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FabLabs in vulnerable communities: STEM education opportunities for everyone

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Abstract

FabLabs (Fabrication Laboratories), also referred to as makerspaces or hackerspaces, are open spaces for collaborative creation and horizontal cooperation, supporting the development of technological skills of its users. They often serve to promote STEM knowledge and engage participants in equitable education opportunities. Drawing from a participatory design methodology and a qualitative research perspective in a collaborative process between universities in Mexico and in the United Kingdom, this paper focuses on the setup of a FabLab in La Campana district in Monterrey, Mexico, an area characterized by its vulnerability and marginalization. Envisioned to serve as both, a STEM learning place and a fabrication workshop for the surrounding community, the FabLab Campana has provided a platform for the democratization of educational practices through the inclusion of participants from different settings, countries and ages, collaborating in the achievement of common goals, while stimulating creative thinking, and strengthening the bonding with participants and their needs. The FabLab counts with a carefully designed program of activities to promote STEM knowledge, an interactive design approach and context, and the development of skills based on dialogic learning. Evidence collected from observations and interviews supports the conception that the STEM learning practices carried out at the FabLab are a rewarding and meaningful experience for all involved, which also help to accelerate the adoption of technological tools in the surrounding community.

Keywords

Makerspaces, Fabrication laboratory, STEM education, community development.

1. Introduction

The increasing need to prepare future labor force with transferable and disciplinary skills in science and technology is pushing education to design innovative learning experiences. In formal and non-formal contexts, approaches like the robotic platforms inside elementary schools and universities [1], construction of portable thermal characterization devices [2], and cross reality environments [3], the implementation of FabLabs (Fabrication Laboratories) are making education exciting and flexible, letting students acquire knowledge and practice their skills [4]. In this quest of designing innovative learning experiences, FabLabs are especially interesting because they have become a meeting point to access equipment and other resources by all type of learners. Moreover, skills such as creativity, innovation, problem solving, innovative thinking, and real-world problems inquiry are stimulated in students [4, 5], which are demanded in workforce competencies.

FabLabs and makerspaces are small-scale workshop areas that offer the opportunity for digital fabrication and rapid prototyping for anyone interested in developing original ideas for solving problems [6]. These spaces are generally equipped with the necessary tools for digital and physical fabrication, including computers, 3D printers, plotters, laser engraving and cutting machines, vinyl cutters, CNC mill, welding, mechatronics hardware, and woodworking [7].

Professor Neil Gershenfeld of the Massachusetts Institute of Technology is sometimes referred to as the inspiration for the FabLab spaces, and who has challenged society to think about personal fabrication as the ability to design and produce your own products [8]. According to the FabFoundation [8] “to be a Fab Lab means connecting to a global community of learners, educators, technologists, researchers, makers and innovators; a knowledge-sharing network that spans 30 countries and 24 time zones”. Thus, this sense of community and belonging is a key element to “create with others”, so that participants recognize common needs, learn from colleagues’ areas of expertise, and promote interdisciplinary skills as the foundation of this maker activity.

A FabLab is a makerspace officially linked to the FabLab network [10], constituted by open spaces for collaborative creation and horizontal cooperation, which involve the development of technological skills of participants. The creation of FabLabs support sharing local knowledge, collaboration across borders [11] and open innovation processes [12, 13, 14], while “democratizing tasks and skills previously only accessible to experts” [15]. They achieve these goals with an open network of FabLabs all over the world, which currently has over 1750 laboratories in 100 countries [10].

Fabrication laboratories represent an opportunity to involve human groups in the proposal of plans for the solution of problems, and the establishment of strategies for social development with the use of technology. In this context, FabLabs promote the generation of opportunities for creativity through the implementation of different functions in a one-stop setting, such as: a space to do, a space for deep work, and a space for collaboration [16]. This happens not only in community scenarios, but also in educational settings where FabLabs have been used to encourage students and teachers to become creators, doers and innovators in areas of Science, Technology, Engineering, and Mathematics (STEM) [17].

FabLabs have a particular potential in the field of STEM Education, given that students who participate in these settings “implement scientific knowledge while gaining relevant technical skills and developing the art of creative thought” [18]. These spaces expand the opportunity to transform educational paradigms as they promote the maker culture, challenging traditional models of teaching and learning. FabLabs promote an *active learning* process in which students are in the center of the educational process as they act as protagonists doing meaningful activities that promote critical thinking [19]. As a result, FabLabs become spaces that endorse a holistic learning, offering insights into the kinds of caring actions, communications and dialogues that are at the heart of a space that redress the bifurcation of cognition and emotion in education [20, 21]. As a consequence, FabLabs usually center educational processes in students, instead of focusing on teachers, because they offer “youth substantial say in what and how they make” [22, p. 37].

Despite the fact that FabLabs “can be particularly important for youth from underserved communities who lack access to quality science elsewhere” [21, p. 80], they could actually bring STEM education opportunities for everyone in the community. Thus, FabLabs do not only allow the creation of solutions, but also the transformation of attitudes and actions through the implementation of learning through making [23]. For example, FabLabs have been used in community projects such as plastics recycling, resulting also in developing gender equality and empowerment among its beneficiaries [24].

