# Innovative solutions for Technology-Enhanced Learning in Digital Fabrication Laboratories

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***Abstract— The present paper illustrates research results of innovative educational approaches deployed by the Digital Fabrication Laboratory of Madrid-based CEU University (Fab Lab Madrid CEU) through the NEWTON project, a large European Union Horizon 2020 project which designs and support innovative solutions for technology-enhanced learning that are validated with diverse audiences, which include primary and secondary schools, institutes, universities and students with special educational needs.***

***The NEWTON technologies involve virtual teaching and learning laboratories (virtual labs), augmented and virtual reality-enhanced learning, adaptive and personalized multimedia and multiple sensorial media (mulsemedia) delivery, gamification and remote access to Digital Fabrication Laboratories (Fab Labs). These technologies are used in conjunction with different pedagogical approaches, including game-based, personalized and self-directed learning methods, as flipped classroom, online problem-based learning and e-practice testing. NEWTON also builds a management platform, called NEWTELP that allow learner and teacher interaction with content and courses and support dissemination of learning content to a wide audience.***

***Index Terms* — Fab Lab, Technology, Education, Digital Fabrication.**

## I. INTRODUCTION

In the last years, different technology-based teaching approaches have been proposed integrating novel practices that use innovative technologies such as virtual teaching and learning laboratories (virtual labs) [1, 2], augmented and virtual reality-enhanced learning [3, 4], adaptive and personalized multimedia and multiple sensorial media delivery [5, 6], gamification [7] and digital fabrication technologies [8 - 12]. Specifically, Digital Fabrication Laboratories (Fab Labs) are considered as attractive models of education, particularly as places to provide training in a range of fields from design thinking to product development [13 - 15]. They make available new technologies and have become a new tool to the conventional teacher-based approach, allowing students to learn design, art, architecture or engineering through the fabrication of small to large scale prototypes using digital fabrication machines, such as 3D printers, laser cutters, vinyl cutters and milling machines.

This paper presents a new Fab Lab initiative designed for the NEWTON Project, a large European Union Horizon 2020 project, which designs and support an educational platform that allows to remotely using Fab Lab machines to students of diverse backgrounds and levels from various institutions (schools, institutes and university faculties). A research study was carried out on diverse audiences through four pilots to evaluate the impact of this initiative on students' knowledge gain, motivation and satisfaction using Fab Lab technologies remotely through the NEWTON platform, as part as their educational activities.

The paper is organized as follows. After the brief introduction, a section given an overview of the methodologies used on the research is described, including the groups of participants and the description of the four Fab Lab pilots conducted during the research. Then, a paragraph describing the data collection methods is included before a detailed analysis of the results and the conclusions of the research study that are summarized in the last paragraph.

## II. METHODOLOGIES

The remote use of digital fabrication technologies through the NEWTON Project platform allows schools, institutes and universities to make use of Fab Lab machines, such as 3D printers, milling machines, laser cutters and vinyl cutters, having access to innovative tools and infrastructures without setting up and maintaining a Fab Lab. The Fab Lab initiative designed by Fab Lab Madrid CEU (the digital fabrication laboratory based at CEU University), provides remote access to these technologies as well as all the materials needed for the instruction of the students on the use of digital fabrication technologies. Each technology is taught in a specific lesson made up of challenges that should be accomplished in order to get a type of certificate that reflects the mastery in that particular lesson.

### *A. Participants*

Participants involved diverse students from primary and secondary schools, institutes and universities, some of them with special educational needs. Four pilots were conducted in three different institutions: CEU Montepríncipe School, the Institute of Technology of CEU University and CEU San Pablo Foundation, all of them in Madrid, Spain. The former is a primary and secondary school, the second one is the faculty in charge of the Department of Architecture and Design and the Deparment of Enginnering of CEU University and the last one is the CEU University Foundation, which is devoted to provide academic and professional excellence, connecting the university with the society through various programs as CEU Best, which involves students that come from a wide range of foundations and ONGs, such as Helping by Doing Foundation, Senara Foundation, Proyecto Esperanza, La Merced Migraciones, Soñar Despierto Foundation, ONG Cesal, Barró Foundation and Asociación La Rueca.

