FAB LAB AS AN IMPLEMENTATION TOOL OF THE CDIO PROGRAM

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ABSTRACT

The CDIO program sustain that the core of engineering is built up on four fundamental activities (C: Conceive, D: Design, I: Implement and O: Operate) and concentrates on the development and spread out of teaching techniques that allow students to master these skills.

Project courses involving the generation of real engineering systems are seen as a great opportunity for students to acquire this knowledge, while collaborating with teammates under the guidance of professors. Unfortunately, it is difficult to find a suitable subject to enable people to practice the whole CDIO chain over the few months of a course. Most projects will end up on the firsts stages of conception (C) and design (D).

We hypothesize that implementation time (construction of real prototypes) is one important obstacle for the practice of the CDIO program, specially if projects are to be done on one-semester courses.

Our proposal is to use Digital Fabrication Laboratories as a tool for the rapid implementation and operation of engineering systems. We report our experience on the development of short period courses involving the whole CDIO chain, thanks to the use of rapid prototyping tools. We comment on how these tools might impact the early conception and design stages as well.

KEYWORDS

CDIO, Fab Lab, Digital Fabrication, Learning System, Rapid Prototyping

INTRODUCTION

The CDIO initiative [1] focuses on teaching engineering by encouraging hands-on learning of product and system building. Students face real engineering problems that require a combination of theoretical and practical tangible solutions. The idea is to expose students to challenging scenarios that require both, disciplinary knowledge and social learning.

Implementing CDIO requires institutions to meet the standards suggested by the community. One such standard (std. 6) deals with the quality of workspaces that are used as physical environment to support product and system building skills as well as social and disciplinary knowledge learning. The initiative proposes that the right selection and adaptation of workspaces is fundamental for the success of CDIO.

Some studies [4,8] have concentrated on assessing the quality of existing workspaces to meet CDIO standards. In this study we focus on the creation of a new workspace specially designed to embrace all the features of this new vision for engineering education.

We have found convenient similarities between the Fab Lab [3] and CDIO programs. While the first aims at democratizing invention, the second aims at improving engineering education. Both have a similar approach to product and system design. We hypothesize that fabrication tools provided by a Fab Lab might bring a solid basis for the implementation of the CDIO curriculum.

Moreover, the use of digital fabrication tools existing on every Fab Lab might bring about important speed up on project execution, enabling for the entire CDIO chain to be explored over the short time lapse of a university course.

The remaining of this paper is organized as follows. We first comment on the implementation of the CDIO program at our own institution. Secondly, we describe the concept of a Fab Lab. Then we present the design of our own CDIO inspired Fab Lab. We present a few case studies on the use of digital fabrication and CDIO and finally we present the conclusions of this study.

IMPLEMENTING CDIO AT UNIVERSITY OF CHILE

The School of Physical and Mathematical Sciences (FCFM) at University of Chile adopted the CDIO initiative in 2007. This was in the context of a curriculum reform of 13 undergraduate programs: Geology, Astronomy, Geophysics, Physics and nine Engineering specializations.

Our engineering programs share all a core of mandatory courses for the first two years, containing three fully CDIO oriented courses - *Introduction to Engineering I, Introduction to Engineering II* and *Work Project* - where students deal with applied problems to be solved using dedicated workspaces and modern tools, including laser cutters.

After the common core period, each engineering discipline have courses with design-implement experiences, but usually near the end of the program and, in most cases, without interacting with other engineers or professionals.

We decided to encourage CDIO practical integrated learning experiences (std. 7) by implementing a Fab Lab [3]. This was thanks to a government academic innovation fund called FIAC UCH1102. The new space is expected to provide tools for digital fabrication not only for the projects within our minor, but also for a wide range of courses and academic activities.

The digitally accelerated CDIO cycle brings new interesting challenges by enabling the development of more ambitious projects that can be addressed on a shorter time span. We expect to promote attractive and strategically viable projects that can be developed by different groups in different periods while keeping people interest in getting involved.

