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Kids make their own robots: good practices from the eCraft2Learn project

I bambini creano i propri robot: buone pratiche dal progetto eCraft2Learn

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Abstract

This paper focuses on the small-scale pilots with learners that were carried out in Greece in the frame of the eCraft2Learn project including activities that aim at reinforcing learning by making in STEAM education. In the context of the pilots, 13-17 years-old students worked with digital fabrication and making technologies for creating robotic artefacts. In the framework of an appropriate pedagogical model that supports different steps highly interlinked, the teachers and students were invited to work together and explore the fun and the challenges of the making process using the eCraft2Learn learning ecosystem. In this line, a number of good practices were identified related to the facilitation of the learning process, the support of the ideation, the boosting of the *can-do* attitude, the embracement of failure and the encouragement towards sharing projects, experiences and ideas. Most of these practices are reflected in video-recorded episodes accessible through this paper.

Keywords: educational robotics; maker movement; eCraft2Learn project.

Abstract

Il presente lavoro documenta le prime applicazioni realizzate in Grecia, nell'ambito del progetto eCraft2Learn, dedicato a rafforzare la formazione nell'area STEAM con il learning by making. Studenti tra i 13 e i 17 anni hanno applicato tecnologie digitali e tecniche artigianali per creare artefatti robotici. Nell'ambito di un modello pedagogico appropriato, in grado di supportare diversi passi altamente interconnessi tra loro, i docenti e gli studenti sono stati invitati a lavorare insieme e ad esplorare gli aspetti di divertimento e di sfida relativi al processo creativo utilizzando l'ecosistema di apprendimento eCraft2Learn. Nel progetto sono state identificate una serie di buone pratiche relative alla facilitazione del processo di apprendimento, al supporto all'ideazione, al rinforzo di un atteggiamento positivo, all'accettazione del fallimento e all'incentivazione della condivisione di progetti, esperienze, idee. La maggior parte di queste pratiche sono state video registrate e sono rese accessibili attraverso il presente articolo.

Parole chiave: robotica educativa; maker movement; progetto eCraft2Learn.

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1. Introduction

Robotic technologies if coupled with proper learning methodologies such as suggested by Constructivism (Piaget, 1974) and Constructionism (Papert & Harel, 1991) can provide learning experiences that promote young people's creative thinking, teamwork, and problem-solving skills (Alimisis, 2013), the essential skills necessary in the workplace of the 21st century (Fullan & Langworthy, 2013). Studies report a potential impact on learners, both in subject areas (Physics, Electronics, Mathematics, Engineering, Computer Science and more) and on personal development including cognitive, meta-cognitive and social skills (Alimisis, 2013; Alimisis, Moro & Menegatti, 2017; Moro, Alimisis Iocchi, in press).

However, robotic technologies are often used in education in a way reinforcing old methods of teaching (Alimisis, 2013). Mere demonstrations of robots or teacher-guided approaches for step-by-step assembly of one or few predefined models treat children rather as passive consumers than creative makers and active learners, and cannot support this way the development of creativity, entrepreneurship, critical thinking, collaboration and problem-solving skills. In addition to this, the commercial robotics kits come often with ready-made robots, inherent lock-in mechanisms, closed hardware and/or software, or with cookbook-like recipes for the assembly of predefined models. This situation results in "black boxes" for children that cannot promote deep understanding of what is a robot and how it works (Alimisis, 2013; Alimisis & Kynigos, 2009).

This paper claims that the future of educational robotics should be envisioned in close connection with the maker movement which has emerged in education with the great promise to democratise access to opportunities for learning by making, for skills development and for fostering positive attitudes and openness to making for the future generations of citizens (Blikstein, 2013; Schon, Ebner & Kumar, 2014). Having its roots in Papert' s constructionism (Papert & Harel, 1991), the maker movement offers a vision for a robotics education that will enable learners to make their own robotic artefacts using the "white box" paradigm where learners become "makers" of their own transparent robotic artefacts (Alimisis, 2013).

In the next sections, this vision for educational robotics is exemplified with exemplary projects and good practices emerged in pilots with learners that were carried out in Greece during the eCraft2Learn project (eCraft2Learn, 2018). Finally, the paper concludes with pinpoints and key takeaways for teachers and researchers.

2. Description of the eCraft2Learn Pilots in Athens

2.1. The context

The informal eCraft2Learn lab was established in the Technopolis City of Athens (Figure 1), a former Gas Factory that was restored to an industrial and cultural park, an ideal place for hosting the eCraft2Learn initiative (https://project.ecraft2learn.eu).

The old machinery remained in the place creating an inspiring scenery with strong conceptual symbolism to making and engineering practices.

Figure 1. The informal pilot site in the Technopolis City of Athens.

The 1st pilot round was conducted with 24 students 13-17 years old. The same number of students participated in the 2nd pilot round. During the 1st pilot round 6-8 teachers were active in the eCraft2Learn lab undertaking the role of the coaches. During the 2nd pilot round 4-5 teachers were active in the eCraft2Learn lab. All the teachers had attended training courses before the pilots with the children (Alimisi, Loukatos, Zoulias & Alimisis, 2018).

The 1st pilot round lasted 30 hours (Autumn 2017-Winter 2018) and the 2nd pilot round 20 hours (Spring 2018) on Saturday mornings. The duration of the 2nd pilot was shorter because the students were more familiar with the eCraft2Learn tools and thus they entered directly into the making process working on their own projects.

The Figure 2 summarizes the key information regarding the two pilot rounds in the Athens pilot site.

