RAISING STUDENTS' INTEREST IN STEM EDUCATION VIA REMOTE DIGITAL FABRICATION: AN IRISH PRIMARY SCHOOL CASE STUDY

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Abstract

In this paper, we describe an ongoing educational program, called *NEWTON Fab Lab STEM*, developed by the EU Horizon 2020 NEWTON project team. It aims at evaluating the impact of using digital fabrication as a support tool to raise students' interest in STEM subjects. We also present a case study of a small-scale pilot test that was deployed at Saint Patrick's Boys National School in Drumcondra, Dublin, Ireland. Results show that 83% of students who took part in the pilot test would like to integrate digital fabrication technologies in science classes.

Keywords: Digital fabrication, Fab Lab, STEM education, technology.

1 INTRODUCTION

The number of students in Science, Technology, Engineering and Mathematics (STEM) has been dwindling in recent years. In fact, since 2000, the rate of European graduates in STEM disciplines has dropped by 3% [1]. This decline is due primarily to the perceived idea that STEM subjects are difficult. To address this concern, many initiatives have been launched in different European countries. Examples include cl@ssi 2.0 [2] in Italy, Escuela 2.0 [3] in Spain and CAPITAL [4] in the United Kingdom. Still, most of these projects have not been widely successful as they were designed for specific countries and they have targeted one audience type only (i.e., primary or secondary school students).

Trying to fill this gap, the EU Horizon 2020-funded project [5] was launched in 2016 to build a pan-European learning network platform that supports fast dissemination of learning content to a wide audience in a ubiquitous manner. Indeed, the NEWTON project provides diverse forms of teaching and learning (e.g., formal and non-formal), supports different educational levels (i.e., from primary school to university), and integrates novel learning and teaching practices designed based on innovative technologies such as gamification [6,7], multi-sensorial content [8-10], and virtual labs [11]. The project also employs content personalization and adaptation to fit perfectly users' profile and deploys state of the art digital fabrication labs (Fab Labs) [12] to enable remote access to different fabrication technologies (i.e., 3D printers, laser and vinyl cutters, and milling machines) and virtual learning content.

The NEWTON project relinquishes the classical approach that considers the educator as the only source of information and the classroom as the only place where knowledge can be disseminated. Instead, it endorses a technology-based student-centric approach that enables students to learn from different sources (e.g., classroom, information repositories, social networking, and online training) and to control the flow of information in line with their specific needs. In this way, the NEWTON project adheres to today's learners' mindset that favors education, which is relevant to the real world they live in and which is interesting and fun [13].

To validate the effectiveness of the NEWTON project's approach, multiple small and large-scale pilots have already taken place in several European countries (i.e. Ireland, Italy, Romania, Spain and Slovakia). Over one thousand students from different educational levels, including students with special needs, are estimated to take part in these pilot tests. This paper describes one of the small-scale pilots, labeled *Fab Lab STEM*, deployed by the NEWTON project team at Saint Patrick's Boys National School (B.N.S) in Drumcondra, Dublin, Ireland. The *NEWTON Fab Lab STEAM* involves remote access to digital fabrication facilities, mainly 3D printers, to enable students to fabricate small-scale prototypes (i.e., ceramic vases). It has two major goals. First, it seeks to consolidate STEM subjects via considering Fab Lab technologies as a support tool that can provide students with a personalized learning environment in which they can put into practice the different theoretical concepts

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acquired in class. Second, it aims at helping students develop various skills and capabilities such as creativity, problem solving and team work. In doing so, we believe that we can raise/arise students' interest in STEM subjects.

The rest of this paper is organized as follows: Section 2 surveys some related work. Section 3 describes the methodology used for the Fab Lab STEM pilot while Section 4 outlines the deployment phase of the Fab Lab pilot test at Saint Patrick's Boys National School. Section 5 presents the results alongside the analysis and Section 6 concludes the paper.

2 RELATED WORK

The *NEWTON Fab Lab STEM* endorses a new learning approach that favors the use of technology as a building material to promote concepts such as "learning by doing" and "enjoying while learning". It is inspired by Neil Gershenfeld and Paulo Blikestein visions [14,15] that advocate the use of Fab Lab technologies as a tool to improve people's skills and an alternative to the conventional classroom education. Indeed, Blikestein created and deployed a new type of digital fabrication laboratory, called FabLab@School, at Stanford University targeting school children. It focuses on STEM disciplines and accommodates a teacher preparation program that is meticulously designed to enable FabLab@School's full integration within the schools' curricula.