In order to design the Fab Lab initiative, we first contacted with the institution's teachers and faculty members to identify the contents to be included in the classes, which was based on their class curriculum. After that, we suggested a possible project to be designed and fabricated by the students using one of the four Fab Labs technologies available. Fifty four students took part in four pilots: 65% of the sample identified as male and 35% as female. 18% of the participants were gifted students and 68% of them were considered in risk of social exclusion.

### *B. Pilots testing the NEWTON Project Platform*

The paper describes four Fab Lab pilots in which students engage remotely with digital fabrication technologies. The pilots were carried out in three different institutions to evaluate the impact of the Fab Lab education initiative on students' knowledge gain, motivation and satisfaction using digital fabrication technologies remotely through the NEWTON Project platform.

The first pilot was carried out at CEU Montepríncipe School involving ten gifted secondary school students and tested the remote use through the NEWTON Platform to 3D printers, as support tools oriented to design and fabricate parametric vases modeled using doubly ruled surfaces (hyperbolic paraboloids) to demonstrate the concepts developed by the students in theoretical geometry classes using a hands-on approach.

The second pilot was focused on the implementation of the design of a drone using a fuselage capable of accommodating an imaging package or other instrumentation. Open software was used for the design of the pieces while the fabrication involved the remote use of the Fab Lab laser cutter machine, monitored through the NEWTON Project platform by the participants of the pilot: seven students studying at the Department of Engineering of the Institute of Technology at CEU University.

The third pilot was centered on the fabrication of small-scale architectural models using remotely a vinyl cutter machine to test possible designs made in a parametric software called Grasshopper. Thirty students in risk of social exclusion studying at the Department of Architecture and Design at CEU University's Institute of Technology were involved in this pilot.

Finally, the last pilot was carried out with a group of seven students that came from different foundations and ONGs, thanks to a program called CEU Best implemented by CEU Foundation, which provides instruction in technical skills to young people coming from different backgrounds that are considered in risk of social exclusion. The aim of the class was to improve the design of a small medical device (a new-born incubator) to be fabricated using a milling machine monitored remotely.

The Fab Lab educational initiative is designed to follow a project based learning approach, where students work collaboratively on the design and fabrication of a prototype. All the pilots involved the following stages. Classes start with a short introductory class on digital fabrication, showing possible applications of Fab Lab technologies in different disciplines and fields. After that, a theoretical introduction is given to teach some concepts related to Design, Geometry and Maths to be applied on the design of the prototype. Finally, students focused on the design of the prototypes using open-source 3D modeling parametric software. They are provided with paper-based and video-based tutorials that show the steps to follow and the commands to execute when manipulating the software.

The next stage is focused on the use of the NEWTON Project platform [16] that allows to easily using Fab Lab machines remotely, so that students are able to send their designs to be fabricated even if they are not physically in the Fab Lab. The Fab Lab NEWTON Project platform is a proprietary Cloud Platform developed at CEU University to deploy, scale, manage and orchestrate containerized cloud applications and micro-services. The cloud hub monitors in real-time the status and the resource availability of all the interconnected Fab Labs and routes a fabrication batch to the Fab Lab that is geographically closer to the student. After sending the files through the platform, students are given a short presentation that explains how the Fab Lab machines can fabricate their designed models using a virtual reality application.

### *C. Data Collection*

The core of the evaluation procedure employed at the Fab Lab educational initiative was developed by the NEWTON project's Pedagogical Assessment Committee [17] and it is indicated below. First of all, all required forms for ethics approval were provided to the responsible faculty members and teachers in order to be distributed to participants, such as the *Informed Consent Form*, the *Informed Assent Form*, the *Plain Language Statements* and the *Data Management Plans*. Parental /guardian consent on an *Informed Consent Form* (ICF) for all secondary school students was collected before starting the pilot. As students were sufficiently able to understand the proposed research, they were informed about it, including via the *Plain Language Statement* (PLS), to have their questions and concerns addressed and to express their agreement or lack of agreement to participate. Students expressed their agreement to participate on the *Informed Assent Form*.