	1st pilot round	2nd pilot round
Total participants	24 students (13-17 years old)	24 students (13-17 years old)
No. of teachers	6-8 per class	4-5 per class
Team work approach	Work in teams of 3-4	Work in teams of 3-4
Time	3 hours every Saturday	3-4 hours every day for a week
Total duration	30 hours, November 2017-February 2018	20 hours, June 2018

Figure 2. Information about the pilots.

2.2. The eCraft2Learn methodology

The first projects that the students were involved in were proposed by the teachers, who exploited the list of the indicative scenarios introduced during their teacher training (Alimisi et al., 2018). Easy to start with projects were selected with the aim to smoothly familiarize the students with the available tools. As the sessions were progressing the teachers were reducing the level of support encouraging students’ choice in project selection.

More precisely, students were asked about any possible idea that they would like to implement in the near future. Noteworthy, through their daily diaries, they were encouraged to periodically document their ideas for new projects. Their responses on this matter were not very enlightening in the beginning. However, as they were becoming more familiar with tools and the technologies, they started expressing interest in working on specific or thematic projects. In December, being in Christmas mood, some teams were noticed to give a Christmas touch to their artefacts and discuss the implementation of Christmas-related artefacts. The review of the students' diaries brought also additional interesting ideas into focus: many students expressed an interest in creating a moving robotic artefact that could be controlled by them. Some of these ideas were rather general while some others more specific. For example, they were referring to robots that move and change colours, to solar cars, vehicles with many sensors, cars that move around and follow commands and more. Building upon this interest, the teachers supported a relevant project for Do-It-Yourself (DIY) automobiles providing students with the freedom to personalise their automobile, to add specific behaviours and functionalities and to give it the form they liked. During the 2nd pilot round, most of the projects came directly from the students.

The Figure 3 presents the projects that were carried out during the two pilot rounds. As one can notice, some ideas for projects were proposed by the teachers whereas some others came directly from the students (mainly during the 2nd pilot round), either as an extension of an existing project topic or as a completely new idea. During the 2nd pilot round, most of the projects came directly from the students.

Projects	The project idea/topic was suggested by the teachers	The project idea was extended by the students resulting to a new project or an advanced one	The project was built upon another project that had been earlier implemented	The project idea came from the students
1st pilot round				
The Lighthouse project	x	x		
The Shy Rabbit project	x			
The Sunflower project	x	x		
Christmas artefacts				x
DIY automobiles	x	x		
2nd pilot round				
The Voice Driven Face	x			
DIY automobiles (advanced versions)			x	x
The 3-level security control				x
The joypad for controlling a video game				x

Figure 3. The emergence of project ideas during the pilots.

The generation of ideas was also important during failures; failures were part of the making process (i.e. failed prints, artefacts that did not operate properly) and often the students were invited to share their ideas regarding possible solutions for overcoming the emerging problems. The teachers discreetly observed and supported this process; in some cases, teachers' intervention was more dynamic by providing useful explanations (i.e. in making circuitry more transparent, increasing students' understanding of electronics) to help students move forward. Frequently, teachers were encouraging the team to bring these ideas in plenary session for the benefit of the whole class. Sharing existing ideas, plans for implementation, problem solving practices and thoughts in the team and in the plenary were seen as a process that could significantly boost the generation of ideas for new artefact constructions.

There was also encouragement towards analysing ideas, breaking down complex activities into sub tasks, keeping notes about Science, Technology, Engineering, Arts and Math (STEAM) concepts related to their project (i.e. electrical circuit making), listing the material that would be needed, sketching the structure of the construction, visualizing the key processes. This was actually the stage of planning that in many cases was embedded in the ideation process, re-visited and creatively re-approached by the teams during the creation of the artefacts and the programming phase. In a way, these practices show how the stages of the eCraft2Learn methodology are interlinked (Alimisi et al., 2018). Most of the teams created paper-based plans while other teams agreed orally on the steps to be undertaken. A Unified User Interface (UUI, https://ecraft2learn.github.io/uui/index.html) (UUI, 2018) platform offered students several tools for planning their computer-supported artefact constructions (Figure 4).

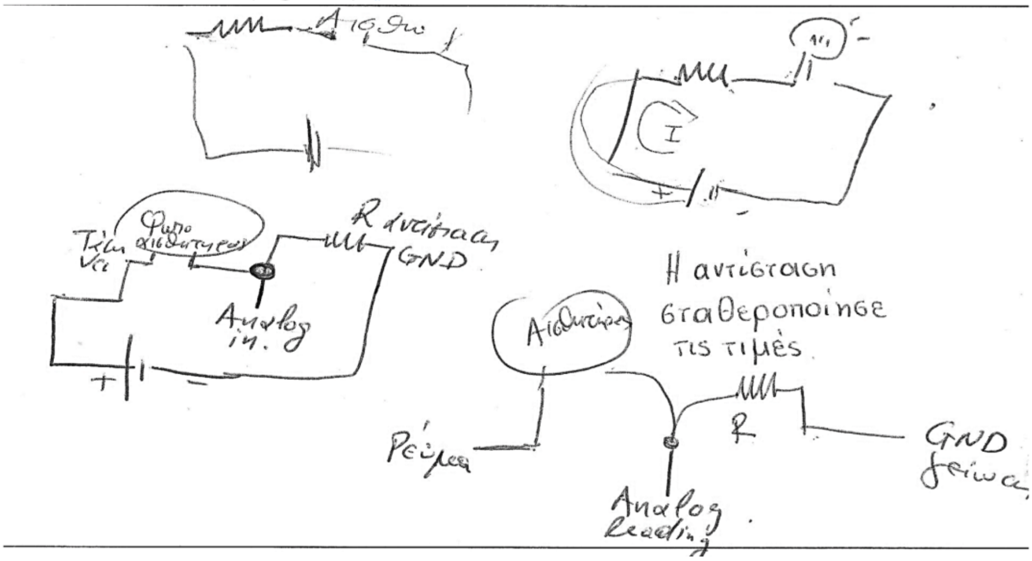


Figure 4. Sketching the electrical circuits for the "Christmas Artefacts" project.

