Digital Fabrication as a Tool for Teaching High-School Students STEM at the University

Covadonga Lorenzo
CEU University
Madrid, 28925, Madrid (Spain)
clorenzo@ceu.es

IDC '17, June 27-30, 2017, Stanford, CA, USA

ACM ISBN 978-1-4503-4921-5/17/06.
http://dx.doi.org/10.1145/3078072.3084323.

Abstract
In the current paper is documented an ongoing education program designed at FabLab Madrid CEU (the Digital Fabrication Laboratory based at CEU University´s Institute of Technology) to teach high-school students STEM in a university environment through digital fabrication technologies. Inspired by the ideas of Neil Gershenfeld and Paulo Blikstein, we are using digital fabrication as a learning tool through which we attempt to create a working educational environment to improve the motivation of the students to finish their pre-college studies and to start a career at the university. All the pedagogies that we are exploring though the programs are based on Seymour Papert concepts related to the use of technology as a building material, the need of a 'learning by doing' approach, the importance of learning to learn to keep learning or the benefits of enjoying while learning.

Author Keywords
FabLab; education; design; fabrication, high-school students; university.

ACM Classification Keywords
D.2.2 Design Tools and Techniques.

Figure 1-4. High-School students working on a model of Oiza's BBVA Building.

Introduction

Four years ago, I founded FabLab Madrid CEU, the Digital Fabrication Laboratory at Madrid-based CEU University's Institute of Technology where I was working as an Associate Professor at the Department of Architecture and Design. The FabLab was created to allow Architecture and Engineering students to improve their skills on digital fabrication thanks to the use of next generation technologies and advanced technological languages. Our university is run by the CEU Foundation, devoted for the development of education and along with our university it runs Barcelona and Valencia-based CEU universities and a great number of high-schools throughout Spain. Due to our link with the Foundation it was usual for us to receive groups of high-school students at our facilities several times a year.

During the guided visits that I was conducting, I became to realize that high-school students were amazed by the projects that we developed and the machines that we used, and that they were willing to participate at the workshops that we offered to our university students. Besides, their teachers were completely surprised with the interest that students seem to show, because as they told me, it was difficult for them to keep their attention and motivation on a conventional work session.

It was then when we thought that it could be a good idea to involve high-school students in some activities developed at the FabLab to motivate them in their current studies and make them see the relevance of what they were learning at their high-schools for their future university careers.

Background

As any FabLab (fabrication laboratory) of the FabLab network, we are a small-scale workshop that has been offering personal digital fabrication in our facilities during the last four years inspired by the ideas of Neil Gershenfeld. [1] We are equipped with an array of flexible computer-controlled tools that cover several different length scales and various materials, with the aim to 'make almost anything'. [2] As the design of this new high-school student program involved expanding the profile of our users to teenagers, I looked for some guidance that helps me to succeed on this ambitious endeavor. I found out the work of Paulo Blikstein related to digital fabrication and education [3], which led me to the understanding of digital fabrication as a learning tool through which I could attempt to create a working educational environment that improve high-school students' motivation showing them practical applications of the theoretical concepts that they were acquiring at their high-schools.

Besides, some of the pedagogies that I was trying to explore and implement were inspired by some of Seymour Papert's ideas which I discovered during a research that I conducted while writing my doctoral thesis. I tried to implement concepts as the use of technology as a building material, the need of 'learning by doing' approach, the importance of learning to learn (to keep learning) or the benefits of enjoying while learning. In fact, some researchers have credit him as the "father of the maker movement" [4] even defining constructionism as "learning by constructing knowledge through the act of making something shareable".[5] Other studies suggested that integrating mathematics, science, and engineering "in a highly motivating task that makes use of digital fabrication, could facilitate

Figure 5-8. High-School students working on a model of Oiza's BBVA Building.

learning, developmental skills, and student engagement". [6] They even affirmed that engineering design could be used as an interesting teaching pedagogy for developing mathematics content while implementing tools for digital fabrication. And more recently, another group of researchers studied the use of digital fabrication and ¨making¨ to produce methodological change in teaching practice in schools. [7] They found out, among other things that all through the process of designing and producing each project, the students developed their critical thinking skills and had an impact in their self-esteem offering them an alternative way to deal with problems and making decisions.

Methods

"I fell in love with the idea that a technologically rich environment could give to children who love ideas access to learning-rich idea work, and to those who love ideas less, the opportunity to learn to love them more". [8] The idea of running a program with high-school students at the university facilities came from this Papert statement, in which he highlighted the importance for students motivation of creating a technologically rich environment that offer them direct access to what he defined as 'learning idea work', a new concept that prioritize ideas over skills or knowledge.

Thinking about this, I began to realize the potential of the FabLab environment and the digital fabrication tools to change the student's misconception that learning is related to acquire knowledge and skills, to a new definition of learning that involves materializing their own ideas thanks to the use of new programming languages and technologies.