Since then, a growing number of programs have been launched to demonstrate the positive impact of digital fabrication on education. For instance, SCOPES-DF [16] is a project developed by FAB Foundation to promote the use of digital fabrication in STEM education. It consists of a network of Fab Labs, located in multiple countries, which provide various resources that are used to develop lesson plans aligned with the U.S. national education standards. AuLAB [17] is a Spanish project developed by LABoral Art Center in collaboration with the Ministry of Education of Asturias. It targets primary, secondary and vocational education students and aims at adapting education to the needs and peculiarities of each one of these groups. In Ireland, two projects are worth mentioning: Fab Lab Limerick [18] and WeCreate [19]. Both offer cultural and educational programmes for students, designers, crafters and entrepreneurs, bridging the gap between these technologies and creatives from all disciplines. The *NEWTON Fab Lab STEM* shares the same aspirations with all these projects. Yet, what distinguishes *NEWTON Fab Lab STEM* from the rest is its support for remote access to Fab Lab technologies, enabling students, including those with special needs, to benefit from Fab Lab experience anywhere, anytime.

3 METHODOLOGY

The *NEWTON Fab Lab STEM* pilot was developed to target Fab Lab instructors alongside students and teachers from primary and secondary schools. It focuses on enabling students to fabricate small-scale prototypes to grasp the theoretical concepts covered in class using a hands-on approach. It also strives to develop various skills among students such as creativity, problem solving and team work. Students taking part in the *NEWTON Fab Lab STEM* pilot are required to design and fabricate ceramic vases using a remote 3D printer and the PLA filament, with sandstone and a binding polymer, that creates the ceramic surface finishing. The *NEWTON Fab Lab STEM* pilot involves three stages: 3D modeling, preparing 3D files, and sending the files to the 3D printer.

3.1 3D Modeling

The first phase of the *NEWTON Fab Lab STEM* pilot consists of designing the ceramic vases using a free 3D modeling software, called FreeCAD. Students are required to design two types of vases: square-based and triangle-based, each of which is made of three parts: top, middle and bottom. To do so, students are provided with paper-based and video-based tutorials that explain the various steps to follow and the different commands to execute when manipulating the software (i.e. how to work in different workbenches, how to visualize the 3D model from different angles (top, bottom, front view and axonometric views), how to create primitive objects, how to transform them, how to do Boolean operations, and how to change dimensions and assign properties to the created objects).

3.2 Preparing 3D Files

Once the modeling phase is completed, students generate the stereolithographic files that will be used by another free software, called Ultimaker Cura, to prepare the files that will be sent to the 3D printer.

As in the first stage, students are given paper-based and video-based tutorials to learn how to import stereolithographic files and to set the different parameters such as quality, infill, material, speed, temperature and support. When finished, students save the files in GCode format. Although each student is required to design all parts of each vase, they can prepare the files for only one part to be sent to the 3D printer.

3.3 Sending Files to the 3D Printer

The last stage of the *NEWTON Fab Lab STEM* pilot consists of sending the design and GCode files to the 3D printer located in Madrid, Spain. To this end, students are presented with a paper-based tutorial that explains how to send the files using the Cloud Hub interface, which was developed at CEU San Pablo University. Once the files are sent, students are given a short presentation that explains how the 3D printer will fabricate the designed 3D objects.

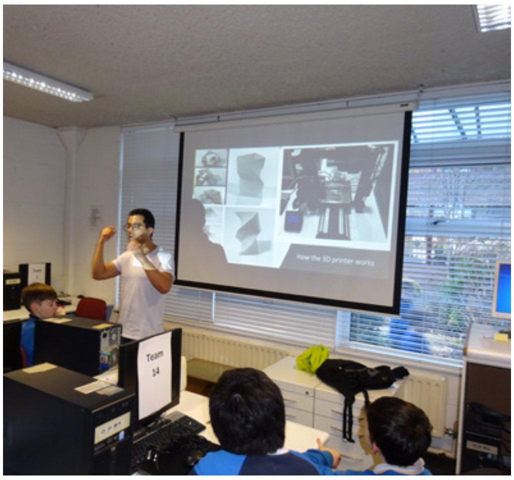

Figure 1: A brief presentation given by the NEWTON project team to the Saint Patrick's B.N.S students about the different components of a 3D printer and how they work