FAB LABS AND THE DIGITAL FABRICATION REVOLUTION

A Fab Lab is a workshop that provides open access to a variety of digital fabrication tools [3]. These spaces were conceived at the MIT Center for Bits and Atoms (CBA) while carrying research on machines that might be capable of “making almost anything”. Researchers found that a particular collection of state of the art tools was sufficient for prototyping at a wide range of scales (micron to meter) and with a great variety of materials (plastics, ceramics, metals, etc.).

A key issue on their finding is the low cost of the proposed digital prototyping tool set. The core set of machines required for a Fab Lab can be purchased today with a budget of USD $100,000. At this cost many institutions and entrepreneurs around the world can have access to modern means of invention that were previously available to a few.

Fab Labs have been spreading around the world in the form of a network of collaborating laboratories. Today there is about one hundred laboratories operating in different places, ranging from rural areas, inner city locations and university research environments. The rapidly growing community gathers every year on the International Fab Lab conference, an opportunity for sharing experiences and ideas for community problem solving, business incubation, technological development, etc.

People working on a Fab Lab can share digital models and complete machine specifications, usually in the form of an open hardware. The community members can assume that fabrication processes and machines will be equivalent across laboratories and thus concentrate on the digital design of a particular hardware. This is similar to the case of open software production were contributors assume their software will operate under similar processors.

Users can easily transform their ideas into actual physical products. Functional prototypes can be rapidly tested leading to the identification of improvements. Several trial and error design cycles can be experienced, observing a radical contrast with time consuming traditional manufacturing. These early testing steps enable the overall project to experience many Conceive, Design, Implement and Operate cycles.

Most of these trial-error cycles usually involve more theoretical and technical knowledge to be introduced into the project, which also means more peer-to-peer interaction. Digital fabrication also allows to easily distribute the workload of designing different parts that should be integrated with resources from different disciplines.

These digital fabrication tools are described in the Fab Lab toolset specification [6], to say 3D printers, laser cutters, CNC routers, 3D scanners, cutting plotters, etc. The Fab Lab community also defines a common set of capabilities and processes. The idea is to facilitate knowledge sharing across laboratories so that global projects can be addressed with collaboration of multiple laboratories.

Opposed to the model where the technical knowledge is concentrated in few people, the Fab Lab community encourages people to learn by themselves the use of machinery and to teach to their peers. Therefore workspaces should cope with the demand of many users.

FAB LAB AND CDIO WORKSPACES

With the aim of providing a workspace that supports and encourages learning of product and system building, disciplinary knowledge and social learning (CDIO std. 6) we implemented a new Fab Lab. Our design is heavily inspired by the CDIO principles and contains the machine set recommended by the Fab Lab community. Figure 1 shows our 500 square meters workspace layout, which is in the final stage of construction.

Thematic spaces are arranged on a single open space that encourages group interaction instead of isolating activity into small rooms. Table 1 describes our Fab Lab thematic areas, equipment and how they satisfy space requirements for the CDIO activities.

