

NEWTON FAB LAB INITIATIVE: ATTRACTING K-12 EUROPEAN STUDENTS TO STEM EDUCATION THROUGH CURRICULUM-BASED FAB LABS

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Abstract

This paper presents *NEWTON Fab Lab Initiative*, an educational platform which is part of the EU Horizon 2020 NEWTON project. It enables students to learn complex theoretical concepts via fabricating small to medium size prototypes using Fab Labs technologies. The goal is to attract K-12 students to STEM education by promoting new concepts such as “learning by doing” and “enjoying while learning” in order to dispel the common belief that STEM-related subjects are hard or boring. Two small-scale pilots were carried out in two schools (i.e., an Irish primary school and a Spanish secondary school) to assess the effectiveness of the NEWTON Fab Lab Initiative. Thirty nine students took part in the pilots that consisted of modelling and fabricating 3D ceramic vases. Motivation and affective state questionnaires were provided to students before and after using the *NEWTON Fab Lab* technologies. Results showed significant improvements in terms of students' interest in science classes and students' engagement. Results also showed a significant drop in students' boredom after using the *NEWTON Fab Lab* technologies.

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

1 INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM) are foreseen to be the true drivers of Europe's future economy. Indeed, an increasing number of jobs will come to depend on STEM skills, and such careers are among the fastest growing worldwide [1]. Unfortunately, the gap between the job market demands and the availability of these skills keeps growing. In 2016, 40% of European employers had difficulties finding people with the right skills [2]. One of the key factors contributing to this situation is the drop in the number of graduates in STEM-related studies, often perceived as too difficult or too boring. As such, attracting students to STEM education from young age is key to ensure long-term STEM pipeline outcomes, enabling Europe to remain globally competitive.

Part of the STEM disengagement problem has to do with the poor academic preparation for college, which begins in grades K-12 [3]. Indeed, traditional teaching methods considering the educator as the only source of information are often seen as dull and obsolete [4]. Moreover, STEM concepts are usually taught independent of one another and are not associated with any of the practical skills required by STEM occupations.

Holdren *et al.* [5] emphasized that in order to inspire students to learn STEM, there is a need for both rigorous K-12 education curricula and new initiatives. In this regard, various technology-based learning techniques have been proposed to improve students' attitude toward learning STEM-related subjects. They integrate novel learning and teaching practices designed based on innovative technologies such as flipped classrooms [6], gamification [7, 8], virtual labs [9, 10], adaptive multimedia [11, 12], multi-sensorial content [13], augmented and virtual reality [14, 15]. These approaches have demonstrated promising results in terms of improving learners' (i.e. from primary school to third level education) knowledge gain in STEM-related subjects.

Recently, a growing number of studies [16 - 24] have demonstrated the great impact of fabrication laboratories (Fab Labs) [25, 26] on students' academic and personal progress. These laboratories are considered as small workshops, equipped with a set of computer-controlled tools (e.g., 3D printers, laser and vinyl cutters, and milling machines) that offer personalized digital fabrication. Although Fab Lab-based learning has existed in pedagogy for years, uncertain and unknown is the extent to which it can shift students' attitude toward STEM. To the best of the authors' knowledge, none of the existing studies have considered this aspect.

This paper presents the *NEWTON Fab Lab* initiative, an educational platform that aims at promoting curriculum-based Fab Labs (i.e. using Fab Labs as a complementary tool to the classic teacher-based approach) to permit students to learn concepts such as geometry, design and engineering through fabricating small to medium size prototypes.

This initiative is part of the EU Horizon 2020 NEWTON project¹ whose main objectives are to design, and implement, integrate and disseminate technology-enhanced learning applications and innovative learning approaches. NEWTON Project investigates the impact of using innovative technologies such as augmented reality and virtual reality, virtual labs, adaptive and personalised multimedia and multiple sensorial media [10, 11, 28, 29]. Innovative pedagogical approaches such as problem based learning, flipped classroom and game-based learning and gamification [6, 7, 8] combined with the above mentioned technologies were deployed in over 20 STEM related small and large scale pilots.