The assessment procedure included the following activities. To fully understand student's impressions and get in-depth information about the participants' experience we used information collected from questionnaires. Our aim was to measure student's response to the lesson rating their perceptions about the quality and impact of the Fab Lab technologies, as well as their opinion about how their use increased their knowledge, skills and motivation. We were also interested into analyze whether the participants were able to use Fab Lab machines with confidence during the lesson and if they felt ready to design and prototype by themselves using the skills learned during the pilot.

There were handed-out three questionnaires before starting each pilot: the *Demographic Questionnaire*, a *Knowledge Test on Learning* to investigate the participants' level of knowledge on the subject and finally, the *Affective and Motivation Questionnaire* regarding traditional technology classes. There was also handed-out another questionnaire after the pilots: the *Affective and Motivation Questionnaire*. To gather accurate information about each pilot, we also collected data through observation using notes, pictures and video data. Besides, to determine the student's state of skills we reviewed the student's prototipes to know their level. Finally, we asked faculty members and teachers to complete *Teacher Surveys*.

## III. RESULTS

The research study evaluates the impact of the Fab Lab educational initiative on students' knowledge gain, motivation and satisfaction using Fab Lab technologies remotely through the NEWTON platform during the pilot. Fifty four students took part in the four pilots and provided answers to the various questionnaires in the PAC toolkit. Analysis of the results was performed considering four aspects: frequency of use of technology (groups A1, A2 and A3), educational ability (groups B1 and B2), opinions about the methodology used in conventional classes (groups C1 and C2) and interest on adding more technology in the classes, on site or remotely, to improve the learning experience (groups D1 and D2).

When asked to report the frequency of use of technology indicating the purpose of use, most students (40%) said they were moderate users of personal computers and smartphones and the remaining were either frequent (30%) or infrequent (30%) users.

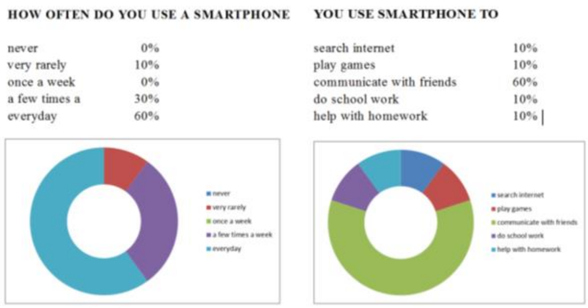


**Fig.1. (a & b) Frequency and purpose of use of technology**

When asked about their grades on courses at the school, institute or university, student's answers ranged among low (35%), average (35%), good (20%) and very good marks (only 10% of students). Students were also asked to rate their feelings about their interest in conventional classes and also, if they though there were something they would change about them to be more easy to approach and active using more technology in the classroom on site or remotely. When asking students about the first question 50% of students said that they were very interested on conventional classes, while 45% were *"Extremely interested"* and only a 5% answered *"Somewhat interested"*. Related to the possible use of Fab Lab technologies to enhance the learning experience, answers ranged between *"Extremely interested"* (70%) and *"Very interested"* (30%) if the technologies could be used on site, while students interested in remote access ranged between 50% *"Extremely interested"* and 50% *"Very interested"*.

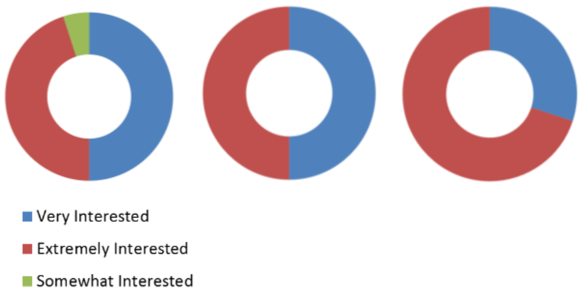


**Fig.2. (a, b & c) Motivation of students in conventional courses (left), on-site (center) and remote (right) access to Fab Lab facilities.**

### A. *Knowledge and Skills Gain*

When using NEWTON Fab Lab technologies, students showed promising improvements in terms of learning outcomes. NEWTON Fab Lab technologies have had an impact on students, motivating them to learn and keep engaged in classes. The greatest increases (43%) were found among students who frequently use technology, followed by those who use it moderately (35%). There have also been encouraging improvements among students who have worse grades, and students who had a neutral attitude toward studies. However, these improvements are not as important as the ones achieved by students who get good marks and those who have a good attitude toward studies and about using new technologies in class.