In order to design a successful program aligned with all this previous studies but including also the involvement of high-school students in a university environment, their participation in projects to develop in cooperation with university professors and college students and the fabrication of designs that explain, not the theoretical concepts learned at the high-school but the application of this principles into a professional career, I implemented a case-study design that included a two-week summer program in which teens, program supervisors and instructors worked together to develop a short intensive project similar to a first-year graduate school project with group discussions and reviews, training sessions in graphics and digital fabrication skills and direct access to the FabLab.

Participants

The summer program was designed for those high-school students that were finishing up their junior year of high school and were thinking about their future, in order to motivate them to finish their studies and explore the possibilities of studying a career at the university. The youth are between the ages of 15 and 18 and included both genders. Each year the number of student goes from 15 to 20. Our design team included one program supervisor, in charge of tracking the progress of the teens; ten university professors, in charge of the theoretical classes and finally, a laboratory technician and two college students that participated as FabLab Instructors.

Procedures

Due to my background as an Architect, the program has been created as a two-week program to introduce them to a career in the design and building professions. The idea was to take advantage of the university

Figure 9-12. High-School students working on a model of Madrid Rio facilities.

facilities and the city of Madrid, both understood as a kind of dynamic laboratory of architectural speculation. To that end, the program included instruction in freehand sketching, model-making and a short introduction to digital representation as well as a field trip to a Madrid's architectural landmark, and concluded with an exhibition of the student works and a reception for students and their families. Each year we are exploring a new architectural landmark, so that students can learn from the previous ones but at the same time, explore their own ideas to represent and fabricate a new model without seen previously a possible solution. We have worked on the BBAA Building by Javier Saénz de Oiza; Atocha Train Station, by Rafael Moneo and some facilities at Madrid Río.

The first approach to the architectural landmark involves a guided visit in order to encourage students to explore the building through freehand sketches and pictures that allow them, in a later session to use computer aided design to create a 3D model, some technical documentation (as plans, sections and elevations) and finally, a scaled model using CNC and laser cutter machines. Along the way they are requested to explain their way to approach to each assignment and to discuss it with the faculty and classmates but each day they have to end the session with a final drawing or a final prototype (not only ideas) to share with the group.

Data analysis

The analysis of the design sessions is being developed in five phases. After each session, the program supervisor (that attended the sessions to take notes, pictures and video data), meet with professors and instructors involved on this specific session to interview them and review the work developed by the students (drawings, notes, models, etc). Later on, using video data, photographs, and field notes the program supervisor wrote a account of each session to describe the progress and evaluate the results. At the end of the summer program there is an exhibition of the work developed by students where the program supervisor met again with all the instructors and students as well as their families that attend the event. There, the supervisor talks with students and families to collect video data of some interviews. Then a paper is written to be discussed in a congress to test previous results in order to add this information on the design of the next year course. Finally, we are now analyzing the findings on the previous years in order to see the evolution of the students during this program.

Findings

Based on the previous data analysis we have find some results although we are still working on a more in depth data analysis. As from the beginning of the summer course students have to hand-in at the end of each session a sketch or model of what they have been working on, we have realized that on the first sessions the results are not often what they expect but that make them realize how far are the perfect ideas that they have in their minds of their physical materialization, and consequently how important is to find enough time to bring these ideas to life. As soon as they realize that a prototype should be finished at the end of each session adding improvements to the previous ones, they work more focused on their tasks. And as quickly as they have something made by them in their hands, they are more motivated to keep working and transforming these first prototypes to get a more accurate final architectural model. This

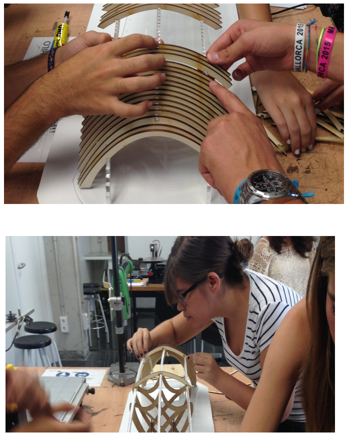

Figure 13-14. High-School students working on a model of Madrid Rio facilities.

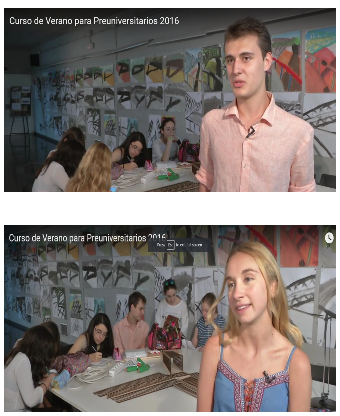

Figure 15-16. Interview with High-School students.

approach to fabrication though a spiral design process that allows them to work over previous prototypes is something that I learned from Neil Gershenfeld but also from John Dewey studies. [8] Thanks to that students gain experience through repetition and as the level of detail increase, they are more motivated to find additional ideas.