These spaces represent an open and flexible scenario to democratize innovation in societies that have experienced vulnerability and marginalization. They also open the possibility to do, produce, and create with a perspective of transformation of the self and the community [25]. Furthermore, they can empower the perspectives of societies with the openness of their format, allowing participants to use their social and cultural capital to solve everyday problems and generate long-lasting solutions [26]. In this context, it is relevant to consider that "the growth of the maker movement and the FabLabs is giving everyone access to advanced manufacturing technologies and projects, creating both digital and physical networks, while maintaining a distributed and decentralized structure" [27, p. S3122]. Social development is impacted by FabLabs by giving people the opportunity to access resources and information to make changes in their immediate contexts, without the need of the mediation of government agencies or external institutions.

Finally, FabLabs represent a major movement in which Information and Communication Technologies (ICT) are used with the aim of improving the teaching and learning processes in the undergraduate and graduate educational levels. In this process, the development of competencies in both students and professors is a key element when talking about innovation and education [28]. Fabrication laboratories and maker spaces contribute to build connections between the physical and scientific dimensions of knowledge [3]. Therefore, they help to enhance situated learning environments in which students and professors cooperate to achieve common objectives in the task of “doing” and “creating”. Also, they link social needs with the tasks that are done within an educational context.

Given the attributions of FabLabs as spaces where STEM education and social transformation collide to transform a community, we envisioned and established a FabLab in a marginalized district of Monterrey, Mexico (see also [29]).

2. Methodology

This section describes a general context of the FabLab where this research took place, the participants, the instruments and data collection, as well as analysis strategy.

2.1 General Context

FabLab Campana is a fabrication laboratory situated in the facilities of a local high school in Monterrey, Mexico (Northeastern part of the country). Fab Lab Campana is named after La Campana – Altamira district in the municipality of Monterrey, holding several conditions of social and economic marginalization. These conditions compromise the development opportunities of its members and play an important role as external factors that prevent participants from fully taking advantage of their set of abilities.

Located in a district in Monterrey that holds some characteristics of marginalized conditions, such as poverty, violence and low social development, CBTIS 99 is a high school that belongs to the Mexican national educational system, in its technical formative curriculum, and is aimed to provide education to continue into the higher university level along with practical knowledge that could be used to allow the young population to start participating in economic activities.

FabLab Campana is located in the facilities of CBTIS 99 and represents an open space of collaboration and co-creation for the community in which it was established. Since its opening, it has involved different stakeholders: administrators and students from CBTIS 99, the FabLab manager, nonprofit organizations (FabLat Kids and FabFoundation), students and academics from Tecnológico de

Monterrey (communitarian social service students), children and parents from the community [29]. Thanks to the commitment and passion of school actors, this FabLab has experienced growth and development within the members of this high school and the general community.

2.2 Distribution of the longitudinal study

FabLab Campana has been in operation during two academic semesters (January-May 2019 & August-December 2019) with previous work on the diagnosis and definition of the project starting in 2018. Each of the three periods in which work has been carried out regarding the design, creation and implementation, represents a phase of the research process in which data collection, analysis and interpretation were held.

2.2.1 Phase 1: Diagnosis.

The first phase started with a scoping workshop where the design of a makerspace aimed to empower the community through non-formal STEM learning and making was explored in detail [29]. With the use of community design strategies, the project team engaged in field work, to identify a viable location to establish the makerspace. Having established the location, a series of co-design workshops were run, involving students from Tecnologico de Monterrey, academics and professional staff from higher education institutions in Mexico and the United Kingdom, staff and students from CBTIS 99, as well as members from the wider community. These workshops were designed to engage participants in identifying relevant problems in their community, and viable solutions that could be developed through a makerspace, fostering a divergent thinking and encouraging the use of creative prototypes to develop practical solutions to address the problem. The physical and socio-economic conditions of the community were captured by observation, personal interviews, and focus groups. The data collected was brought up to the workshops, so the participants could work using co-design thinking methodology [29].

2.2.2 Phase 2: Start of operations.

The second phase of the project was conducted from February 2019 to May 2019, matching the official calendar of educational activities for students in CBTIS

99. This phase consisted in the co-creation and initial implementation of the FabLab Campana, name given to the makerspace. This space was installed with the planning and strategies of multiple participants and institutions that were involved in the development of STEM educational activities. The design, fabrication and installation of a compact makerspace was carried out by Tecnologico de Monterrey (Mexico), the Open University, the University of Leeds and the University of Bath (United Kingdom), as well as CBTIS 99 as the host institution. The principals of CBTIS 99 allocated a classroom to set up the materials, digital fabrication machines, and furniture of the laboratory. In this phase also, training sessions with key actors were planned and executed in order to familiarize them with the core ideas of STEM education and fabrication laboratories. Two weekly workshops were established for the operations: Friday evenings with CBTIS 99 students, and Saturday mornings with children from the community. In addition, two projects were implemented with CBTIS 99 teachers who used the FabLab in their classes to strengthen the formal curricular knowledge of their courses.