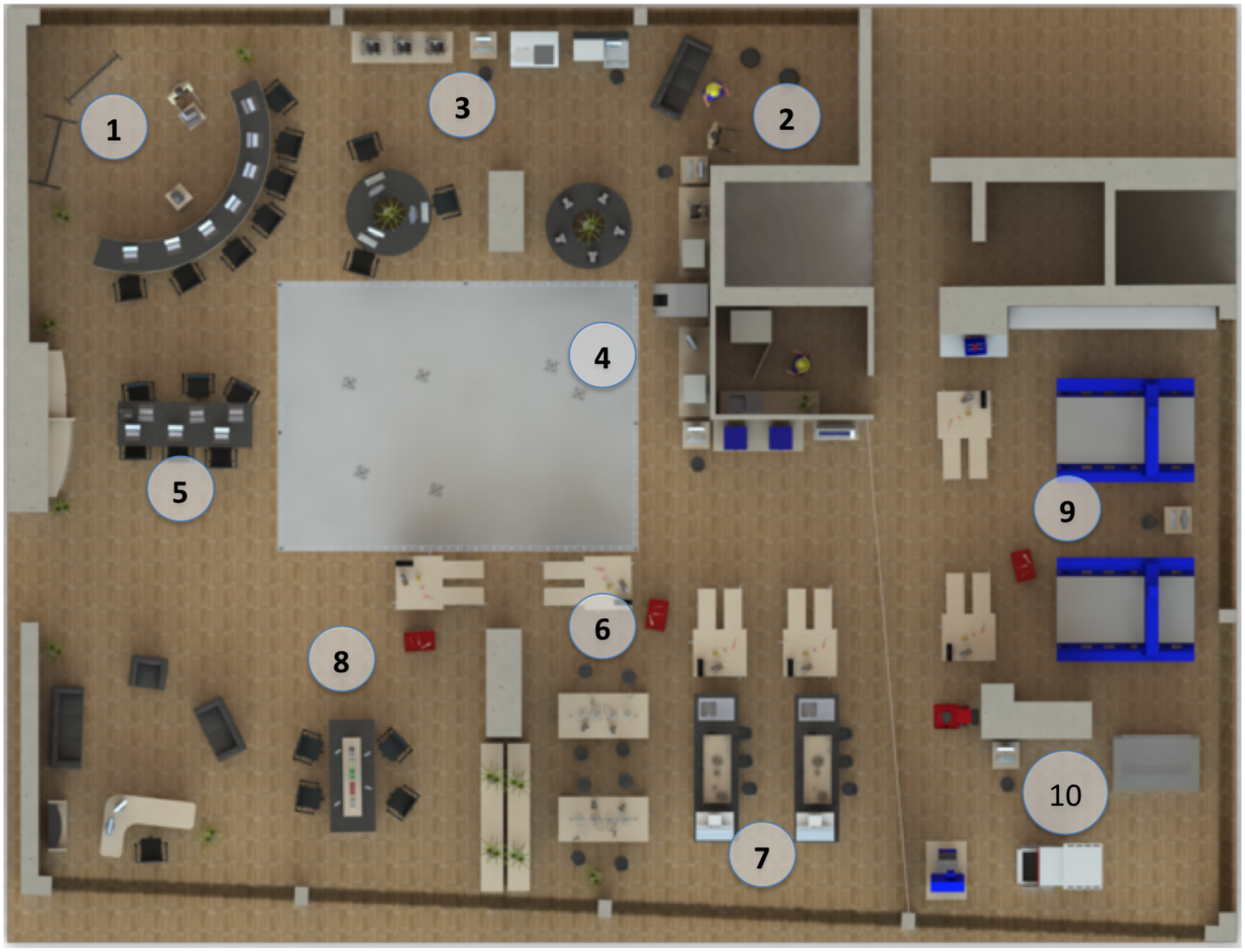

Figure 1. Layout of our Fab Lab at UChile. Different thematic areas are indicated on Table 1.

Thematic laboratory desktops were implemented to hold up many active projects in parallel, to say assembly, pneumatics, chemical and wet laboratory desktops (Figure 2). There is also a video-conference space to enhance innovation opportunities through active interaction with other Fab Labs abroad and/or with other engineering schools (Figure 3).

To assess the quality of our Fab Lab in terms of the CDIO standard, we carried out the CDIO workspace benchmarking [9]. According to this tool, the Fab Lab design covers the essential and desirable attributes since the laboratory is focused on fabrication tools in an open and inclusive space, promoting interaction and knowledge sharing. Moreover the Fab Lab encourages users to operate machines directly instead of relying on specialized technical staff. The operation techniques are shared among users themselves, although there is always a supervisor.