One of the most extraordinary transformations that I have seen on them is the self-confidence they gain during the program, possibly, due to the fact that they become autonomous on their learning experience working hand by hand with their classmates and instructors during the workshops. In fact, many of them came to the program thinking that they were going to be taught by professors and took them some time to understand that they had to take charge of their own learning, for example, discussing with their classmates and instructors the best way to fabricate their designs. As soon as they understand that they are in charge of their projects and that the accurateness of the drawings and models that they develop is related to the implementation of their ideas, they start to get involved in all the decisions defining a unique learning experience. This idea of learning while finding the way to learn is implicit in some Papert's articles, [9] in which he emphasizes how crucial is for the success of the students and for their future lives to find by themselves the way to learn how to learn.

In the book Mindstorms [10] Papert found out that one important difficulty in mathematics education was the social construction of math in our culture as an alienated thing. The use of Logo and the computer allowed students to learn and integrate math in their everyday life. What I tried to explore in this program was the use of digital fabrication in the same way that Papert used Logo. The idea was to take advantage of the interest that students might find out in building an architectural model to make math and physic for them useful for the design. To that end, the workshop required an introduction to teach some concepts related to physics and math to solve problems related to the geometry of each part as for example, how to slice the model into smaller parts that should be later assembled or how to use measurement tools and Boolean operations to work in a 3D design environment. As incredible as it seems, finding out that math and physic were useful for solving everyday life problems was a revelation for some of the students.

Another idea that interested me was extracted from Papert's article Teaching Children Thinking [11]. Here, Papert suggests that on a good learning environment the child should be in charge of the technology, not the technology in charge of the child, offering what was a new image of children using computers as tools for creativity. We tried to transfer this idea of 'teaching thinking' to the program giving the students the possibility to use the FabLab machines by themselves helped by an instructor. In our opinion, the fact that they wanted to materialize an idea with a technology that has some limitations on size, lengths, widths or materials among other things, took them to think about new ways to experiment with the technology in order to get the result they were expecting.

Conclusions

As the education program presented at this paper is an ongoing program we have to keep working on the data analysis to get to a conclusion but the first results based on a general data analysis seems to prove that

Figure 17. High-School students' final exhibition.

Figure 18-20. Interview with High-School students.

the program increase the motivation of the students on STEM courses as a complement of the formal education provided by the high-schools. It seems that the program achieve the objective of encouraging students to enjoy technology and make it part of their future life as some of the students are now enrolled in our degree programs at the university. So it seems that the succeed on the program implementation confirms the potential of digital fabrication to be used as learning tool, through which it is possible to create a working educational environment to show high-school students practical applications of the theoretical concepts that they are acquiring during pre-university studies guiding them to the university studies thanks to their involvement in a university environment and their participation in projects in cooperation with university professors and college students. And finally, they seems to validate the ideas of Seymour Papert related to the use of technology as a building material, the need of a learning by doing approach, the importance of learning to learn (to keep learning) or the benefits of enjoying while learning but in this case applied to the fabrication of designs that explain, not the theoretical concepts learned at the high-school but the application of this principles into a professional career.

Acknowledgements
Our thanks to high-school students and instructors involved on the high-school programs that run at FabLab Madrid CEU for the materials and the images used in this paper.

References
1.Neil Gershenfeld. 2005. *Fab. The Coming Revolution on your Desktop*. Basic Books, New York.

2.Neil Gershenfeld. 2012. "How to Make Almost Anything. The Digital Fabrication Revolution". *Foreign Affairs*, 91/ 6, Council in Foreign Relations, New York.

3.Paulo Blikstein. 2013. *Digital Fabrication and 'Making' in Education: The Democratization of Invention. In FabLabs.* J. Walter-Herrmann & C. Büching (Eds.), Bielefeld: Transcript Publishers.

4.Halverson, E. R., & Sheridan, K. 2014. *The maker movement in education*. Harvard Educational Review, 84(4).

5.S. L. Martinez & G. S. Stager 2013. *Invent to learn: Making, tinkering, and engineering in the classroom*. Constructing modern knowledge Press.

6.R. Q. Berry, G. Bull, C. Browning, C. D. Thomas, G. Starkweather & J. Aylor. 2010. *Use of digital fabrication to incorporate engineering design principles in elementary mathematics education.* Contemporary Issues in Technology and Teacher Education, 10(2).

7.S. Tesconi S. & L. Arias. 2014. *Making as a Tool to Competence-based School Programming*. Fab Learn Conference Paper, Online resource. Retrieved January 2017 from: http://fablearn.eu/2014/wp-content/uploads/fablearn14_submission_161.pdf

8. Seymour Papert. 2000. *What's the big idea? Toward a pedagogy of idea powe*r. IBM Systems Journal, v. 39.

9. Jon Ord. 2012. John Dewey and Experiential Learning: Developing the theory of youth work. *Youth & Policy* 108

10. Seymour Papert. 1980. *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books, New York.

11. Seymour Papert. 2005. Teaching Children Thinking. Contemporary Issues in Technology and Teacher Education, 5(3). Association for the Advancement of Computing in Education (AACE).