2.2.3 Phase 3: Expansion.

During the third phase of the project, conducted from August to December 2019, we focused on the expansion of activities, and on maintaining and increasing the number of users of the FabLab. Saturday mornings were chosen to conduct workshops with children from the community, while CBTIS 99 students were given access to work in the FabLab during class days with supervision and guidance from a newly appointed manager from CBTIS staff, dedicated exclusively to this space. Regarding the sessions conducted on Saturdays, undergraduate students were recruited through the communitarian social service program of Tecnológico de Monterrey. These students were from diverse academic backgrounds and orientations, as the focus during this period was the co-design of new activities that could be conducted using the FabLab space and equipment. The goal was to link technical and leadership skills using the FabLab hardware, communication and bonding between participants, and the promotion of community wellbeing [30, 31, 32]. Students were prompted to communicate with members of the community to actively engage them in horizontal dialogue in order to connect their specialized knowledge with the children's needs and abilities. The activities were designed in collaboration with university students, professors from Tecnológico de Monterrey, and participants from the wider community of the district, with the objective of making the sessions attractive for the children. Each activity was tested at campus prior to their implementation at the makerspace. By the end of this phase, several members of the community were identified as returning members from the previous phase, and communication was established with them to promote their regular attendance and to gather new ideas, as well as identifying concerns to be considered for future activities.

The paper herein focuses on the operations of the FabLab during the three phases of the project, related to STEM and creativity workshops for children and the community in general. It contributes to strengthen the findings of a previous research on the topic [29].

2.3 Participants

The study had a total of 285 participants for the study. The participants of the FabLab came from a network built from several educational organizations: Tecnológico de Monterrey, The Open University, CBTis 99, and the Latin American Network of FabLabs (FabLat).

Table 1 shows the information about participants during the first and second phases of the project. This table also includes 3 project leaders and researchers that only participated during the co-creation and installation of the FabLab.

Table 1

FabLab Campana Participants during the first and second phase of the project

Institution	Participants	Role	Role Description	Age Range
	2	Project leaders	Design, plan, implement and coordinate activities in the FabLab	25-50
Tecnologico de Monterrey (Mexico)	30	Community Service Students	Undergraduate students who volunteered to commit their community service hours to the project	18-22
	2	Graduate Students	PhD students who supported the coordination and implementation of the Fab Lab activities	25-35

CBTis 99 (Mexico)	1	School Principal	Organize and authorize FabLab operations	35-60
	1	FabLab Manager	Support the use of FabLab equipment and maintenance	25-30
	4	Teachers	High school professors who integrated FabLab activities to the formal curricula in their classes	30-45
	10	High school Students	High school students who are frequent users of the FabLab for projects guided by the teacher in CBTis 99	16-20
Primary schools (Mexico)	32	Primary school Students	Pupils who attended Saturday workshops led by Tecnologico de Monterrey	7-12
	2	Parents of Primary School students	Parents who occasionally attended the workshops with their children	35-60
The Open University (United Kingdom)	3	Project leaders and researchers	Design, plan, implement and coordinate activities in the FabLab	35-60
FabLab Network	103	Partner Guests from the FabLat Network	FabLabs that had interactions with FabLab Campana in two of the workshops	7-60

Table 2 provides a description of the overall participants during the third phase of the project. The second phase was supported by the inclusion of 10 new students from the communitarian social service program of Tecnologico de Monterrey, who replaced the ones from the first phase. In addition, two of the workshops were carried out in alliance with the FabLat network, and one workshop with the Girl Up Monterrey organization, a student group for teaching STEM subjects with a gender perspective. During the fall semester of 2019, the coordinators from Tecnologico de Monterrey made the call for 10 communitarian social service students to register for the project “Creating, Learning, and Connecting with FabLab Campana”. This project aimed to reduce the digital gap in children and youth of La Campana - Altamira district through STEM workshops, activities and events that use digital and physical prototyping tools. The community service students received training in the previous mentioned tools including CNC and laser cutting machines, 3D printers and CAD modelling software.

Table 2

FabLab Campana Participants during the third phase of the project

Institution	Participants	Role	Role Description	Age Range
Tecnologico de Monterrey (Mexico)	2	Project leaders	Designing, planning, implementing, and coordinating activities in the FabLab	25-50
	10	Communitarian Social Service Students	Undergraduate students who volunteered to commit their community service hours to the project	18-22
	3	Graduate Students	PhD students who supported the coordination and implementation of the Fab Lab activities	25-35
CBTis 99 (Mexico)	1	School Principal	Organizing and authorizing FabLab operations	35
	1	FabLab Manager	Supporting the use of FabLab equipment and maintenance	40
	5	High School Students	High school students who are frequent users of the FabLab for projects guided by the teacher in CBTis 99	16-20
Primary schools (Mexico)	34	Primary School Students	Children who attended Saturday workshops led by Tecnologico de Monterrey	7-12
	3	Parents of Primary School Students	Parents who occasionally attended the workshops with their offspring	35-60
FabLat (Latin America and Japan)	30	Partner guests from the FabLat Network	FabLabs that had interactions with FabLab Campana in two of the workshops	7-60

During the operations of FabLab Campana the managing team decided to establish for the first year of operations a strategy to publicize the figure of the FabLab and its affordances. Following that strategy, a total of 22 workshops were offered through the two academic semesters, as shown in Table 3, serving CBTis students and teachers, as well as children from the surrounding primary schools. These workshops had specific objectives to develop abilities in STEM education: creativity, digital fabrication, electric engineering, artistic skills, sociocritical perspectives, as well as networking, and community services.