4 CASE STUDY

The *NEWTON Fab Lab STEM* pilot test was deployed at Saint Patrick's B. N. S. in Drumcondra, Dublin, Ireland. Twenty-nine 6th graders, between the age of 10 and 12, took part in the pilot test. They worked in pairs to design the vases' three parts and to prepare the 3D files. The pilot test was carried over two days (19th and 21st February 2018), each of which consisted of a 3 hours long session. On the first day, students were asked to design the two types of the ceramic vases using FreeCAD. On the second day, students used Ultimaker Cura to prepare the 3D files and to send them to the 3D printer using the Cloud Hub interface.

Figure 2: Students from Saint Patrick's B.N.S in Dublin modeling the ceramic vases using FreeCAD

Multiple tests and questionnaires were distributed at the beginning and at the end of the pilot test to assess students' learning experience. Before starting the pilot test, students were handed two questionnaires: Demographic and Learner Motivation & Affective State (Pre) as well as a Knowledge Pre-test to evaluate the participants' familiarity with the 3D printing concepts. Similarly, at the end of the pilot test, students were given two questionnaires: Learner Motivation & Affective State (Post) and the Learner Usability along with a Knowledge Post-test. This is to measure the students' perception about the *NEWTON Fab Lab STEM* pilot and the level of expertise they acquired in designing and modeling 3D objects.

Beside the tests and the questionnaires, the NEWTON project team members documented their observations during the pilot test. These observations provided valuable insights on how things went and the possible improvements to be implemented to make the Fab Lab experience better. In addition, four students, selected at random, were interviewed at the end of the pilot test. Each interview lasted five minutes where participants were asked to express their opinions about the *NEWTON Fab Lab STEM* pilot's usability and its impact on STEM education.

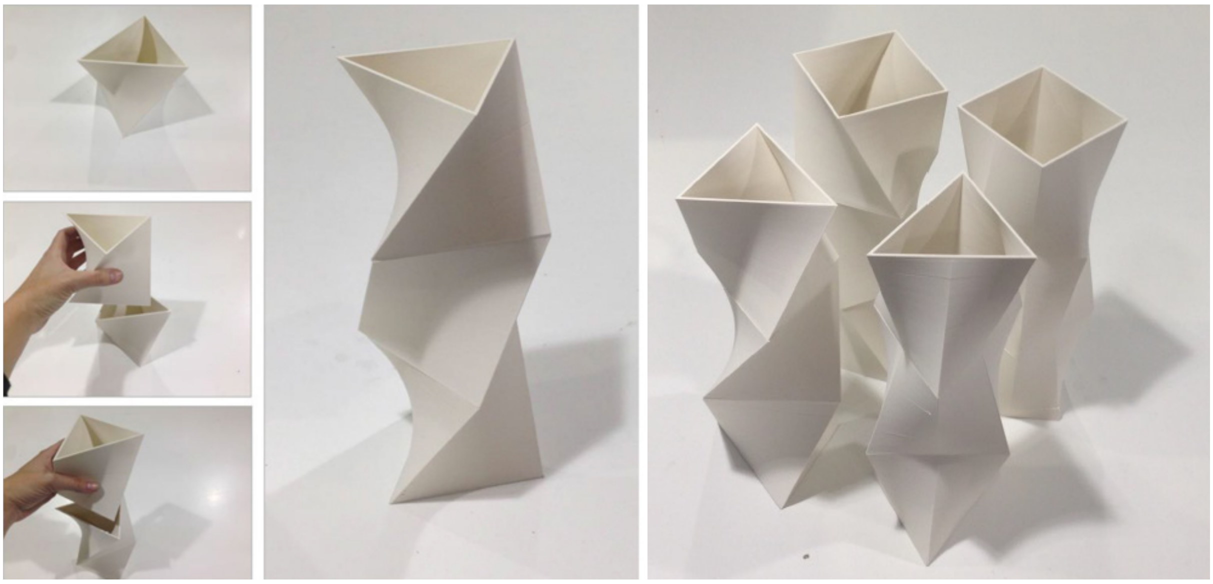

Figure 3: Ceramic vases created by the students of Saint Patrick Boys School in the context of the NEWTON Fab lab Pilot Test

5 RESULTS

Table 1 summarizes the analysis of the pre-test and post-test questions. We observe that most students were not familiar with the Fab Lab concept nor were they acquainted with the 3D printing process. Yet, after taking part in the *NEWTON Fab Lab STEM* pilot test, most students were able to describe the concepts of 3D printing and 3D modelling and to name the tools that they used to fabricate the 3D objects. It is worth mentioning that only 24% of students were able to correctly describe the *NEWTON Fab Lab STEM* pilot process. We believe that this is mainly due to the way the question was asked as most students got confused and described their Fab Lab experience.

