20. Advanced Education through Innovation via Remote Access to Digital Fabrication Technologies

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The lack of students interested in STEAM subjects (Science, Technology, Engineering, Art and Mathematics) remains a major problem in schools nowadays. There is now a call for innovation among professionals in current STEAM practice oriented to research and design new educational programs and pedagogical tools to increase the interest of students in this type of courses.

NEWTON is a large European Horizon 2020 project, that is squaring up to the challenge of the next generation of technology enhanced learning, using innovative tools to ensure students stay engaged on multiple levels. The project harness collaboration from six universities and eight industry partners across seven European countries to the task of reimagining the online classroom experience using novel digital learning technologies. Here, it is presented a new educational program designed for the NEWTON project at Fab Lab Madrid CEU, the digital fabrication laboratory based at CEU University, to be deployed at schools based in different European countries. It targets the use of novel technologies and pedagogical tools for teaching STEAM, using remote access to Fab Lab facilities, gamification approaches and a distributed platform to raise student's interest in technology through collaborative and inclusive activities.

1. Introduction

STEAM subjects are often perceived as difficult, requiring extra effort from students to achieve. As a result of that, a lack of engagement with these type of courses has become a big issue. According to some researchers (Henriksen, Dillon & Ryder, 2015), the rate of European graduates in STEAM has decreased. Common in some initiatives in Spain (Fernández, Martínez Torán,

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Leslabay & Esteve Sendra, 2018) is the idea that students can be motivated though the use of new educational programs and pedagogical tools oriented to the development of knowledge and skills. That is the case of programs that have been developed during the last years in our country, such as AuLAB (Tesconi & Arias, 2014), a program conceived as a didactic project addressed to primary, secondary and vocational students, developed with the participation of educational centers and teachers with the aim of adapting education specifically to the needs and peculiarities of each group of students. Also, it should be mentioned *Breakers*, a training program on digital fabrication for young vulnerable to promote their active and participatory social inclusion and to improve their employability. The program is being carried out in Spanish Fab Labs and Makerspaces (García, 2016).

It is also worth to mention educational initiatives that are running in spaces grouped in CREFAB (the Spanish Network of Creation and Digital Fabrication), a Spain-based community of practice focused on overcoming technology barriers through digital fabrication, democratizing access to the digital world for all and improving competences for the 21st century. Innovative practices carried out by CREFAB's members in their spaces are oriented to avoid the lack of access to technology, aiming to narrow the digital divide. Finally, mention should also be made to the programs designed at Fab Lab Madrid CEU, oriented to improve learning processes through digital fabrication (Lorenzo, 2017), teaching STEAM workshops at the university campus to motivate high-school students on their future careers (Lorenzo, 2017) and using design and digital fabrication technologies on active learning (Lorenzo & Lorenzo, 2018).

The new educational program which is presented here is aligned with the above mentioned initiatives, going a step forward to include remote access to digital fabrication technologies, allowing also access to students with disabilities and special needs. It has been designed to target the use of novel technologies and pedagogical approaches for teaching STEAM, testing remote access to digital fabrication facilities, using game based learning and a distributed platform designed to raise student's interest in STEAM courses. The program is part of the NEWTON project, an European Horizon 2020 project that is squaring up to the challenge of the next generation of technology enhanced learning, using gamification, multisensory and multimodal learning, interactive augmented reality teaching assistants and digital fabrication tools to ensure students stay engaged on multiple levels. It harnesses collaboration from universities and industry partners to the task of reimagining the online classroom experience, using pioneering digital learning technologies. NEWTON has exciting implications for students and providers of online STEAM courses where the course subject matter can be challenging to adapt to the technology-enhanced learning environment and where early drop-out rates continue to be worryingly high. The project is being validated in real life pilots across Europe, using a network of innovative secondary schools, digital fabrication laboratories, vocational establishments and third level institutes permanently working on the development of good teaching practices.

2. Exploring Innovative Teaching Approaches

The goals of the distributed educational program designed at Fab Lab Madrid CEU seek to motivate students in STEAM courses through constructionist hands-on workshops related to disciplines as Science, Technology, Engineering, Art, Mathematics and Design, proving that learning is not related to acquire knowledge and skills but to materialize ideas, thanks to their application on a practical project. Activities have been designed to encourage students enjoying technology through the development of digital fabrication projects that allow them to entirely design and fabricate an object by their own. The aim is to engage students by the idea of making something, seeing them design something themselves and making a finished product. To do that, it is necessary to provide a good learning environment, so that students can be in charge of the technology, offering the opportunity to use Fab Lab's tools to students that are not physically in a Fab Lab. In order to test our approach when designing the pedagogical contents and activities of the educational program, various experiments and pilots have been previously carried out at the Fab Lab during the last two years. All of them have been implemented to test new teaching approaches that could validate the effectiveness of the educational program with students from different levels and/or special needs.