As the sessions were progressing, students based on their interests and working at their own pace were engaging more naturally in the creative production of different artefacts. Different projects were going on at the same time, different challenges were calling for solutions, lots of hands-on making activities inspired students to dig deeper and to extend their ideas. Moved by the fun of making, many students were noticed to stay longer in the eCraft2Learn lab than initially planned.

2.3. Team work, distribution of roles and challenges

Role distribution was often noticed in the teams; some students were in charge of the electrical circuit making, others more into programming, some others were more involved into 3D modelling and handcrafting. The role allocation happened at team level and was not enforced by the teachers. However, there were few teams where the team members were involved in all the parts of the project development supporting one another. The teachers intervened only in cases whenever a member of the team was inactive or marginalised. Teachers were mainly trying to understand the reasons behind the inactivity and to create a situation where through the interaction with the other team members a role for him/her would emerge. For example, in one of the teams there was a young boy rather introvert always absorbed by his smartphone. The teacher of the team told him that it would be very useful to record the artefact construction process using his smartphone as this would allow the sharing of the work online ensuring greater visibility. The student took happily the challenge and started observing what was going on but (initially) only through his smartphone lenses as he was video-recording the process of the construction. Smoothly, he was taken over by the making spirit and was noticed to participate more, to express ideas for alternative solutions and become active member of the team.

2.4. A closer look into the aspect of sharing

The sharing of the making processes with others was considered of great importance. Teachers encouraged all the teams to share the current status of their work in the end of each session, to talk about the processes that they went through and their future plans. In addition, the teams were encouraged to showcase their work in the school community and the wider public. In this light, the students presented their projects in the Athens Science Festival 2018 (Figure 5) and interacted with visitors of all ages and from varying scientific backgrounds as well as with other teams of students that participated in the festival either as exhibitors or visitors.

Figure 5. eCraft2Learn children exhibiting in Athens Science Festival 2018.

Students and teachers were also noticed to record their work using their smartphones or cameras. At a later stage, some of this material was uploaded by them in their social media accounts. UUI tools were also used to share parts of the artefact construction. Although not practiced by all the teams, some teams encouraged by their teachers were seen to upload their 3D models (i.e. the nameplates for the DIY automobiles) from the Tinkercad environment (https://www.Tinkercad.com) to the Thingiverse Community (https://www.thingiverse.com).

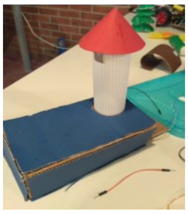
2.5. The role of the teachers

The description above revealed already many interesting aspects for the role of the teachers in the making process. Given the different ages in the team, their contribution on the formation of the teams early in the beginning and their remedial actions were also of great importance. The teachers have undertaken several roles; they have acted as supporters of the learning process, co-makers, boosters of the collaborative work and the sharing process at team level and beyond. Though most of them adopted smoothly these roles, in the beginning they were concerned about their self-image in the class. Their concerns revolved around the question: "What if we do not manage to support the students? What if we cannot answer their questions?" As long as they started seeing the eCraft2Learn lab as a making environment and themselves as co-makers, co-designers and facilitators of the learning process, their stress smoothly eliminated allowing them to stand by the students as coaches. The teachers supported significantly the generation of ideas prompting for relevant team discussions and existing project ideas extension. In addition, they boosted a lot the "Can-do" attitude, sharing their enthusiasm with the students and creating an atmosphere conducive to learning (Figure 6).

Figure 6. Empowering students and sharing feelings of excitement.

3. The eCraft2Learn Projects

In the context of the two pilot rounds, several projects were implemented. In the Figure 7, these projects are listed together with short descriptions.

Title of the project	Representative picture	Brief description of the project and video link
The lighthouse project		The lighthouse blinks only in dark https://youtu.be/tj_HaMKu3eY

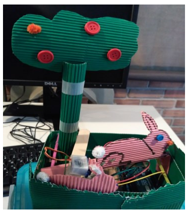
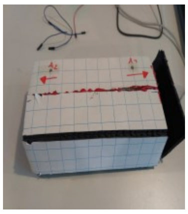
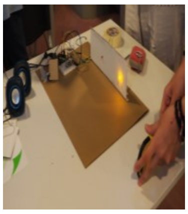
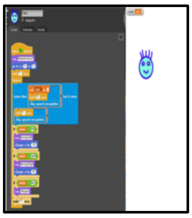
Title of the project	Representative picture	Brief description of the project and video link
The shy rabbit project		The animal reacts at loud sounds https://youtu.be/TryERYW835w
The sunflower project		The phenomenon of phototropism and the case of the sunflowers https://youtu.be/YfQa5e01zbc
Christmas artefacts		Several computer-supported artefacts that reflect the Christmas mood. https://youtu.be/QpJ8oxm4sxo
The DIY automobiles		Several types of DIY automobiles with simple or more advanced functionalities https://youtu.be/x6MKmQSq9CE
Video game joypad		A joypad for controlling a video game made in Scratch https://youtu.be/QZHyYlv87no
The 3-level security control system		A security system for a museum with three control zones https://youtu.be/kIENH2QB8as
The voice Driven Face		A face that follows voice commands. A project that is based on Artificial Intelligence services

Figure 7. List of the projects that were carried out.