In terms of functionality, the Fab Lab machines and working desktops can be used by at least 50 users simultaneously. This is perfectly feasible in the available 500 square meters space. This is equivalent to five small course groups. The idea is that machines will be used by supervisors, managers and students, all sharing their knowledge.

Table 1. Fab Lab UChile Thematic Areas and Equipment in relation to CDIO activities.

	Thematic Areas and Equipment	**C**	**D**	**I**	**O**
1	Videoconfere, lecture and tutorial spaces (Polycom V500 Video Conference System, LED 50" display, DLP projector)	X	X		X
2	Design and meeting studio (Wacom tablets, photo cameras, large format printer)	X	X		
3	3D Printing space (High resolution photopolymer 3D printer, Professional FDM 3D printer, 3D Printing Cluster with 8 Personal FDM printers)		X	X	
4	Scanning space (Roland DG LPX-600 3D scanner, 12 Optitrack S250e large volume motion capture sensor arena, kinect sensor)		X		X
5	Computer lab (8 Design workstations)	X	X	X	X
6	Assembly workshop (6 Assembly desktops, 2 pneumatics desktops, variable speed scroll saws, drills, dremels, dustbuster, digital embroidery)	X	X	X	
7	Wet lab (2 Chemistry desktops, 2 fume extractors)			X	
8	Electronics lab (1 Electronics desktop, oscilloscopes, signal generators)			X	X
9	CNC workshop (Shopbot PRSalpha 96 CNC, Shopbot 5-axis CNC, Shopbot Desktop 3+1 axis CNC, Roland DG MDX-20 Desktop CNC)			X	
10	Cutting workshop (Roland DG GX-24 vinyl cutter, Epilog laser cutter)		X	X	

Regarding ownership, the operation costs are to be handled by each course budget. Projects outside courses should be self sustainable. The laboratory count with enough supplies to satisfy initial demand, avoiding the supply delivery delays.

The management is to be handled by a dedicated supervisor, and after the first usage periods, some responsible tutors recruited from the laboratory's crew. They are responsible to carry on the equipment maintenance, while the cleaning is responsibility of each user.

The access is open to students during a fixed schedule (supervisor responsible), during courses (teacher responsible) and with the possibility of coordinating off the schedule. We will grant public access to the community.