A research study was carried out in an Irish primary school and a Spanish secondary school to evaluate the impact of this initiative on students' attitude toward learning STEM. Results show that the *NEWTON Fab Lab* initiative can foster students' interest to learn STEM-related subjects even if they have negative or impartial attitude toward learning STEM. It also made students feel more engaged and less bored while learning compared to the classic teacher-based approach.

The rest of the paper is organized as follows. The next section gives an overview of the methodology used for the *NEWTON Fab Lab* initiative along with small-scale pilots that took place at the two schools. The following section presents the results while the last section summarizes the paper and outlines the conclusions of the performed research study.

2 METHODOLOGY

Owing to the high costs of setting-up and maintaining Fab Labs, most public schools worldwide are unable to afford them. The idea behind the NEWTON Fab Lab Initiative is to enable such schools to remotely access existing Fab Labs, deployed within the same country or even worldwide, rather than pressuring them to invest in expensive digital fabrication equipment. The NEWTON Fab Lab Initiative promotes the concept of curriculum-based Fab Labs to enable students to make use of digital fabrication to grasp the theoretical concepts using a hands-on approach. It consists of three lessons, each of which focuses on a specific technology (i.e., 3D printing, computer numerical control machine (CNC) and Laser and Vinyl cutters). These lessons are considered as quests to achieve fixed goals, which can be individually adapted to meet the course outcomes.

Each lesson is made up of a series of challenges to keep students interested while providing them with a sense of achievement. Every time a challenge is completed, students are awarded points to track their progress. When all challenges in a lesson are accomplished, certificates are handed out to students. For each lesson, there exists three certificate types: beginner, intermediate and advanced, each of which reflects the mastery of the theoretical concept used in that particular lesson. Obtaining the advanced certificate in a lesson grants the student the *Hero* status in that lesson. Holding the *Hero* status in all the lessons grant the student the *Super Hero* status.

2.1 NEWTON Fab Lab Initiative small-scale pilots

To validate the effectiveness of the NEWTON Fab Lab Education Initiative, two small-scale pilot-tests were carried out in two different schools. Both pilots involved the 3D printing lesson, which is made of three levels:

- *Beginner*: focuses on geometry, perceived to be very difficult by most students in primary and secondary schools. The goal is to help students improve their visual imagination and their understanding of graphic projections. It involves the design and the fabrication of ceramic vases using 3D printers.
- *Intermediate*: focuses on teaching students physics and math concepts (e.g. form analysis and spatial reasoning) through the design and fabrication of 3D mini-rockets.

¹ <http://www.newtonproject.eu/>

- *Advanced*: aims at teaching students coordination and team work through fabricating a 3D prosthesis hand for a child.

The research study presented in this paper involves the *beginner* level only. It has four stages:

- *Modelling the ceramic vases*: consists of using *FreeCAD*², an open-source 3D modelling software, to design the ceramic vases. Students have the option to choose between two types of vases: square-based and triangle-based. Each vase is made of three parts: top, middle and bottom, and is fabricated by a team of three students, each of whom oversees the fabrication of one part. They are provided with paper-based and video-based tutorials that show the various steps to follow and the different commands to execute when manipulating the software.
- *Preparing models for 3D printing*: consists of using *Ultimaker Cura*³, another open-source software, to prepare the ceramic vases for 3D printing. As in the first stage, students are given paper-based and video-based tutorials to learn how to set up the various parameters like infill, speed and temperature. These files are then saved in GCode format.
- *Sending GCode files to the 3D Printer*: consists of sending the GCode files to the 3D printer located in CEU San Pablo University, Spain. To this end, students are provided with a paper-based tutorial that explains how to login and use the *newtelp*⁴ platform, developed by the NEWTON project team.
- *3D Printing presentation*: once the files were sent, students are given a short presentation that covers how the 3D printer will fabricate their designed models.