Noteworthy, some projects have been approached from several teams; thereby several different robotic artefacts were created under the same project idea or topic. The projects were interdisciplinary in nature bringing together a combination of different disciplines from the field of STEAM.

Two indicative projects are described in detail below including the context, the implementation and the technical part.

3.1. The Shy Rabbit Project

The idea for this project came from the teachers who felt that they should boost the ideation stage by proposing simple projects that would allow students to explore additional eCraft2Learn tools and later on to build on the knowledge gained. The main task for the students was to look online for information about the reactions of animals (such as the rabbit or others) at loud sound and to realise this behaviour in their own artefacts.

The project was considered ideal for novices as it was further introducing them into sound sensors and related programming concepts. A worksheet was given to the students to support their engagement in the project, available in the Educational Resources, in the Worksheets section in the UUI (2018).

The scenario of this project offered students opportunities to express their creative skills and to involve themselves in handcrafting. Some teams were noticed to make drawings, to break down the project into smaller tasks and to plan the next steps to be undertaken (Figure 8).

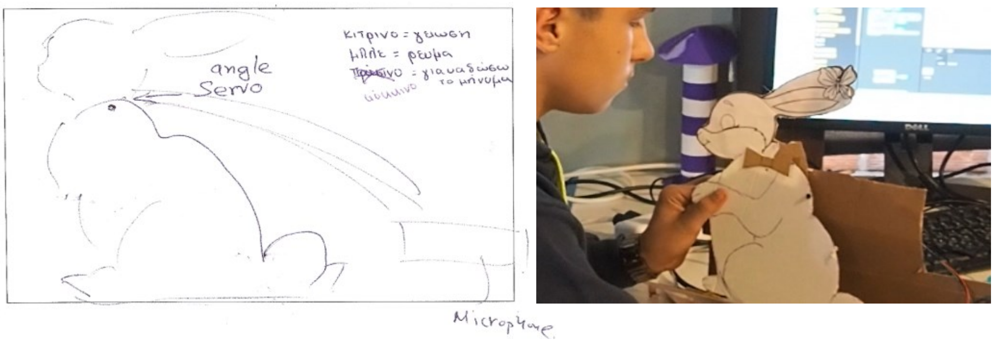


Figure 8. Student’s drawing on paper as of the planning phase (left) and the created artefact (right).

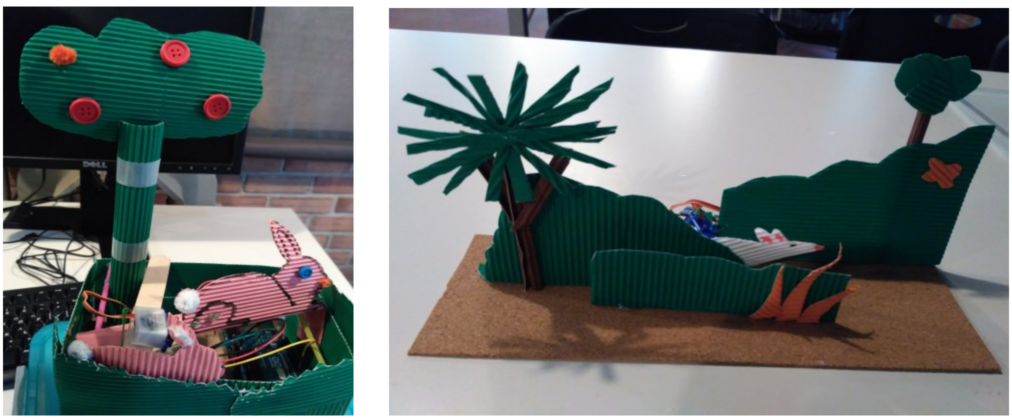


Figure 9. Two implementations for the Shy Rabbit project.

The project offered also opportunities for discussion, mainly revolved around technical issues (i.e. the power of the motor in the case of using heavy cardboard) or the way of representing the behaviour of the animal at loud sounds. Different implementations were made as indicated in the representative pictures below (Figure 9).

Most of the teams completed the project within 3-4 hours. The hardware and materials that were used included: cardboards, recycled materials and many different types of paper for making the structure and the rabbit, wooden sticks, wires, LEDs and breadboards, small microphones equipped with preamplifier, small angle servos, and Arduino Uno boards (https://www.arduino.cc).

In terms of software, the students used either the Ardublock (http://blog.ardublock.com) or the Snap4Arduino (http://snap4arduino.rocks) programming environment. To program the rabbit so that to intercept a noise, students connected a microphone into the A0 input of the Arduino board and sketched a program that was polling values from this input. By observing the noise values that were being recorded, they defined a critical sound level value that corresponded to "tranquillity" and updated the code instructing an angle servo motor to "wipe" (i.e. to turn left and right several times) whenever sounds considerably louder than this threshold value where being captured. In order the servomotor to function properly, a PWM capable pin was used that controlled the angle parameter (Figure 10).