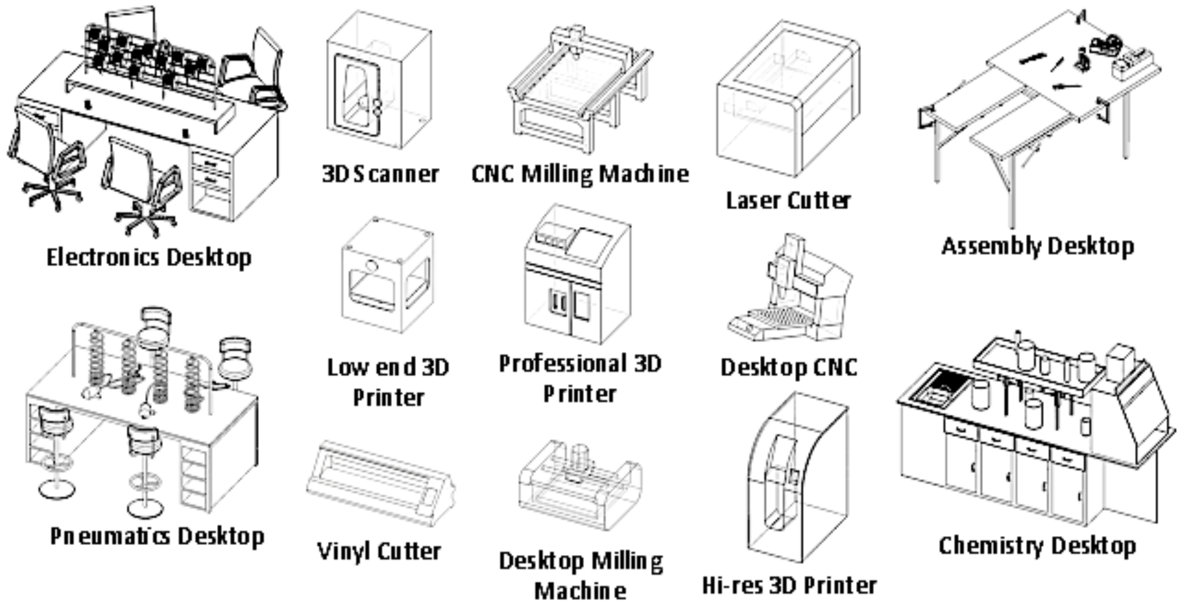

Figure 2. Desktops for specialized work on electronics, pneumatics, chemistry and assembly. Also are shown most of the digital fabrication tools available on the Digital Fab Lab UChile, as 3D Printers, CNC Milling Machines, Vinyl Cutters and Laser Cutters.

(a) (c) (b)

Figure 3. Different conceptual views of the laboratory design. (a) A partial view of the assembly area, where many discipline oriented desktop are gathered. (b) View from the video-conference area. (c) View of the Motion Capture structure and the video-conference areas.

PROMOTING OPEN SOURCE HARDWARE IN CDIO SPACES

Open source hardware enables people to modify their own technology while sharing knowledge with an international community of makers. This is especially appealing to CDIO since it is a way to promote product and system building at an international level.

The open source hardware association (OSHWA) defines open hardware as "*hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design".*

Creating open hardware products enables students to get valuable feedback from potential users all around the world. Moreover, documentation used to publish open hardware facilitates the continuation of projects that might extend beyond one semester.

New students can rapidly grasp the development status of a long lasting project by reading the open hardware material that should provide documentation, user manuals, PCB layout data, source code, CAD design files, bills of materials and schematics.

At the moment, however, there is an absence of standard method for publishing, maintaining and reviewing open source hardware material. There is also a lack of agreement with respect to the best standard formats. Another inconvenient is given by the fact that documentation is a time-consuming process.

A Fab Lab appears as a great place to promote the generation of open source hardware. From our experience, the use of online version control tools such as GitHub [4] is convenient to keep track of contributions to the project, online documentation, and overall progress.

CASE STUDIES

In this section we present some examples on how Fab Lab tools have positively influenced the implementation of CDIO principles at our engineering school.

Picosatellite and Rockets

A small satellite development project started two years ago at the Engineering School. This educational project is called SUCHAI, which stands for *Satellite of the University of CHile for Aerospace Investigation.* The project comprises the construction, development, integration, launch and operation of a 1U CubeSat.

Some Fab Lab tools were already available from the beginning of our satellite project, thus we started exploring how different concepts of digital fabrication could benefit the initial prototyping stages of our CubeSat as well as facilitating the production of laboratory equipment [5].

Initially, we decided that the best approach for the success of the project was to integrate commercially available components (COTS). However, we observed that digital fabrication tools were quite useful for producing physical layouts of the final satellite. These could be even used for the construction of final satellite parts. Figure 4 shows our initial CubeSat prototypes produced using laser cut and 3D printing.

The use of digitally fabricated versions of the satellite and its components not only improved the actual understanding about the limitations that the students were about to face, but also enabled the rapid conception of new ideas and solutions related to optimization of space and weight.

The digital design tools showed to be very effective at triggering creativity. Even though these tools seem more appealing to mechanical engineering problems, they proved to be effective for the electrical engineering students (EE) as well.