2.1. Fab Lab Experiments

Experiments carried out at Fab Lab Madrid CEU during the NEWTON project focused on the use of 3D printing technologies applied to STEAM courses. This technology has been used as a support tool to fabricate small-scale prototypes using a hands-on approach to demonstrate and prove concepts learned by students on theoretical classes taught at their school. The idea was to test the use of problem solving activities, where students come to class to solve problems themselves, rather than watching a tutor solving them. The assessment was done through test performed before and after the workshop to be sure students learnt the digital fabrication workflow. Teachers checked the answers given in the test and students also learnt from their classmates and instructors. Data collection methods included formal and informal feedback from students, group reviews during the class and questionnaires.

The first experiment involved primary school students from Madrid-based CEU Sanchinarro School and was related to the design and fabrication using a 3D printer of chess sets for visually impaired. The experiment was part of the project entitled *CEU Investiga* and allowed students to learn how to design and fabricate chess sets pieces, as well as how to customize them to be used by visually impaired children, encouraging social inclusion. A chess competition held at the end of the experiment proved to be an excellent way to integrate children with disadvantages, promoting on involved students cognitive skills.

Figure 1. Primary school students involved on NEWTON experiments.

The second experiment was held with high-school students and focused on the design and fabrication of ceramic vases, using new materials. We were looking for increasing student's motivation on STEAM subjects through the direct access to the Fab Lab facilities and innovative methods that prioritize ideas over skills or knowledge. Participants designed their own vases after a geometry class that explained them how to create complex surfaces, using open source 3D design software. Afterwards, they learnt how to use a 3D printer to produce ceramic vases. Students were invited on campus and carried out the workshop in the Fab Lab. This was during class time; students were introduced to a range of staff including lecturers, PhD students and technical support staff. It has the added bonus of exposing students to the university environment and access to equipment that would otherwise have been unavailable.

The third experiment was implemented in cooperation with Fundación Oxiria, a foundation focused on students with special needs. It was held with students with intellectual disabilities who were finishing their studies in Floristry at ISEP CEU (Instituto Superior de Estudios Profesionales), an institution run by CEU Foundation. The experiment focused on the design and fabrication of flowers using a 3D printer and open software. The aim was to show the application of STEAM content on their job as florists. Content was shaped to meet the needs of the subject area that students were learning at ISEP, as well as the age, level and abilities of the participants we were engaging with. Thanks to it, participants built their confidence while gaining practical, teamwork and leadership skills on the application of digital fabrication tools to real life.

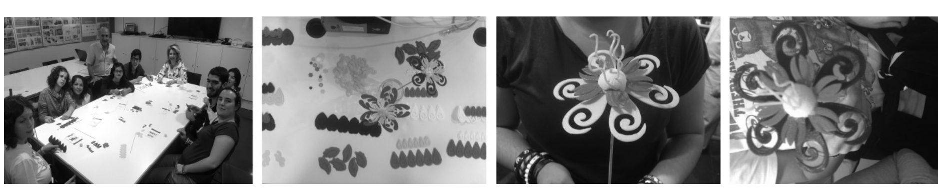

Figure 2. ISEP Students involved on NEWTON experiments.

The last experiment was focused on the design and fabrication of mini-rockets using 3D printing technologies. It involved students aged 13-14 years old and included a first session where they were taught theoretical concepts related to Physics and Maths to be applied on the design and fabrication of rockets. Both subjects were useful to carry out the workshop, since students were supposed to design previously to the fabrication processes. Computer aided design required knowledge in vectors, geometry and the use of Boolean operations of addition, subtraction and intersection to carry out the designs. This experiment included a practical workshop on the use of a 3D printer. Finally, a competition was held to test the rockets trajectory, in order to understand the practical applications of the theoretical concepts learned during the first session.

Figure 3. Secondary school students involved on NEWTON experiments.

2.2. Fab Lab Pilots

After the experiments, it was necessary to target remote access to Fab Lab technologies for those students from different countries that couldn´t access to a Fab Lab. To that end, we implemented three pilots that tested remote access to digital fabrication facilities from students at CEU Montepríncipe School (Madrid), St. Patrick's School in Dublin (Ireland) and Liceo Scientifico G. Da Procida in Salerno (Italy). The pilots were focused on the design and fabrication of ceramic vases through the use of free 3D software and 3D printers. The educational content was related to the study of Geometry using open design and digital fabrication technologies. It allowed us to test the motivation of students on STEM courses, the potential of digital fabrication to help in developing new skills in the fabrication of ceramics, in a way that conventional approaches had failed to do. Also, if the learning that it was achieved was retained by learners and they were able to apply on the design and fabrication of other products. And finally, if the virtualization of Fab Lab machines allowed students to remotely engage Fab Lab activities and to learn the Fab Lab workflow (Gershenfeld, 2005) to design and fabricate their own designs.