Table 3

Workshops topics and approaches

Target learner	Topic	Creativity	Digital Fabrication	Electric	Mechanic	Artistic skills	Sociocritical prospective	Networking and community
				Second Phase				
Kids	Robotic Arm			x		x		
	Paper Circuits	x				x		
	Drawing Robot			x	x			
	Emosilla Circuit			x		x		x
	Molds for chocolate		x					x
	Augmented Reality					x	x	
	Koinobori (Global Kids Day)		x			x		x
High school students	Laser Cut Wallets		x					
	3D printing	x	x					
	T-shirts with vinyl	x	x					
	Creative circuits			x				
Teachers and high school students	Design Thinking	x						
	Prototyping	x	x					
	Total	5	6	4	1	5	1	3
				Third Phase				
Kids	Bichobot			x				
	Alebrijes					x		x
	Cardboard Automata		x		x	x		
	Future of La Campana	x					x	
	Car				x	x		
	FabLat Fest	x						x

	Bracelets		x			x		x
	LED Cards			x		x		
High school students	FabLab Latin America							x
	Total	2	2	2	2	5	1	3

2.4 Instruments and Data collection: Meaning and Categories from a Qualitative Perspective

For the first phase of the project, a methodology of co-design was used. Derived from the early workshops, one of the ideas of social innovation to intervene in La Campana – Altamira district was the installation of the FabLab. Taking that idea, in the workshops conducted during the first phase, emphasis was made in identifying the needs of the community from an external perspective, and to present them to the members of the community and to CBTis staff to have their feedback. The main idea of this was to match the issues that constitute obstacles for the students and community members to access better living conditions, with opportunities for social mobility. In this phase, workshops aimed to develop new schemes of thinking to address those issues. Members of the community then presented prototypes that could be developed at the FabLab, and that were meant to solve several problems in their daily life. It was through this dialogue, that innovative solutions started to flourish from the community, using the newly acquired knowledge and guidance from the mentors. The goal was to develop an agenda for working in improving their life and the expectations from their own perspective, but with cooperation of students and academics, thus, creating ideas to work with by co-design.

During the second and third phases, students from Tecnologico de Monterrey engaged in a more direct and open communication, they organized several meetings to present an initial idea of work, to be always contrasted by dialogue with members of the community and now with the children attending the FabLab sessions on weekends. Listening to the children was key to modifying several prototypes so they can be centered around a problem perceived by the participant but involving the use and implementation of diverse STEM knowledge, managed by the students of social service to be seen as part of creative and useful ways of learning. This participation and decision-making centered in members of the community and children, strengthened by students of Tecnologico de Monterrey, and guided by their professors, was effectively a co-creation of the Fab Lab. Using the methodology of co-creation, children also brought every session data about their problems to be solved and worked with their mentors to make objects oriented to solve their practical problems. The role that the FabLab played in the lives of participants was decided by themselves and was part of the co-creation process.

Throughout the different phases of the project, a qualitative research perspective of data collection and analysis was followed [33, 34]. Drawing from a naturalist approach in which data was gathered in the original setting where participants interacted (fabrication laboratory and spaces of community collaboration), we followed a multi-sited qualitative inquiry process. During the research activities, multiple researchers from diverse settings contributed to the generation of field notes and analysis of the findings. Multiple meetings were held in the process of drawing conclusions from the research methods.

The qualitative research approach was suitable to understand the meaning and categories that participants brought to the experience of "making" in the context of a fabrication laboratory that promoted STEM topics. Thus, as researchers, we did not aim to establish a generalization on how Fab Labs work, but to identify how this particular setting was working and the characteristics of the interactions among participants. Thus, conclusions were directed towards a profound comprehension of the influence of these spaces as enablers of educational opportunities for everyone. Also, qualitative findings provided lessons to be implemented in this Fab Lab and to be considered in similar contexts (other Fab Labs or makerspaces).

To achieve the objective of a deep understanding of this setting, during the three phases of the research process, we used the following instruments of data collection:

(1) Field notes: They were created after each session (training session with key participants and sessions held in the Fab Lab). These instruments allowed us to apply a process of participant observation [35] in which researchers had an active role in the collection of relevant data according to the objectives and research questions.

(2) Semi-structured interviews: Furthermore, interviews were carried out with participants since the beginning of the first stage until the end of the research methods. Interviews consisted of the following questions:

- How do you define social innovation?
- What is the impact of "FabLab Campana" in the community?
- How did you live social innovation within this project?
- How was your personal life influenced by this project?
- How would you motivate other people to join this project?
- What do you think are the benefits of the collaboration of Mexico and the UK in these projects?

(3) Image analysis: We selected relevant pictures and products from the Fab Lab in order to analyze them within the research objectives.

(4) Focus group: a focus group was carried out to discuss the operations of the FabLab with the community service students.

2.5 Data Analysis

The analysis and interpretation of information was carried out with the use of the software MAXQDA, compiling documents, identifying codes, and constructing categories from the perspective of participants.

3. Results

The implementation of FabLab Campana resulted in multiple outcomes. Sections 3.1 to 3.3 cover outcomes related to 3 categories that emerged from the codification process: a) Cooperation, b) Dialogic space, and c) Rewarding and meaningful experiences for the participants. Each category has indicators as displayed in Table 4. Finally, section 3.4 states lessons learned from the overall design, implementation and operations of the FabLab from the point of view of the project leaders and participants. This is carried out in order to contribute to the analysis and learnings for the implementation of new FabLabs with similar characteristics in other settings.

Table 4.