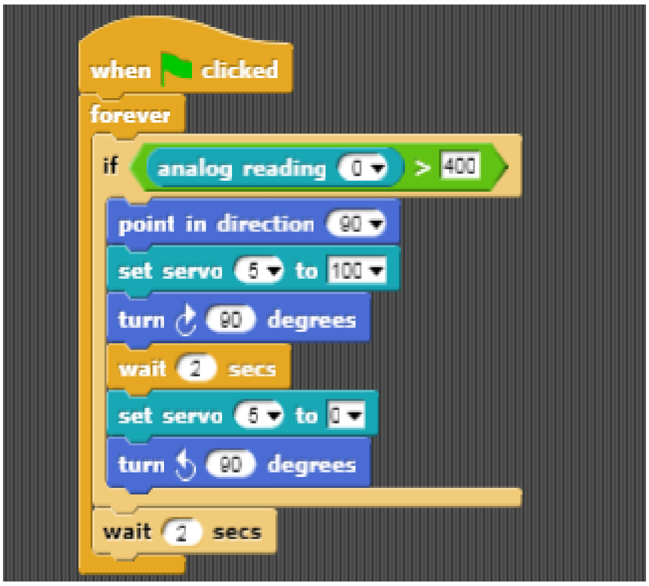


Figure 10. Indicative script for making the rabbit to intercept loud sounds.

3.2. The DIY Automobiles Project

In this project, students were encouraged to make a robotic artefact capable to move around (left, right, forward, reverse) using servo motors. The teams focused on adding wheels and connecting them to servo motors, programming the movement and addressing a specific behaviour, and finally making the robot autonomous using a solar bank.

The engagement in the DIY automobiles project offered opportunities for students to explore scientific and engineering principles behind building a solar-powered car, learn concepts related to motion and friction, understand the need for lightweight materials and constructions and to engage into programming tasks and electrical circuit making, and to print 3D modelling objects for their robots (i.e. cases for solar banks, name tags, etc.)

Different types of DIY automobiles were created during the pilots that fall broadly into four main categories:

1. simple DIY automobiles: The simplest robotic vehicles were able to move back and forth using USB cables or power banks to supply motors and Arduino board. Programming took place either in Ardublock or Snap4Arduino (Figure 11);

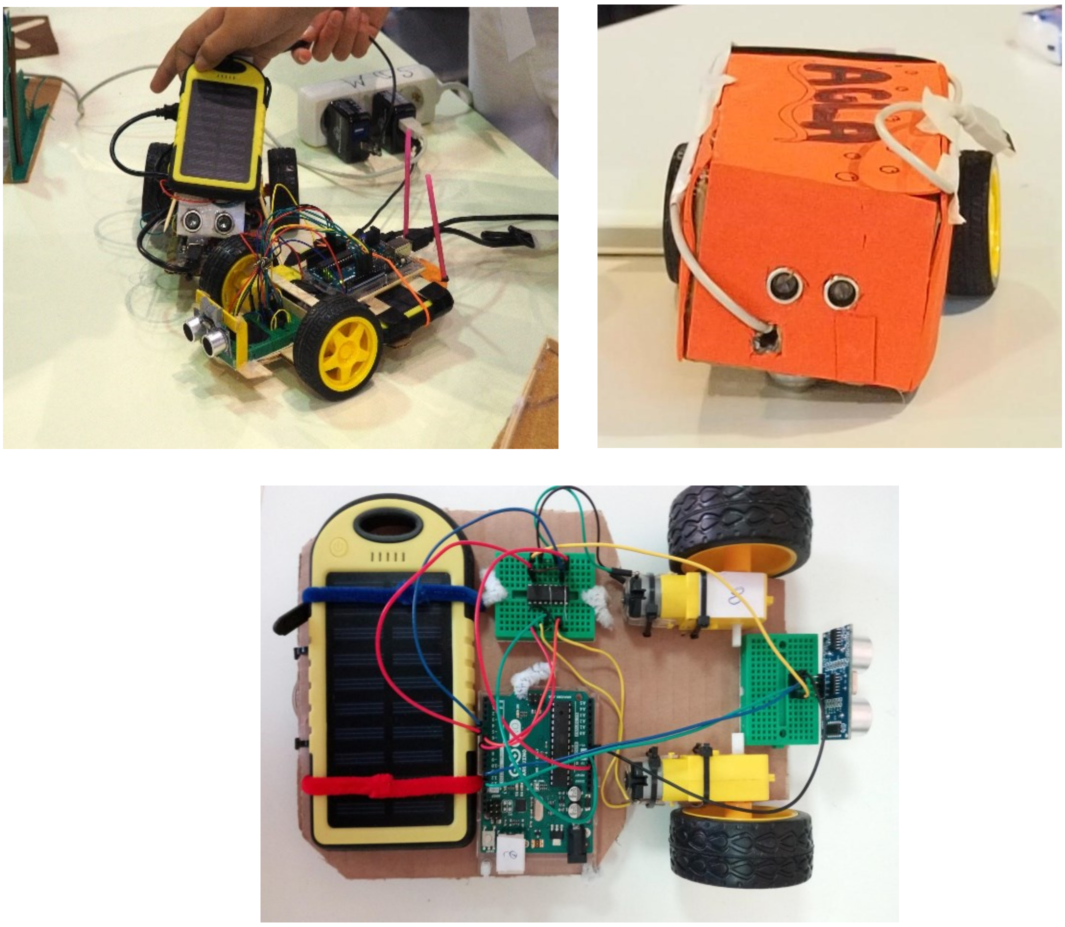


Figure 11. Students' DIY simple automobiles.