3. Testing Fab Lab Experiments and Pilots

After experiments and pilots deployment, the data analysis allowed us to reflect on the results and learn some lessons to be applied to better design the educational program, To collect data, teachers took notes and pictures of the activities and observed group interaction among groups of students. There were also focus groups involving some students to gather information regarding usability of Fab Lab technologies. Besides, questionnaires were distributed to teachers and students to measure their response to activities, rating their perceptions and opinions. A summary of findings regarding the learner motivation are listed below:

a) 100 % of students were extremely interested (60%) or very interested (40%) in Fab Lab technologies.
b) Students also stated to be somewhat (30%), very (30%) or extremely (40%) confident that they were able to solve any problems and challenges they had experienced during the lesson.
c) About their feelings while they were learning, all of them felt extremely (60%) or very much (40%) engaged. They didn´t neither feel anxious about it (100%) nor even bored (100%). On the contrary, they felt slightly (30%), somewhat (10%), very much (30%) or extremely (30%) relaxed.
d) 100 % of students answered they didn't feel sad or angry. On the contrary, they felt somewhat (10%), very much (60%) or extremely (10%) happy and they enjoyed very much (20%) or extremely (80%) during the pilot.
e) 100 % of students said that learning Fab Lab technologies was really interesting and enjoying. They also stated that using digital fabrication technologies made them more enthusiastic about learning STEAM (70 % of students agree or strongly agree with it).

A summary of the findings regarding the usability of digital fabrication technologies are listed below:

a) Regarding to usefulness, 50 % of students agreed (30%) or strongly agreed (20%) on the idea that remote access to digital fabrication tools could help them to be more effective in a science class while the remaining 50% answered neutral. On the other hand, 70% of students agreed on its usefulness.
b) In relation to the ease of use, only 30% of students agreed on it, while the remaining 70% was neutral. On the other hand, 50% of them stated that it was necessary to have written instructions for using Fab Lab technologies.
c) 80% of students answered that they would recommend the use of Fab Lab technologies to a friend. The same percentage agreed on the statement that Fab Lab technologies were funny to use. However, only 50% of them replied that they felt they needed Fab Lab technologies in their life. 80% of students strongly agreed on their satisfaction using Fab Lab technologies.

Results of the evaluation processes showed a high degree of satisfaction among students. Fab Lab technologies were proved to be intuitive tools to be included as part of the program, allowing students to fabricate prototypes to test theoretical concepts taught during the school's core subjects. It was also clear that Fab Lab technologies could be used by students from different backgrounds following safety protocols under the supervision of Fab Lab instructors. During the pilots some goals were also achieved, as the high motivation of students through the use of digital fabrication technologies. Besides, students could virtually operate the equipment of a Fab Lab (3D printers) thanks to the use of the Cloud Hub application, a platform that allowed them to send their files from their school. In relation to design processes, questionnaires revealed that students where highly motivated and pretty interested on the activities, although they also said that they needed close instructor guidance.

To overcome the lack of self-confidence of those students who felt that they need instructor's guidance, we decided to include on the educational program a game based approach combined with remote access to digital fabrication tools that proposed students small challenges to test their knowledge and to get some rewards. That will allow them to feel they have progressed and that they are qualified to work autonomously in a Fab Lab using digital fabrication tools.

4. Designing a Distributed Educational Program

In STEAM education, the design process can be used to develop, renew and enhance any aspect of learning and teaching. Teaching itself is increasingly described as a designerly task (Laurillard, 2012; Brown & Edelson, 2003; Goodyear, 2015). The above mentioned researchers suggest there are some guidelines that could contribute to improve teaching, as rewarding students for their efforts, providing regular assessment of progress, accommodating diverse styles of teaching and staying in touch with students during the whole activity.

Based on the results of Fab Lab experiments and pilots, it was clear that the design of the educational program should integrate a variety of technologies, as game-based tools that should be combined with digital fabrication technologies to assure regular student's assessment, providing them with rewards for their achievements. Besides, remote access to Fab Lab tools should be provided during the whole program to engage students and stay in touch with them. Finally, more educational content was planned to be added to the NEWTON platform to provide teachers and instructors tools to use diverse styles of teaching.

