#/?type=circuits&collection=designs).

The students submitted their work online using the platform https://eclass.gunet.gr/

5.1 Findings from students’ reports

Whenstudent-teachersentered the lab for first time, which wasin full action with children doing their projects, they were rather surprised to find out that “*There was no table, no books and no seat. [The trainer] was sitting with the children in the groups and if it wasn’t for the age difference that helped us understand who the teacher is, we would have thought there was no teacher, at first glance.*”.

The participants in general appreciated the eCraft2Learn ecosystem as a valuable environment to foster STEM Education; in their own words “t*here was a lot of hands-on activity on, a real making atmosphere with a lot of trial and error, shifts in the roles of the students, good collaboration; they were also noticed frequently to take initiatives to change their initial plan/design...”.*They found that “offers valuable opportunities for learning”; they recognised that “*the educational journey is more importantthan the accomplished tasks”.* They found useful the scenario given to the children because *“inspiration through pre-developed scenarios is needed to help students see the main functionalities and the available tools and to start imagining their own more (or not) complex projects*”.

Regarding the role of the teachers they appreciated the transformation of their role to that of a coach: “*We have seen most of the teachers acting as real coaches during the pilots, sitting next to the students and becoming members of the group, helping discretely when it was needed, answering questions from students, pointing out resources on the web, encouraging and motivating students to work in inventive ways*”.

Others recognised that transformation of teacher role is always a challenging task. They criticised aptly the few cases of teachers who were observed to act as traditional instructors either giving some short lecture or taking a leading role and substituting students in their work especially with circuits assembly and programming tasks; in students' words "*The children of the observed group did not participate in the construction of the circuit and the code for the lighthouse's activity. Instead, the circuit and the program were built by the group's trainer...*".In another casethey observed that "*There was a difficulty regarding the code writing; because of time limitation and increased difficulty, it was delivered to them as a typical lesson by the trainer*". Another teacher again was criticised as acting in an behaviouristic way: "*he under took the task of the circuit creation and the programming task as well; His role in that case was the transmission of ready knowledge…*". They identified also imbalances in children's work "*it was observed that the group put more emphasis in the construction of the object (lighthouse) than in the creation of the operational program and circuits, which were also requested for this process*".

Students' comments and criticism in general provide positive indications that they have understood well the concept of the eCraft2Learn ecosystem and are in close connection with the spirit of STEM Education. Their involvement in the specific workshop seems to have deepened their understanding of STEM Education, enriched their conceptions about STEM teacher's role including that of a coach and possibly inspired a more pluralistic STEM teaching repertoryenhanced with the eCraft2Learn technologies and pedagogy.

5.2 Findings from students' scenarios and simulations

In the 2nd part of their assignment the students have designed interesting learning scenarios and simulations that might be realized in the eCraft2Learn environment. The scenarios have addressed different STEM topics in an interdisciplinary way. The proposed learning objectives are closely related to STEM Education putting emphasis rather on skills development than on knowledge acquisition. The description of students' and teacher's role is clearly influenced by their eCraft2Learn experience. They suggest an active role for students in the frame of a project-based methodology where students are assigned the role of designer, maker or problem solver. Teacher's role is suggested as that of the facilitator of student's learning resembling much the role of the eCraft2Learn coach.

Using the simulator Tinkercad Circuits, students have created successful simulations of Arduino-based circuits and the relevant code to bring the circuits in life in the frame of their scenarios

Two indicative examples of students' scenarios and simulations are presented below:

"*A blind pedestrian wants to cross a street in the city center. Make traffic lights appropriate for blind pedestrians adding a buzzer that, when light turns green for pedestrians, will emit a specific sound for blind people to cross the street either automatically or after pressing a button*" (Fig. 2)