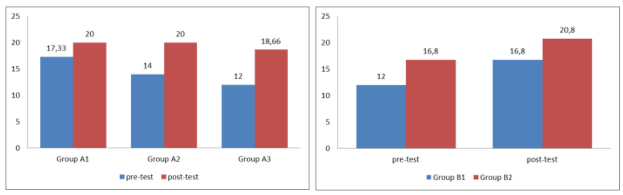


**Fig.3. (a & b) Pre-test and post-test scores based on frequency use of technology (left) and students' grades (right) on infrequent (Group A1), moderate (Group A2) and frequent (Group A3) users of technology and students with average (Group B1) and good marks (Group B2).**

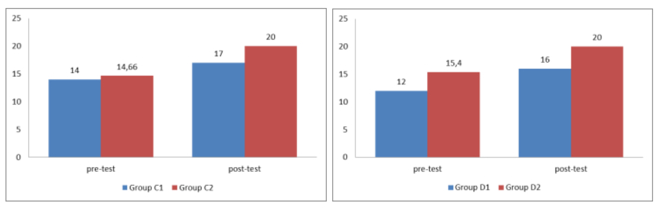


**Fig.4. (a & b) Pre-test and post-test average scores based on students' attitude toward students (left) and about using new technologies (right) on students with neutral (Group C1) and good (Group C2) attitude**

**towards studies and students with neutral (Group D1) and good (Group B2) interest on learning using technologies in class, remotely or on-site.**

After using NEWTON Fab Lab technologies, the groups that benefited the least in terms of knowledge gain are infrequent users of technology and those who have neutral attitude toward studies. It is noteworthy to mention that all students showed a gain in knowledge.

### *B. Learners Motivation*

The results of learners motivation showed a positive impact in students' interest and confidence, as well as increases of 25%, 21% and 12% in their engagement, happiness and enjoyment when learning using NEWTON Fab Lab technologies. 60% of students felt more engaged, 50% felt happier and 60% felt more joy when learning using these technologies. Results also showed increases of 5%, 2% and 5% in students' anxiety, sadness and relax respectively when learning using new technologies, as well as declines of 52% and 32% in students' boredom and anger: 50% of them felt less bored and 100% felt less anger.

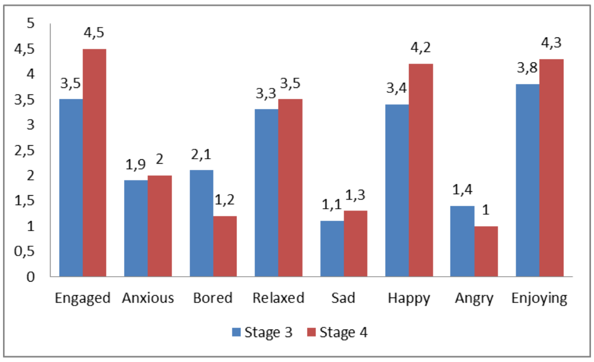


**Fig.5. Feelings while learning (all students)**

Students' interest and confidence after using NEWTON Fab Lab technologies in moderate and frequent users of technology and students with better grades have increased, whether if they have a neutral or positive attitude toward studies or technology. Decreases are noticed in infrequent users of technology and those with worse marks.