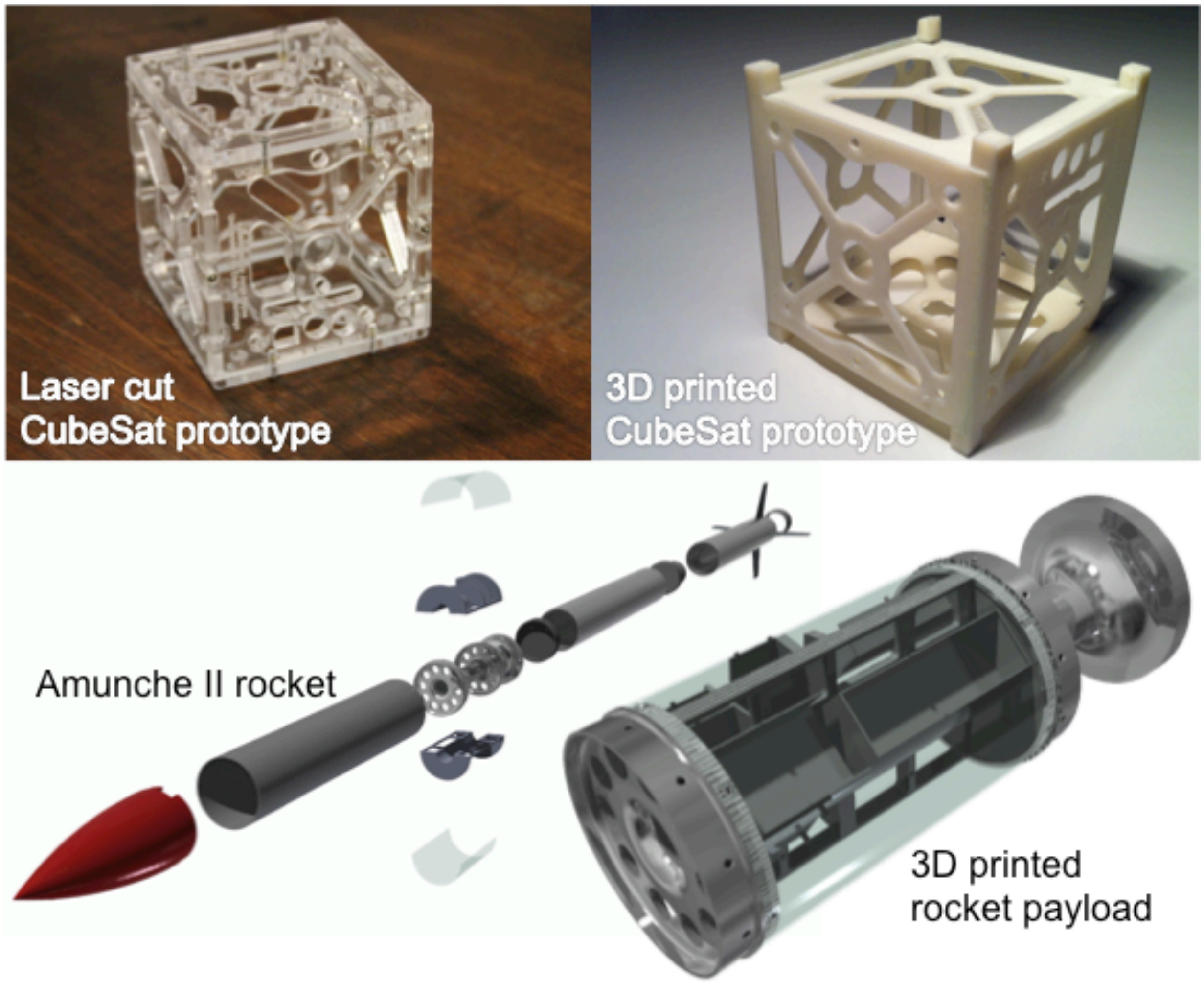

Figure 4. Application of Fab Lab tools to aid satellite and rocket projects. Laser cut and 3D printed CubeSat prototypes are displayed on top. These replicas were used to practice the placement of internal components as well as to test the antenna deployment mechanism. The rocket Amunche II is also illustrated on the bottom part of the figure. The rocket was designed to reach 6km height. Various electronic boards were arranged as payload using 3D printed cases.