2. DIY automobiles that perform complex movements: Due to the lightweight construction materials and a smart choice of wheels, the DIY automobiles of this category could perform complex movements, turn left and right, freeze or move backwards when obstacles were ahead and more. Noteworthy, to address this advanced behaviour a more advanced script was needed. LED lights that were blinking according to the movement were also attached. These artefacts were mainly Arduino-supported artefacts and were able to calculate the distance from obstacles (via distance sensor readings) and avoid them (i.e. by going a few centimetres back and turning to the left or right before moving forward again).

3. Programming took place either in Ardublock or Snap4Arduino (Figure 12);

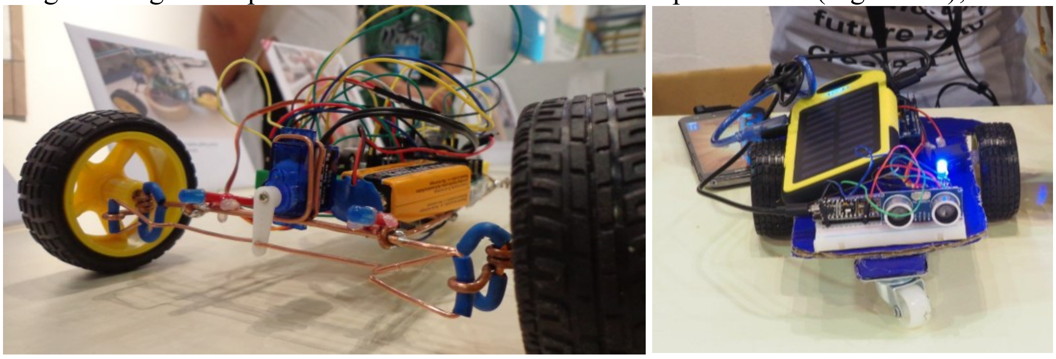


Figure 12. Advanced DIY automobiles.

4. Adding some 3D-printed and sketched objects: this category includes automobiles that can detect obstacles, perform specific movements and in addition at least one of their parts was 3D-printed. 3D modelling took place in Tinkercad and the slicing in the Cura environment. 3D pens were also used in some cases for decorating the artefact. The artefacts were based on Arduino or RPi3 boards (Figure 13);

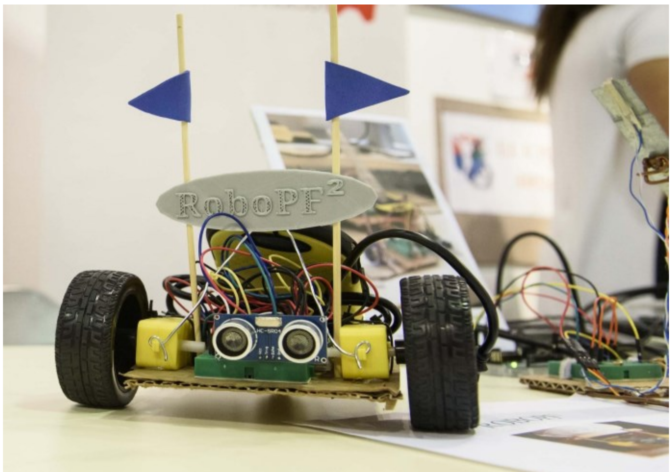


Figure 13. DIY automobile with a 3D-printed nameplate on the top.

5. DIY automobiles with remote control: during the 2nd pilot round one team developed an interest in remotely controlling the DIY automobile using a tablet or a smartphone (Figure 14). Building upon previous designs, after many improvements and new developments to achieve the remote control, the team successfully completed the project. The robot was based on a RPi3 board instead of Arduino and used the RPi3 built in Wi-Fi unit to communicate with the Snap4Arduino environment on the workstation unit or with a tablet device through the MIT App Inventor software (http://appinventor.mit.edu/explore) (Figure 15).

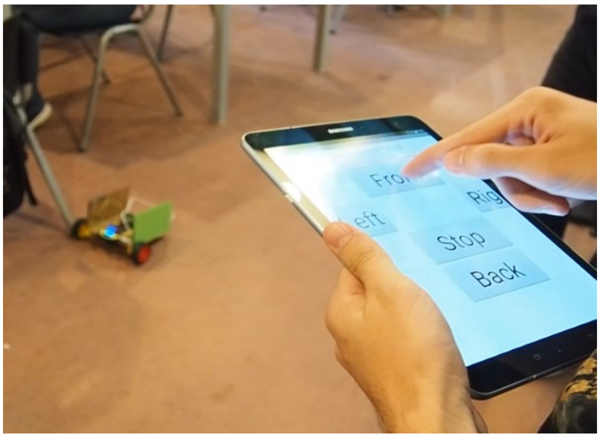


Figure 14. Remote control of the DIY automobile.