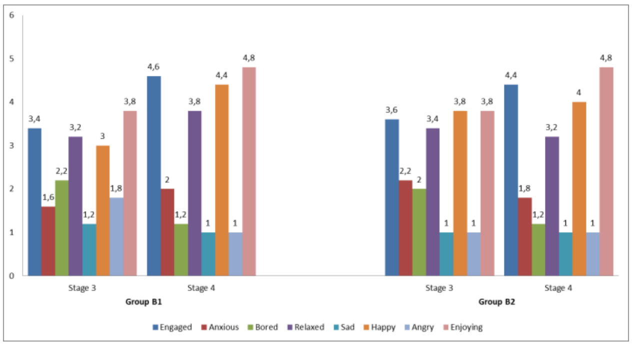


**Fig.6. Feelings while learning regarding educational ability on students with average (Group B1) and good marks (Group B2).**

Using NEWTON Fab Lab technologies made students feel more engaged, happier, enjoying and relaxed (except for students of groups A3 and B2) and also, less bored and angry. Among all the positive feelings, results showed encouraging increases in students' engagement (25%) happiness (21%) and enjoyment (12%) when learning using Fab Lab technologies, as well as big drops in boredom (50%) and anger (32%). Results are promising, especially among gifted students who sometimes show signs of boredom, non-engagement, demotivation and hostility in classes.

### *C. Learners Satisfaction*

Regarding learning satisfaction, the students in all groups reported that they felt engaged, interested and positive (except for infrequent users of technology). Furthermore, Fab Lab technologies had also a positive impact on students' enthusiasm from all groups. Besides, some infrequent users of technology, those with good marks and those with neutral attitude toward technology have affirmed that the use of NEWTON platform to remotely monitor Fab Lab machines made them more interested in studies, which goes in line with NEWTON goals.

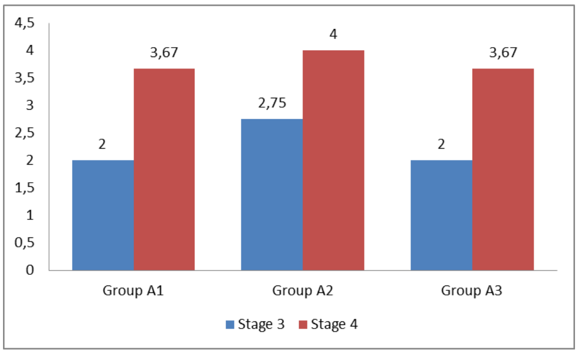


**Fig.7. Satisfaction with NEWTON on infrequent (Group A1), moderate (Group A2) and frequent (Group A3) users of technology.**

The groups that showed the highest improvements in terms of learner satisfaction are moderate users of technology and students with average marks, while the groups that showed the lowest improvements were infrequent users of technology, students with good grades, those who have neutral attitude toward studies and technology. It is noteworthy to mention that only students who have a very good attitude toward school have affirmed that technologies didn´t make them more interested in studies.

## IV. CONCLUSIONS

The four pilots included in this paper investigate the impact of students' knowledge gain, motivation and satisfaction using digital fabrication technologies remotely through the NEWTON Project platform. Results show that the Fab Lab Initiative can encourage students to learn even if they have neutral attitude toward studying. There have also been encouraging improvements among students who have worse grades. In this regard, it is noteworthy to mention that all students showed a gain in knowledge

On the other hand, results showed a positive impact in students' interest and confidence, as well as high increases in their engagement, happiness and enjoyment, respectively when learning using NEWTON Fab Lab technologies in moderate and frequent users of technology and students with better grades. Besides, a slightly increase in students' anxiety, sadness and relax has been detected.

Regarding learning satisfaction, except for infrequent users of technology, all students reported that they felt engaged, interested and positive. Furthermore, Fab Lab technologies had also a positive impact on students' enthusiasm from all groups. It is also worth to mention that some students with a neutral attitude toward technology as well as some infrequent users of technology have affirmed that the remote use of Fab Lab machines through the NEWTON platform made them more interested in studies, which goes in line with NEWTON goals

In order to improve the initiative and based on the lessons learnt, there are some proposals for improvements to be considered. For those students with a previous experience using Fab Lab technologies that preferred to monitor the machines on-site, we suggest the use of Augmented Reality technologies during the workshop to make the experience more realistic. Besides, a more interactive experience to improve the explanation of theoretical concepts and the correct use of the design software in the first stages of the lesson could be implemented, as the use of some practices that complement the text and video tutorials, such as webinars or forums could be implemented to improve the lessons.

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