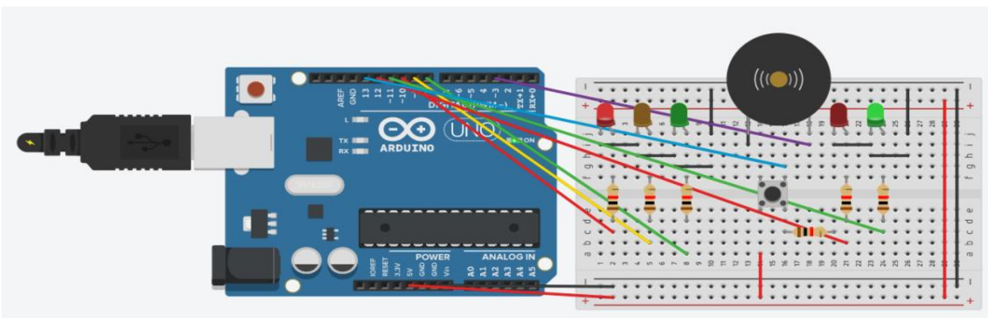

Figure 2. Tinkercad simulation of traffic lights with Arduino board, breadboard, LEDs, buzzer, button

Another interesting scenario simulated (Fig. 3) the automatic parking aid for cars equipped with a distance sensor informing the driver for the distance from the wall. Circuit with Arduino board, buzzer and ultrasonic sensor programmed to produce sound waves of different frequency depending on the distance of an object detected by the sensor.

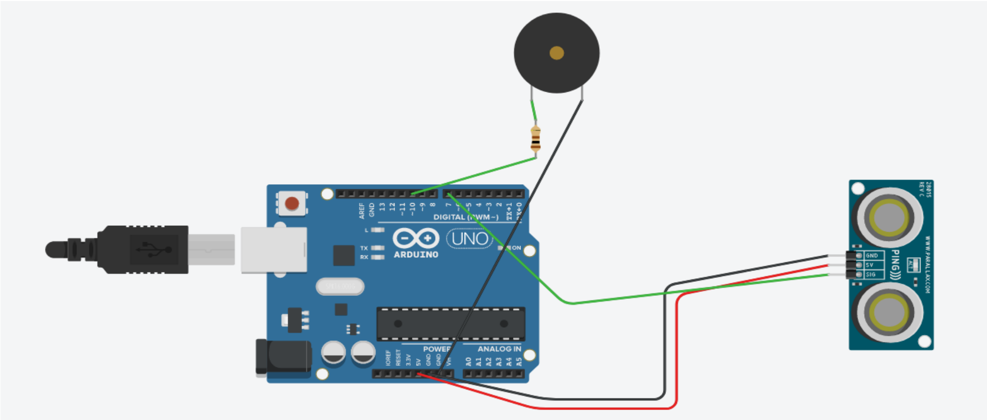

Figure 3. Tinkercad simulation of automatic parking aid for cars: circuit with Arduino board, buzzer and ultrasonic sensor

6. Conclusions

In the training events reported in this paper, student-teachers have undertaken several roles. They have first acted as observers and co-learners with children in the eCraft2Learn lab doing STEM projects focused on robotics. Next to this, they have made their own practice doing the same projects from scratch. Then they have become evaluators of the eCraft2Learn ecosystem in critical mind and finally designers of their own STEM scenarios and simulations.

Checking students' reports and the whole work, we have found that this training experience was useful for student-teachers in multiple ways. They have experienced through physical participation an authentic maker space (the eCraft2Learn lab) which offers a broader conception of STEM methods and tools; they have observed directly young students (13-17 years) working on STEM projects and had the opportunity to co-work with them which is a valuable experience since allows deeper understanding of the way young students work while doing STEM projects; they have made self-reflections reporting and evaluating their experiences from the eCraft2Learn lab which helps to assimilate and hopefully adopt good practices they have seen in the lab and finally to argue in critical mind against practices not compatible with the principles of STEM Education.

Though these claims need more evidence and systematic evaluation, the experimental training events reported in this paper have provided encouraging indications that STEM teacher training might be benefited if it combines the academic teaching with direct experiences and practical training in authentic maker spaces, preferably with the parallel participation of young makers in the lab. In addition to this, STEM student-teachers' work in maker spaces like that reported in this papermight be considered to become an integral part of their final thesis.

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