Codification Indicators and its sub indicators

Cooperation	Dialogic space	Rewarding and meaningful experiences
Facilitating group discussion	Sequentiality	Connecting hobbies to Fabrication
Intercultural sensitivity	Positioning	Connecting to social needs
Asking for help	Historicity	Motivation to learn
Openness to new ideas about how to proceed	Plurality	Connecting to the future
Willingness to find solutions to the problems		Learning
Teaching and sharing knowledge to achieve a goal		Commitment

3.1 Cooperation

The first category of results deals with the development of cooperation among participants, which was apparent in a variety of situations among the FabLab Campana participants, as is reflected in Table 5 and Table 6. While Table 5 focuses on the results of the first phase of the project, Table 6 focuses on the second phase. Results indicate that FabLabs are not only characterized by specific technical and instrumental aspects belonging to the digital and maker fields but a sense of widespread community with the values of solidarity and collaboration [36].

Table 5.

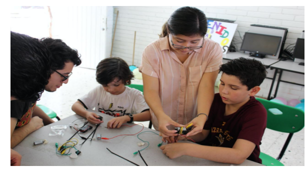
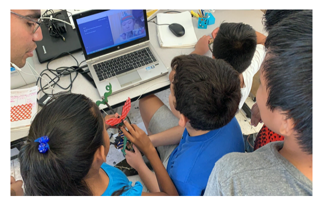
Cooperation among FabLab Campana participants during the second phase

Item	Participants	Topic of the Session	Cooperation indicator	Example

1	Community Service students and children	Robotic Arm	Facilitating group discussion	The Community Service students had to design and prepare an engaging activity for the children. There were two good ideas (to build a cardboard machine and to make a robotic arm) and the group split in two. They were hesitant in giving in to the other group's ideas until they finally agreed to get together and discuss what activity was best for the purpose of the session. They chose the robotic arm and they all contributed to it.	
2	Community Service students, children and FabLat Kids	Emosilla Circuit	Teaching and sharing knowledge to achieve a goal	For some children it was easy to do this activity because they had previously worked with circuits. One of them (8yo) had produced more elaborated circuits, and when he realized that, he started helping other children to do similar prototypes. They showed reciprocal teaching strategies among peers.	
3	Community Service students and CBTis99 students	3D printing	Willingness to find solutions to the problems	Community Service students were in charge of installing Sketchup (a 3D modelling software) in the FabLab computers for this activity. They tested and realized the computers did not have the requirements to run the software. They spent a couple of days searching for a software the computers would support and decided to try 123D Make. It is an outdated program, but they found a version that worked, installed it and learned how to use it before the session. This is an example of creativity (finding solutions) and persistence (not giving up) of the students.	
4	Community Service students, children and FabLat Kids	Koinobori (Global Kids Day)	Demonstrating sensitivity to diverse cultures	Alejandra was not in town to organize this activity, so she put two of the students in contact with the FabLat Kids collaborators in Brazil and Qatar. They first struggled figuring out the sequence of activities for the workshop, as well as for the construction of the Koinobori because communication was difficult due to language differences. Alejandra motivated them to keep asking and communicating politely until they started to catch the different ways by which the collaborators expressed themselves.	

Table 6.

Cooperation among FabLab Campana participants third phase

Item	Participants	Topic of the Session	Cooperation indicator	Example	
1	Community Service students and children	Bichobot	Facilitating group discussion	Alejandra was teaching the children what happens when the battery and LED make contact. The children were happy to see it lighting. As there were other batteries left on the table, one child put two batteries to light the LED. They all saw it lighting. Thus, another child said, “you should put 3” while another child immediately said “4 at the same time”, they were passing their batteries. Alejandra told them that it was correct, that the lights turn on, but they will burn if they keep doing it.	
2	Community Service students and children	Alebrijes	Intercultural sensitivity	During the Alebrijes session, there was an opportunity to make a connection with a FabLab in Brazil. Kids were previously taught to greet in Portuguese. They were working on Alebrijes at the same time. The FabLab in Japan also connected, and the kids were able to share with them too. Conversations around what they ate, what they liked to do, what they watched, emerged as part of the interaction	
3	Community Service students and graduate student	Alebrijes	Asking for help	The FabLab Campana could not cut larger pieces, so students decided to go to a makerspace located at Tecnologico de Monterrey. Upon their arrival, they were informed that it was not working. They started calling friends for help, as they needed to cut the pieces to make the Alebrijes. They went to a manufacturing lab on campus, but the machines were not properly installed. At the end it was rewarding that asking for help resulted in seeing the children enjoying the activity	

4	Community Service students and children	Future of La Campa na	Opennes s to new ideas about how to proceed	The communitarian social service students instructed the participants to draw a map of the Campana-Altamira community. Immediately after, two other community service students posted flipcharts in the FabLab and suggested a rearrangement of the working tables to facilitate the activities of participants.	
5	Community Service student and graduate student	Cardbo ard Automa ta	Willingne ss to find solutions to the problems	Teams were made to prepare the materials for the cardboard automata activity. Lisa gave Antonio a pair of scissors to cut the box. He replied that they were not sharp enough, and they were not cutting. So, Lisa taught him how to poke the box to cut it. He was reluctant about it but tried it. It did work to do it that way.	