The pilot-tests consisted of two 3-hours long sessions carried over two days. In the first session, students were asked to design the ceramic vases while in the second session, students were required to prepare the 3D files and to send them to the remote 3D printer.

2.2 Participants

Over the course of this study, we worked with two schools: Saint Patrick's Boys National School (B.N.S) in Dublin, Ireland and CEU Monteprincipe School in Madrid, Spain. The former is a primary school while the latter is a secondary school. We worked closely with the schools' principles to identify and suggest the classes to reach out to for participation, based on three criteria: class curriculum, teachers' willingness to participate in the study and students' familiarity with technology (i.e., computers, smartphones, video games). We then reached out to the teachers directly to invite them to participate.

Thirty nine 6th and 7th-grade students between the age of 10 and 13 took part in the pilots. 87% of the sample identified as male and 26% of the participants were gifted students. 10% of the sample reported that they have never used a smartphone while 8% stated that they have never played games on a gaming console (PlayStation, Xbox, Nintendo DS, etc.).

2.3 Procedure

The pilot-test activities were developed in collaboration with two teachers from both schools. The teachers provided the learning goals of the science classes and the NEWTON Project research team discussed ways to adapt the pilot-test to achieve these learning outcomes. The research team and the teachers met again to agree on the schedule and to rehearse the procedures for each pilot session.

Prior to undertaking the pilot, ethical approval was obtained from Dublin City University and CEU San Pablo University Ethics Committees. Consent forms were provided to parents and assent forms were signed by students willing to participate in this study. A description of the project and the pilot were provided in a plain language statement and the data management plan was also made available to both parents and students.

²<https://www.freecadweb.org/>

³<https://ultimaker.com/en/products/ultimaker-cura-software>

⁴<https://newtelp.eu/>

2.4 Data collection

The core of the evaluation procedure (see Table 1) employed in this pilot was developed by the NEWTON project's Pedagogical Assessment Committee (PAC) [27] and was used in all the project's pilots. It includes the following:

- *Learner Demographics questionnaire*: used to collect information about learners such as gender, age, feeling about school, marks obtained in STEM-related subjects, attitude toward STEM and frequency of use of technology (e.g., computers, smartphone and video games).
- *Learner Motivation and Affective State questionnaires (pre and post)*: assess learners' perception toward STEM learning and their emotions while learning before and after using NEWTON Fab Lab technologies. Both had four 5-point Likert scale questions anchored by "strongly disagree" and "strongly agree" or "not at all" and "extremely". The Post questionnaire had five additional 5-point Likert scale questions anchored by "strongly disagree" and "strongly agree" to assess students' attitude toward STEM after participating in the NEWTON Fab Lab Initiative pilot.

It is noteworthy to mention that students' attitude toward STEM when using the classical teacher-based approach is assessed via the *Learner Demographics* questionnaire.

Table 1. Assessment procedures used during the small-scale pilots.

Activity	Session 1	Session 2
Demographics	✓	-
Learner Motivation & Affective State Pre	✓	-
Learner Motivation & Affective State Post	-	✓
Observational Assessment	✓	✓