Table 1. *Pre-test and Post-test results.*

Do you know?	Pre-test		Post-test	
	Yes	No	Yes	No
3D printing	41%	59%	93%	7%
3D modelling	14%	86%	90%	10%
Fab Lab	3%	97%	24%	76%
3D tools & apps.	3%	97%	79%	21%

Fig.4 depicts students' feelings when learning STEM in class as opposed to learning STEM using Fab Lab technologies. All results represent the percentage of students who agree with the specific statements. We observe that Fab Lab technologies made students feel more engaged (34%), less anxious (14%), less bored (21%), happier (10%), and more joyful (38%) compared to STEM lessons in class. However, Fab Lab technologies made students feel angrier (7%) and less relaxed (10%) compared to STEM lessons in class. This is because few students could not follow the tutorials and correctly execute the commands; therefore, they got frustrated and asked permanently for assistance.

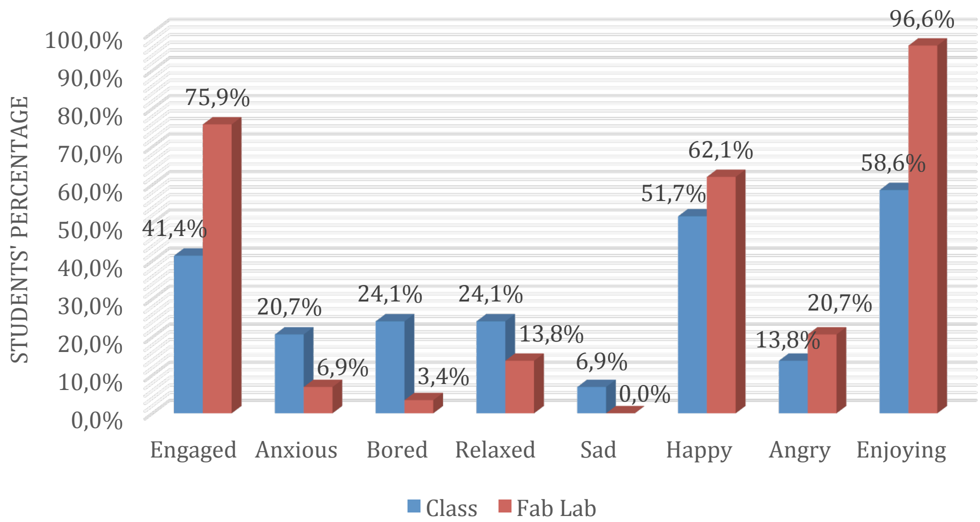

Figure 4: Students' feelings when learning in class vs. when learning with Fab Lab

Finally, Table 2 shows the Fab Lab usability evaluation. "A", "N" and "D" stand for "Agree", "Neutral" and "Disagree". We observe that 79% of students found that the *NEWTON Fab Lab STEM pilot* was useful and 90% reported that they had fun using it. In addition, 90% of students reported that they would recommend it to a friend. Note that 45% of students stated that it is easy to learn about Fab Lab against 31%. Again, this is because few students had difficulties following the tutorials and required the NEWTON project team's assistance.

Table 2. *Fab Lab usability evaluation*

Fab Lab	Useful			Easy to learn			Fun to use			Recommend it to someone		
	A	N	D	A	N	D	A	N	D	A	N	D
Percentage (%)	79	21	0	45	24	31	90	10	0	90	10	0

6 CONCLUSIONS

When designing the *NEWTON Fab Lab STEM* pilot, we tried to endorse the concepts of "learning by doing" and "enjoying while learning" in order to improve creativity and make students keener to the possibility of integrating digital fabrication technologies into their schools' curricula. We believe that this approach enables students to focus more on the learning process and to better acquire the knowledge they seek. We also believe that the *NEWTON Fab Lab STEM* pilot test has achieved its major goal: promoting the idea that STEM subjects can be fun, interesting, and relevant to today's learners' mindset.

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