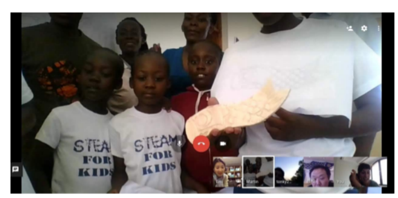
3.2 Dialogic space

Analysis of interviews also revealed that FabLab Campana contributed to the establishment of a horizontal dialogic space [20] in which participants collaborated to achieve educational goals. In this process, participants perceived integration, dialogue, collaboration, commitment and knowledge application as part of the workshop results. Children and volunteers had the opportunity to share the creation and learning process with people from multiple backgrounds, regional settings, and different academic positions. Interdisciplinary projects were held with the inclusion of different users and this helped to improve the outcomes of activities. Table 7 and Table 8 portray examples of the participants' perspectives that provide an account of the creation of a dialogic space that appeared during the activities in the FabLab. Table 7 focuses on the results of the first phase of the project and Table 8 in the second phase.

Table 7.

A Dialogic space second phase

Item	Dialogic indicator	Context	Example

1	Historicity	Before every activity we have a moment of reflection where the guide explains the concept to be learned, through discussion of everyday situations.	For the Drawbot Workshop, we explored the concept of a circuit. Alejandra started asking the children if they have light at home. When they said "yes" they started discussing where the energy to light it on comes from. They mentioned sources like the sun, the air, or the water. Then, Alejandra presented the concept of a power source. Following this, she asked how they turned the light on and off and the kids mentioned the switches, outlets and solar panels, and Alejandra explained the concept of a switch. Finally, she asked what else they can turn on at home and the children mentioned a blender, a washing machine, and a fan. Alejandra motivated them to think what the common component in these items is, until they noticed it is something that spins. She then introduced the concept of a motor. Once they understood what the parts of a circuit are (power source or battery, switch and motor) she gave them the components to build their own circuit and then apply it to an object (drawing robot) just at the objects they have at home.	
2	Plurality	Every year, FabLat Kids organizes the Global Kids Day, an event to celebrate culture through technology. This year we celebrated Japan, learning about Koinoboris (fish of love) and making them with laser cutter and manual techniques too. Kids from all over the world do the same activity simultaneously and we interact	The children of FabLab Campana had the chance to interact with kids from Italy, Venezuela, Peru and the southeast of Mexico. They also watched the video of children in Kenya that had previously done the activity. The aspect they paid most attention to was the language. One of the girls mentioned how Italian was very similar to Spanish. They also learned to say hello and thank you in Japanese and kept repeating it in front of the camera to greet children in other cities.	

online.

3	Sequentiality	T shirts with vinyl cutter workshop led by Community Service Students for CBTis 99 students	Previous to the activity, a Community Service student learned how to use the heat press machine. During the activity he taught one of the CBTis students to use it. He learned fast and found a way to make it perform better. He then assisted his schoolmates to use it and led the rest of the activity which shows a horizontality in the knowledge transference process.	

Table 8.

A Dialogic space third phase

Item	Dialogic indicator	Context	Example	
1	Sequentiality	In the planning session of the cardboard automata a community student service student and a graduate student were discussing how to cut the box needed for the activity	D: What can I do? L: Help me with the scissors that we have to cut the cardboard D: But look, don't cut L: mmmm .. Well, how about we nail the scissors to the cardboard like this? D: ahh yes L: very well you follow him D: ah look at this side of the box is thicker, so it did not cut L: yes, correct so nailing the scissors was better	

2	Positioning	Dialogue in the focus group about the role of community service students	Teacher 1: What did you learn from this experience? Community Student 1: I believe that the biggest commitment we have is to be there for people, is to be and come back to help people to learn more. Graduate student 2: In this project I learned the way in which everyone contributes to the projects. Since everyone is different, everyone sees things differently and maybe you can see different ideas and they can all work, but some end up being better. Community student 3: The fact that I met people who have the same interests as me and I was able to apply everything I've learned for a couple of years at the Tecnológico de Monterrey	
3	Historicity	In the Alebrijes session the first part of the classes evoke knowledge from previous classes	Community Service Student 4: Do you remember what a FabLab is? Child 1: mmm, here Kid 2: a place for item production Community service student 4: great and what tools are in the FabLab? Kid 1: the cutter Kid 4: the printer Kid 5: computers Kid 2: the vinyl machine Community service student: Excellent, well let's review today's activity, let's go to this map. Do you know where Brazil is? Child 1: No Child 6: Yes Child 7: No	

4	Plurality	Dialogue in the focus group about the role of community service students	Graduate student 1: Would you like to be in charge in terms of planning the activities, that is, in terms of choosing. For example, today we are going to do this specific work, is it specifically planned for printing? Community service student 1: well, we could, sorry, keep going Community service student 2: Ah, well, I would suggest that, perhaps my colleagues say something else, but that although we started to plan the activity that is not completely coming from us because their opinion may not be given. I want to think that Ale, who is more of an expert than us, can differ in certain things and we take into consideration, but not specifically the entire activity. Community service student 1: I would suggest that the activity would not start completely from 0, because perhaps we would need the pedagogical, interactive support and what else to say. It could help to have on the one hand the idea of proposing and having structured accompaniment that has as its function, but also having as a repository like the activity, how good these are, the activities, that we did during the semester. Community service student 4: Autonomy, we rather want a study plan, with the activity and the objective that we seek to develop in that part of the activity, and we in the way that it is carried out correctly with the material that is very good for us, so you give us what you want to achieve that I want to do seriously, and we the way to develop it well. Graduate student 1: Yes, yes, yes it would help us. Coordinating teacher 2: yes, it would serve as, of course, without training, but if training, yes, but let's say all of them, then mix for the first 3 days, Community service student 3: I would think that could work	

3.3 Rewarding and Meaningful Experiences

Finally, the longitudinal analysis (first and second phase of the implementation of this project) evidenced that the execution of FabLab Campana displayed a positive and long-lasting impact for all participants, including students from the high school CBTis 99, children of the primary school, project leaders (from Mexico and the United Kingdom) and undergraduate community service students. These results of long-lasting impact were developed not only in relation to how the experience allowed them to learn from the workshops, but also it was about how they developed connections with their context, and they became motivated to learn more.