3 RESULTS

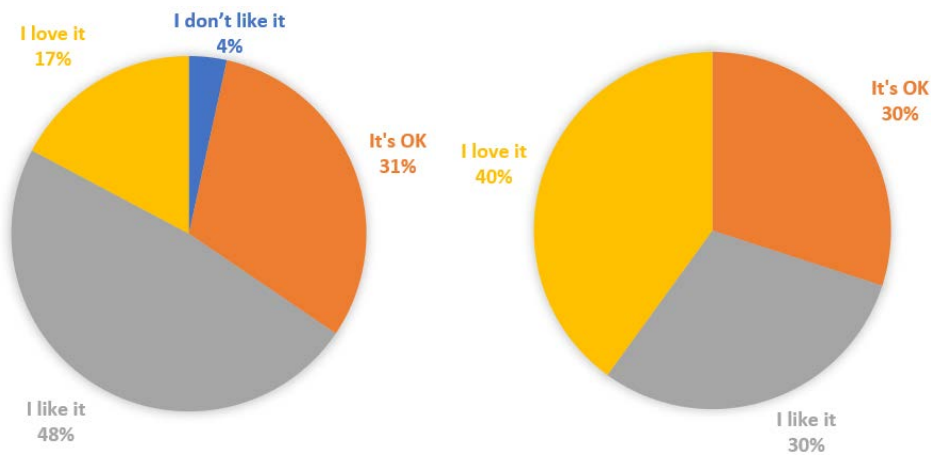
3.1 Demographics

As part of the Demographics questionnaire, students were asked to rate their feelings in relation to learning STEM subjects (see Fig. 1). Most of the answers in both schools ranged between "I like it" and "I love it". These results are encouraging as we seek to enable these students to maintain the same attitude or boost it via the NEWTON Fab Lab Initiative. Still, what is interesting is that one student from Saint Patrick's B.N.S noted that he does not like learning STEM while 30% of the participants from both schools reported that "It's OK". We believe that these students are uncertain about whether they like learning STEM or not, making them predisposed to early disengagement from STEM studies.

3.2 Motivation and affective state

3.2.1 All participants

When asked about their interest in science classes (Learner Motivation & Affective State Pre and Post), students in both schools seemed more interested in them after using the NEWTON Fab Lab technologies (see Table 1). A comparison between the pre and post results revealed statistically significant improvements of 25.3% and 17.9% for St. Patrick's B.N.S and CEU Montepincipe, respectively.



(a) Saint Patrick's B.N.S (b) CEU Montepincipe
 Figure 1: Students feelings about learning STEM (Demographics)

Table 1: How interested are you in science classes?

	St Patrick's B.N.S		CEU Montepincipe	
	Pre	Post	Pre	Post
Mean	3.52	4.41	3.90	4.60
SD ⁵	0.97	0.46	0.99	0.27
SE ⁶	0.18	0.086	0.31	0.08
p-value	< 0.001		0.0095	

Table 2: Students emotions while learning

		St Patrick's B.N.S		CEU Montepincipe	
		Traditional	Fab Lab	Traditional	Fab Lab
Engagement	Mean	3.10	4.07	3.60	4.60
	SD	1.45	0.85	0.27	0.27
	SE	0.27	0.16	0.84	0.84
	p-value	< 0.001		< 0.001	
Boredom	Mean	1.82	1.34	1.80	1.20
	SD	0.79	0.31	0.62	0.18
	SE	0.16	0.06	0.20	0.06
	p-value	< 0.001		0.0051	

To better understand the reason behind such an increase in interest in science classes, we looked at how students rated their emotions while learning using the traditional teacher-based approach vs. using Fab Lab technologies. We focus on two key emotions: engagement and boredom. Table 2 illustrates the results. Comparison between the average scores of the two approaches showed statistically significant improvements of 31.3% and 27.8% in terms of engagement for St. Patrick's B.N.S and CEU Montepincipe, respectively. Results also showed statistically significant declines in boredom of 26.4% for St. Patrick's B.N.S and 33.3% for CEU Montepincipe.

⁵ Standard deviation

⁶ Standard error

Note that the vast majority of students in both schools would like to use more technology in science classes. Comparison between Learner Motivation and Affective State pre and post results showed an improvement of 6.3% ($\alpha = 0.05$, $t(27) = 1.28$, $p = 0.088$) for St. Patrick's B.N.S and a decline 2.20% ($\alpha = 0.05$, $t(9) = 1$, $p = 0.343$) for CEU Montepriincipe. However, these findings are not statistically significant.