We also carried a couple of projects on the design and construction of small rockets. The rockets Amunche I and Amunche II were designed and constructed by teams of ME students. The first rocket was successfully launched, reaching a 1km apogee. Digital fabrication tools were especially useful for manufacturing payload components (Figure 4) as well as for producing and testing apogee detector devices (Figure 5).

Finally, all the designs were easily stored and shared digitally, allowing other students, from other or future projects to have access to the material.

(a) (b) (c)

Figure 5. Rocket apogee detector, which was designed, constructed and implemented using digital fabrication tools. (a) CAD model. (b) 3D printed part. (c) Device assembled.

Project courses in the common core

Inspired by the Olin College experience on teaching engineering [6], the courses of Introduction to Engineering (EI1101 and EI1102) were implemented. These are large courses with nearly 800 students running in eight parallel sections, each developed during the first and second semester of the engineering career. During these courses, students work in teams of five students solving specific problems proposed by their teachers.

Using brainstorming and drafts, students are able to generate CAD models of mechanical parts, which are fabricated using a laser cutter. Then the teams gather together to assemble their projects. Students usually do not have enough time to build more than two prototypes per curse.

During the third semester, students take one of the nearly forty different sections of the course EI2001, *Work Project*. The goal of this course is to conceive, design and implement functional prototypes of engineering systems of moderate complexity taking into account ethics and social components, as well as to progress in the development of their interpersonal competences.

The use of the laser cutter has been an important element for improving the quality of the prototypes constructed by the students. See Figure 6.

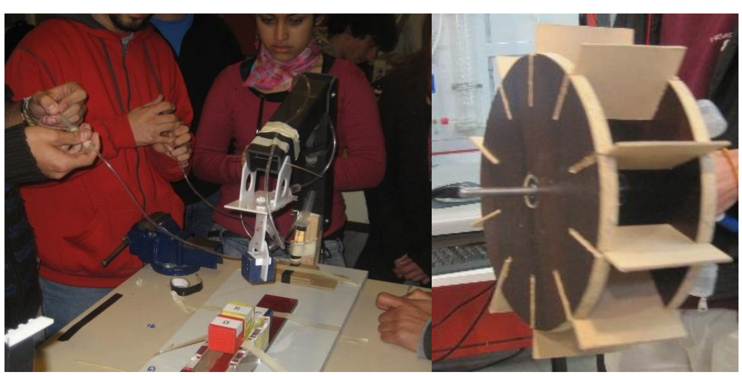

Figure 6. Work done during the *Introduction to Engineering I-II* and *Work Project* courses. Left: Students operating a robotics arm built from laser cut parts. Right: Water wheel with Archimedes screw prototyped using a laser cutter.

CONCLUSION

In the present work we have discussed the impact of using Fab Lab tools on project oriented courses and workshops, and how it has enhanced many course's experiences by empowering students to build functional prototypes in a simple, versatile and fast way. This working methodology is promoted by the Fab Lab's framework, and has shown to be a huge extension to the CDIO's learning approach, since the implementation and operation processes (tethered by old fashion manufacturing techniques) are sensibly speeded up by digital fabrication means.

We also discussed on how the laboratory's layout as workspace may affect the student-machine and interpersonal relations. Thereby, space openness and resources availability are highly suggested, so students can easily interact with each other and have access to these fabrication equipment. We presented how our workspace is designed to enhance these topics.

Finally, we hypothesize on how digital fabrication promotes long term and high scoped projects, so the need to implement a constantly up to date documentation process, emphasizing the project's reproducibility, using resources seen on the Open Hardware/Software worlds (e.g. version control systems), so these projects could be easily handled by different groups in sparse timelapses.

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BIOGRAPHICAL INFORMATION

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