The creation of the FabLab itself brought together a network that connected two different socio-economic contexts: on one side Tecnologico de Monterrey and on the other CBTIS 99. Tecnologico de Monterrey is a private university in which students and teachers have access to infrastructure, scientific and technological changes, and research leading environment. The university has 26 campuses in Mexico, it also offers online education and has recently opened a hub in China for research, innovation and entrepreneurship. On the other side, CBTis 99 is located in the district Campana-Altamira, which has been characterized historically for presenting high levels of marginalization, generating a stigmatization of the area and its habitants which hinders their social inclusion, and promotes the reproduction of the circle of poverty in which they are living.

Thus, the sense of a social connection of knowledge generated among the participants of both contexts became relevant to plan activities and to promote a meaningful learning process in which opportunities were given to appreciate and value the context of each other. The rewarding and meaningful experiences are presented in this section considering one of the two social contexts where participants came from, as well as the phase of the study. Table 9 shows examples of Rewarding and meaningful learning for the first phase, while Table 10 shows examples for the second phase.

Table 9. Rewarding and meaningful learning: Tecnologico de Monterrey second phase

Item	Participants	Reward/Learning	Example

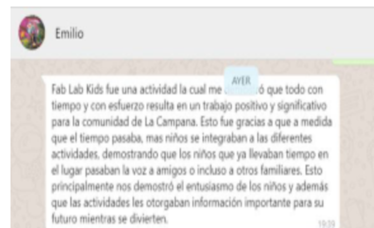
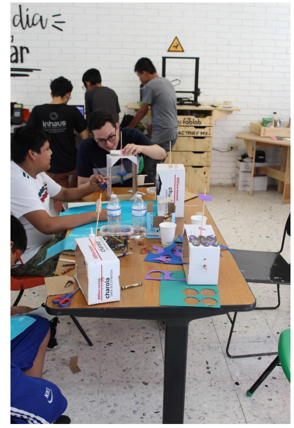
1	Coordinating professor	Commitment	"To keep a FabLab running is not an easy task; it requires an adequate program of activities and promotion of the space, but overall, a high level of commitment. Regarding this, I want to highlight the admirable work of the Community Service students of Tec de Monterrey, led by Alejandra, who week after week planned and prepared the activities."	 Adriana Educacion Tec en línea El Fab Lab La Campana-Altamira se establece como un espacio comunitario para desarrollar la creatividad con el apoyo de tecnología. El mantener vigente un laboratorio de fabricación digital no es tarea fácil; requiere de una adecuada programación de actividades y difusión del espacio, pero sobre todo, de un alto nivel de compromiso. En este sentido, cabe destacar la admirable labor de los chicos y chicas de servicio social del Tec de Monterrey, liderados por Ale Díaz de León, quienes semana a semana planearon y prepararon los materiales para llevar a cabo los diferentes talleres de creación tecnológica. Es así como niños y niñas de 6 a 12 años se fueron sumando cada vez más a este proyecto, en donde cada sábado resultó ser una nueva oportunidad para crear y aprender, siempre con la guía y acompañamiento entusiasta de los chicos y las chicas de servicio social y de Ale Díaz de León. Me siento afortunada por haberme dado la oportunidad de integrarme a estas actividades; considero que para todos ha sido una gran experiencia. Atentamente Adriana Castro Aguirre Coordinadora de la Maestría en Tecnología Educativa
2	Community Service student	Reflection	"FabLat Kids was an activity that showed me that with time and effort you can achieve positive and meaningful work for the community..."	 Emilio AYER Fab Lab Kids fue una actividad la cual me [illegible]ó que todo con tiempo y con esfuerzo resulta en un trabajo positivo y significativo para la comunidad de La Campana. Esto fue gracias a que a medida que el tiempo pasaba, mas niños se integraban a las diferentes actividades, demostrando que los niños que ya llevaban tiempo en el lugar pasaban la voz a amigos o incluso a otros familiares. Esto principalmente nos demostró el entusiasmo de los niños y además que las actividades les otorgaban información importante para su futuro mientras se divierten. 19:39

Table 10. Rewarding and meaningful learning: Tecnologico de Monterrey third phase

Item	Participants	Reward/Learning	Example	
1	Community service student 2	Realization of areas of opportunity	"[The FabLab experience] opened my mind to realize that there are many areas of opportunity to innovate"	
2	Professor TEC 1	Own inspiration	"For me this project has been inspiring, since I have listened to the needs of the community and how solutions have emerged from them"	