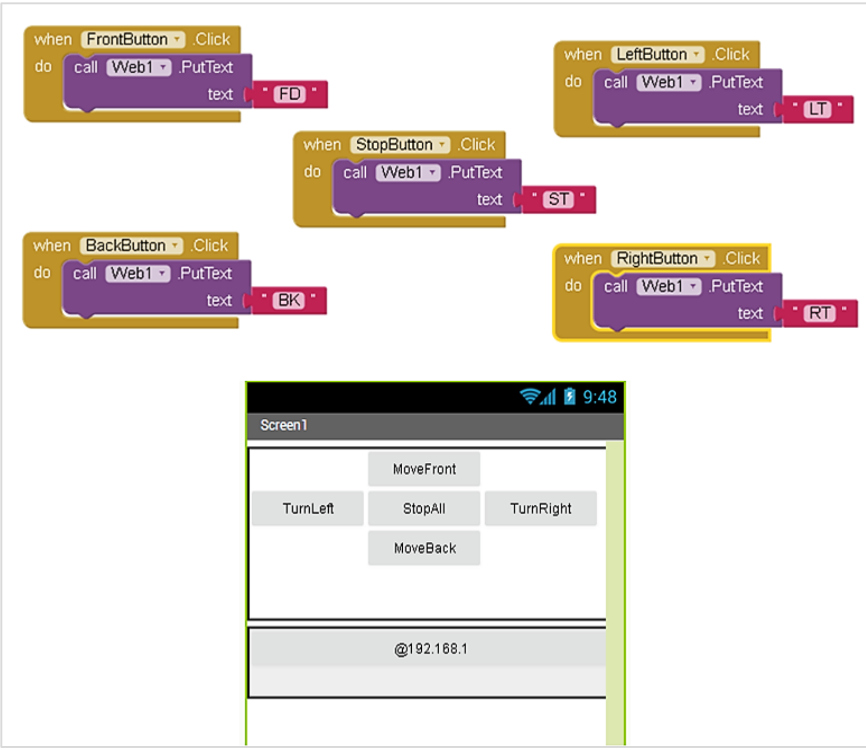


Figure 15. Indicative code and interface design using MIT App Inventor to remotely control a RPi3-based automobile.

The time that was required for each project varied from team to team and from implementation to implementation. Simple DIY automobiles were made within 5 hours but more advanced functionalities and behaviours required more time and lots of tests and experiments. The enhancement of the automobile with 3D printed objects (i.e. nametags, PLA cases) extended the implementation time as 3D printing itself was a time-consuming task. Thereby, depending on the complexity of the artefact 5 to 15 hours were spent.

The list of the hardware and materials that were used in the projects included:

- cardboards, foam board, recycled materials and many different types of paper for making the vehicle body;
- wooden sticks, metal wire, straws to mount the axles, wheels (plastic bottle caps, film canister caps, toy wheels), glue, duct tape;
- jumper wires, LEDs, breadboards, distance sensors (mainly ultrasonic ones), motor driver circuits like the L293D, Arduino Uno boards (for the simpler vehicles), additional RPi3 boards for the remotely controlled robots;
- PLA filament for the 3D printed and 3D sketched parts, 3D pen and 3D printer.

4. Good practices: Pinpointing the benefits for the school community

In this section, we summarize the good practices that were documented in the pilots and we list several video-recorded episodes where most of these practices are reflected. The good practices are thematically categorised in the different stages of the learning process and reflect the steps of the eCraft2Learn pedagogical model and methodology (Figure 16).

Short description of the recorded practices	Link in the eCraft2Learn YouTube Channel
Ideation & Planning These videos demonstrate the ideation and planning process, showcasing how the teachers supported the ideation process encouraging the students to review, analyse and share ideas in teams. The sharing of ideas in the plenary was another practice that took place and significantly boosted the generation of new ideas and the collaborative spirit in the eCraft2Learn labs. The students are seen to discuss their ideas, to identify pros and cons, to consider the materials that will be needed and to discuss on possible solutions. The generation of ideas in most of the cases was followed with plans on paper, documentation and analysis through the UUI tools, draft sketches of the key steps to be undertaken and team discussions. The recorded episodes bring these practices into focus.	https://youtu.be/pOqfKEocHHs https://youtu.be/KASmme8jH08 https://youtu.be/ORXy8OlCy64
Creating & Programming This video demonstrates episodes of the process of creating and programming the eCraft2Learn computer-supported artefacts. Episodes of the hands-on practices, tests and experiments are demonstrated showing the process that the students went through. Failures were part of this process calling for new ideas, new plans, creative problem solving and collaborative work.	https://youtu.be/uFbL76R_kPg
Transforming Teachers' role to that of a coach These videos demonstrate the role of the teachers during the pilots; students' voices regarding the role of the teachers are also brought up. Teachers appear to encourage the students, to help discreetly, to raise dialogues, to act as co-learners and co-makers, to provide information and explanations when needed and to boost the "can-do" attitude.	https://youtu.be/OtEsdBQjYKY https://youtu.be/SYl4kKr7vk0

Short description of the recorded practices	Link in the eCraft2Learn YouTube Channel
Sharing These videos present how the important aspect of sharing was implemented. The following aspects are highlighted: • sharing in big events (such as the Athens Science Festival 2018), showcasing their work and interacting with people of a wide range of ages and background; • sharing in the classroom/lab with a focus on ideas sharing, exchange of good practices and presentation of the current status of work; • sharing online either experiences and artefacts through social media or shareable parts of the work through the tools available in the UUI (i.e. 3D models through Thingiverse).	https://youtu.be/V6n360hagOQ https://youtu.be/6iqC4n1DW_Q https://youtu.be/TL3yhYfJnaA https://youtu.be/972r9HIYUV8

Figure 16. List of good practices.

The good practices that were observed in the eCraft2Learn pilots are presented as they emerged through their authentic context to inspire and encourage more teachers (from formal and informal education settings, in-training or in-service) who may embrace the eCraft2Learn philosophy and situate themselves in the eCraft2Learn ecosystem. The collaborative nature of the maker mindset comes from an embrace of sharing ideas, projects and good practices that encourage the generation of new ideas, enable learners to smoothly shape their own explorations, and embrace failures and setbacks so that to provide opportunities for richer learning experiences.