4.1. Remote Access to Digital Fabrication Technologies

The educational program is focused on the fabrication of objects using 3D software and Fab Lab technologies. We are interested into testing the potential of Fab Lab tools to help students to gain knowledge on Geometry and Arts & Crafts via the fabrication of products. In fact, a Fab Lab is a platform for learning and innovation comprised of fabrication and electronics tools, wrapped in open source software and programs that include 3D printers, laser cutters, vinyl cutters, high-resolution CNC milling machines, large wood routers and electronic tools. (Gershenfeld, Gershenfeld & Gershenfeld, 2017). Digital fabrication goes from design to fabrication, so it begins with a digital design and ends with an output from a fabricating machine. In order to fabricate something, students should be provided with remote access to digital fabrication tools. They also need tutorials that explain how to design and send files to the Fab Lab machines, so that the products can be made.

Remote access to Fab Lab machines has been provided through the Cloud Hub application developed at CEU University. Cloud Hub relies on cloud, Internet of Things and Industry 4.0 technologies and protocols to implement the concept of Fabrication as a Service (Cornetta, 2016). More specifically, Cloud Hub is a complex real-time distributed hardware/software infrastructure that provides a software abstraction layer to the digital fabrication equipment and exposes it over the internet as a web service. The platform implements real-time inter and intra Fab-Lab communication protocols that allow several Fab Labs to be networked and monitored. Every time a fabrication request is delivered to a Fab Lab via the application, the Fab Lab manager is notified and can analyze and approve the design for fabrication using ad-hoc web interfaces. As soon as the fabrication process ends, the system automatically notifies the users that the design has already been fabricated.

4.2. Game-based Learning Approach

A game based learning approach combined with Digital Fabrication technologies can assure regular student's assessment during the educational program, providing also rewards for student's achievements. During the program, the Fab Lab workflow has been designed to be acquired though a game that allowed to turn learners into gamers. Four challenges have been designed: the first one is a quest to learn how to use a software for 3D design and how to design geometric objects; the second is related to prepare the files to be fabricated in a Fab Lab machine; the third teaches students how to send the files from their school to the Fab Lab machines through the Cloud Hub application and finally, the last one is focused on the fabrication of the prototypes from 3D printed pieces that should be assembled to get the final product.

Two kinds of rewards have been planned. On the one hand, Fab Points to be given to those students who finish the challenges. Points act as feedback mechanisms that track progress based on achievement or desired behavior. On the other hand, Fab Lab Certificates are planned to be given to those students that finished the four challenges. Prizes promote lots of activity and when used well create engagement. Besides, certificates are a symbol of mastery and achievement so students can gain self-confidence.

The integration between gamification and Fab Lab facilities has been designed as follows. Teachers are involved on the creation of a game that is assigned to teams of students. The game includes the four challenges explained above, providing students with materials required to solve each challenge (video tutorials, text tutorials, quiz templates, etc.) through the NEWTON platform, as well as the interfaces that allow students to communicate remotely with Fab Lab instructors. Teams of three students play the game working collaboratively and at the same time fight among them to acquire Fab Points, which allows them to get certificates.

4.3. NEWTON Platform

The platform implemented for the NEWTON project integrates and disseminates innovative technology enhanced learning methods and novel tools to create and inter-connect existing state-of the art teaching labs, building a pan-European learning network platform that supports fast dissemination of learning content to a wide audience in a ubiquitous manner. It links all stakeholders in education, enables content reuse, supports generation of new content, increases content exchange, develops and disseminates new teaching scenarios and encourages new innovative pedagogical approaches. Students get access to materials needed through the NEWTON platform. Pedagogical assessment is also monitored through the platform under the supervision of a Pedagogical Assessment Committee that advises teachers and instructors in the procedures to be follow during the activities and workshops designed for the program.

5. Conclusions

This project has shown the experience acquired through the design of an educational program that allows remote access to digital fabrication technologies, based on experiments and pilots that involved students of various ages and backgrounds. All the activities proved to be a motivating experience for participants and levels of satisfaction seemed to be high at the end of these activities. The educational program designed after the results obtained during experiments and pilots looks promising as a pedagogical approach for collaborative design, using remote access to Fab Lab facilities, gamification approaches and a distributed platform to raise student's interest in technology courses. Work is ongoing, and pilots will be carried out on the following months to test the program after the integration of game-based technologies. Although experiments and pilots do not provide validation of the ongoing educational program, they prove that it achieves its goals of motivating students in STEAM courses through constructionist approaches, learning safely the use of Fab Lab facilities and applying the knowledge on the materialization of their own ideas thanks to their application on a practical project.

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