Finally, Fig. 2 depicts students' response to the question: *Would you like to use NEWTON Fab Lab technologies in science classes?* While 87% of the students reported that they want to use Fab Lab technologies in science classes 13% did not answer the question, all of them were from St. Patrick's B.N.S. This is because these students took a long time to finish the pilot and they had to be in the next class; consequently, they could not reach this question.

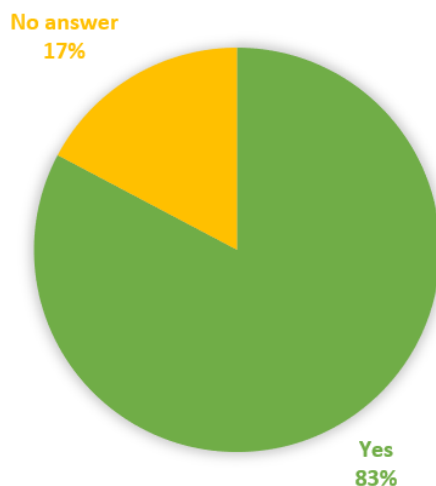


Figure 2: Students' answer to the question: would like to use NEWTON Fab Lab technologies in science classes?

3.2.2 Participants with negative/impartial attitude toward learning STEM

In this section, we focus on participants who reported that they do not like to learn STEM (Group A) or have impartial attitude toward learning STEM (i.e., they chose "It's OK") (Group B) in order to evaluate whether *NEWTON Fab Lab Initiative* can shift these attitudes.

After taking part in the *NEWTON Fab Lab Initiative*, students in all groups seemed more interested in science classes, more engaged and less bored. Results (see Table 3) showed increases of:

- 300% and 28.6% for groups A and B in Saint Patrick's B.N.S and 27.3% for Group B in CEU Montepriincipe in terms of interest in science class.
- 300% and 56.3% for groups A and B in Saint Patrick's B.N.S and 27.3% for Group B in CEU Montepriincipe in terms of engagement.

Results also showed declines in terms of boredom of 33.3% and 33.5% for groups A and B in Saint Patrick's B.N.S and 33.5% for Group B in CEU Montepriincipe.

4 CONCLUSIONS

The small-scale pilots described in this paper investigate the impact of *NEWTON Fab Lab Initiative* on attracting European K-12 students to STEM education. The pilots were carried out in St. Patrick's B.N.S, an Irish primary school, and CEU Montepriincipe, a Spanish secondary school, and involved thirty nine 6th and 7th grade students. Results show that the *NEWTON Fab Lab Initiative* can encourage students to learn STEM-related subjects even if they have negative or impartial attitude toward learning them (groups A and B). Results also show that using *NEWTON Fab Lab technologies* while learning made students feel more engaged and less bored. Such feelings are essential in stimulating students' motivation to engage actively in the learning process, especially for students in groups A and B.

Table 3: Results of participants with negative and impartial attitude toward learning STEM

		St Patrick's B.N.S				CEU Montepincipe	
		Group A (N = 1)		Group B (N = 9)		Group B (N =3)	
		Pre	Post	Pre	Post	Pre	Post
Interest in science classes	Mean	1	4.0	3.11	4.0	3.66	4.66
	SD	0	0	0.60	0	1.15	0.57
	SE	0	0	0.20	0	0.66	0.33
	p-value	-		0.00217		-	
Engagement	Mean	1	4.0	2.56	4.0	3,66	4,66
	SD	0	0	0.93	1.0	0,57	0,57
	SE	0	0	0.31	0.33	0,33	0,33
	p-value	-		< 0.001		-	
Boredom	Mean	3.00	2.0	2.0	1.33	2.0	1,33
	SD	0	0	0.87	0.50	1.0	0,57
	SE	0	0	0.87	0.50	0,57	0,33
	p-value	-		0.00283		-	

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