The documentation of these practices (together with the underlying context) can potentially empower more teachers in implementing similar projects in their classrooms. The projects have a "low floor" and "high ceiling" as they offer an easy entry for novices (low floor) while enabling more experienced learners to work on increasingly more complicated projects (high ceiling); noteworthy, they have also "wide walls" as they can support a wide range of different explorations (Resnick & Silverman, 2005). In this light, the projects and the good practices reported here offer a starting point upon which key stakeholders, including school principals, teachers, teacher trainers, educators as well as the broader school communities, can build extending them in new situations and contexts or inspire new ideas for more advanced and innovative projects. Our goal is not to establish a prescribed set of activities but to encourage actions that help build a stronger evidence base for what STEAM teaching and making experiences work best in different contexts and serve diverse learners.

Reflecting upon the pilots in Athens, some helpful takeaways, that are worth sharing with teachers interested in the eCraft2Learn initiative, are highlighted below:

- call for stepping out of your comfort zone. The teachers in the eCraft2Learn ecosystem should be ready to step out of their comfort zone. Regardless their backgrounds and level of experience, they are invited to enter into teaching situations that they have never experienced before, to apply new practices, to explore new tools and technologies (i.e. 3D printers, digital fabrication, DIY electronics, new programming tools and more) and experience once again what it is like to learn themselves;

- building a welcoming atmosphere. In a team where participants do not really know each other, ice breaking activities can get them comfortable with one another contributing significantly to the team bonding;
- transforming failures into learning opportunities. The eCraft2Learn ecosystem invites failures and exploits them from a learning perspective. The teachers should approach failures as opportunities for creating deeper and richer learning experiences;
- supporting the generation of ideas. It is important to encourage the students to work on projects that are meaningful to them. However, big ideas may not easily emerge. Even when the project scenarios are proposed by the teachers, it is important to offer students opportunities to extend the scenario of the project based on their personal interests and preferences. When the students work on something they really like, it is more likely to dedicate themselves in the making process, to engage in explorations and to come up with new and more advanced ideas;
- creating an atmosphere of curiosity and innovation. Teachers are not the sages on the stage and they are not supposed to have all the answers to the questions that may emerge. They rather help and encourage the students to explore and construct their own knowledge, to organise their thoughts and ideas, to work effectively in teams. They encourage team work, experimentation, hands-on activity, challenge seeking and the sharing of knowledge;
- sharing matters in a maker space ecosystem. It is important to provide students with opportunities to share their ideas, accomplishments, experiences and struggles with each other. It is important to show them that they can build upon the experiences and results of others and others can learn from their own experiences and outcomes. Sharing can happen in the class, in teams, in online platforms, in public festivals, school events and more;
- the importance of adaptation and role shifting. The making process is not linear. It involves several stages that are interlinked and often take place in parallel. As a result, the teachers are moved to take several roles (the roles of the mentor, trainer, facilitator of the learning process, self-esteem booster, co-maker, co-learner, evaluator and more) and adapt their support and guidance based on the needs along the way;
- building partnerships. The eCraft2Learn ecosystem calls for synergies and partnerships among teachers and educators of different disciplines (Science, Technology, Engineering, Arts, Math). In this way, interdisciplinary projects and innovative ideas can be better supported. In addition, within a partnership of teachers, it is more likely to deal with organizational and administrative issues emerging often in the formal or informal education settings.

5. Conclusions

The pilots that were carried out in Athens in the context of the eCraft2Learn learning interventions have allowed us to see how the teachers and the students acted and interacted in the eCraft2Learn ecosystem, what type of support was needed, what tensions existed, how the fun and the challenge of making and digital fabrication were perceived by them.

The support of the ideation process is among the good practices that were highlighted. The teachers tailored their roles and support to the needs of the students and discreetly empowered them so that to develop confidence and to start shaping their own ideas towards robotic artefact construction. The teachers supported the ideation phase with easy to start with projects and worksheets moving the students to extend the project topics based on their interests and personal preferences. In addition, the teachers supported the generation of ideas during problem solving by raising prompt questions that could help the generation of new ideas towards problem solving, providing useful explanations and boosting students' self-confidence and "can-do" attitude.

The sharing of ideas, practices and experiences was considered of great importance as it could inspire new and potentially innovative ideas. A number of good practices for sharing were identified, which included the triggering mechanisms for sharing in the class (presentation of the current status of work and good practices exchange), in well-attended festivals, and online through the social media.

This paper has also described the actual projects that were implemented by the students. Most of the projects were interdisciplinary in nature and focused on different STEAM-related disciplines. The projects may not be spectacular, but each project offered students unique opportunities to explore a rich set of tools and technologies, to act in a team, to be creative, to challenge seeking, to fail and to keep trying, to be involved in problem solving, to communicate and share ideas. Inspired by their eCraft2Learn experiences, some students were seen to re-program how they see school, homework and daily life, i.e. by critically requesting more time while in school for hands-on practices, by voluntarily continue their making projects at home, and by scheduling meetings to discuss ideas for new projects at their free time.

As a matter of fact, in the context of the eCraft2Learn pilots, the students were observed to go through multiple processes: from idea generation, to planning, to collaborative hands-on construction, to problem solving, reflection, sharing, re-design and re-construction. All these processes were interwoven in a constructionist pedagogical model and learning methodology appropriate for the making process.

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