3	Community service student 2	Sense of belonging to a global community	“Connecting with other countries was cool and not only the children were excited about it because it makes you think that it was not only a local project but that it was like something being done elsewhere. And that it makes sense that you were part of a larger movement even though it was a relatively smaller school. And that made me as a student feel cool	
4	Community service student 1	Overcoming own limitations	“I liked [the FabLab experience] it because in my career we don't see anything about laser cutters and I think that the perception or idea I had was very different, I imagined it as more complex, and now I realize that if you bring your degree of complexity but it is to enter within the parameters. And then I knew a little more about 3D technology.	
5	Community service student 4 and 12	Looking at possibilities	Ana and Francisco decided to change the box for the automata. Francisco went to see the rest of the boxes of the rest of the classmates and was observing what the rest had done. Lorena asked Ana why the small box did not work, to which she replied that the circle collided with the straw. Ana said they need to expand the size of the box. Lorena asked if the size of the circle can be reduced. Ana said no because it is already glued with silicone. Lorena told Ana to cut the straw. Ana said, “no I don't think it works”. Lorena grabbed the scissors and told her to try because in any case there was still another other box. Lorena cut it and told Ana to turn the automata and it worked.	

6	Community service student 4	Be the inspiration	I think this helped the children to see that there is more, as they do not occupy many things to do something big. Because many of the activities we did were with the boxes and the spotlights and see that it could be illuminated. They could see that it was only to want "	

Tables 11 and 12 show rewarding and meaningful learning for the second context where participants were coming from. In this case the people related to CBTIS99.

Table 11. Rewarding and meaningful learning: CBTIS99 second phase

Item	**Participants**	**Reward/Learning**	**Example**	
1	CBTis 99 student	Connecting to social needs	3 girls decided to work in the FabLab to prototype a project for the entrepreneurship class. They developed two items of affordable cosmetics made of natural materials and package to fight animal testing and to avoid toxic substances in the skin.	
2	CBTis 99 student	Connecting hobbies to Fabrication	After the vinyl cutting workshop, students spread the word. One of the students came back with some friends and taught them to make and cut stickers for their phones.	

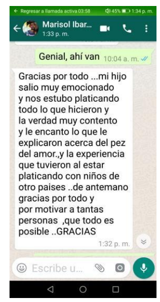
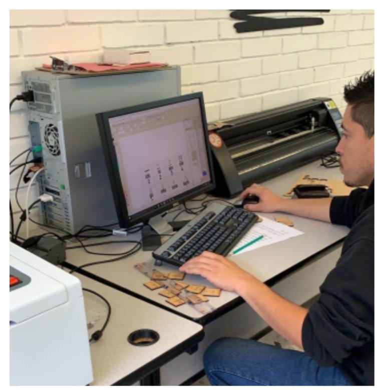
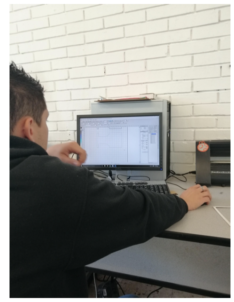
3	CBTis 99 student	Motivation to learn	One of the students that attended all the workshops, got together with other students and started a "Videogamer Club" using the FabLab computers, to learn coding. They didn´t know how to start but talked to Community Service Students and teachers for advice and did some research online to find open software.	
4	Mother	Overcoming own limitations	"Thank you for everything... My son is very excited, and he told us about everything you did. Truly, very happy, he loved what you explained about the fish of love (koinobori) and the experience of talking to children in other countries. Thank you for everything and for motivating so many people to know everything is possible. THANK YOU"	
5	CBTis 99 student	Looking at possibilities	After the Koinobori Workshop, one of the children's brothers got interested in Japanese culture. He did some research on kanjis and came to the FabLab to engrave and cut some in laser.	

Table 12. Rewarding and meaningful learning: CBTIS99 third phase

Item	**Participants**	**Reward/Learning**	**Example**

1	FabLab Manager	Connecting hobbies to Fabrication	“I have always been interested in learning about electronics, programming and now I have the opportunity to be here not only teaching but also learning in deep about what I like"	
2	CBTis 99 student 5	Connecting to social needs	“I would like to make a product that doesn't pollute the environment”	
3	CBTis 99 student 3	Motivation to learn	“It was spectacular… It has interested me since I started listening to it and it was very shocking to know that I have more opportunity to learn things and so on” (Student CBTIS99 1)	
4	Kid 1	Connecting to the future	"I want to become a Paleontologist so I will place myself in the land" [she referred to the model of herself that she had decorated with LED light]	
5	Kid 9 and Community service student 12	Learning	Student 9 did not know what half of 12. So Community service student 12 took a ruler and told student 9, “we are going to advance one by one (he placed the index of the right hand of student 9 at the 0 of the rule and hers in 12)”, and they did so from the end until they reached the center. Thus, they determined that half of 12 was 6.	

4. Discussion

FabLabs promote free decision-making processes and democratic relationships among the community members in a context where interactive design is applied. In the case of FabLab Campana, participants were inspired by the possibility of creating a space for constructing better learning spaces for improving the quality of life of inhabitants of this district. Higher education students grew in empathy, knowledge of science education, and solidarity towards other forms of life in the city of Monterrey. CBTIS students learned about STEM subjects' knowledge, possibilities for prototyping materials in the search of solutions for community problems, and the possibility of better forms of life, a path out of marginalization.

Through the implementation of this fabrication laboratory, educational agents were involved in a participatory and interactive design approach. From a business standpoint, interactive productive design represents an opportunity to use a market-oriented strategy instead of a product-oriented strategy. The benefit is that interactive product design is a major economic and strategic issue in innovative products generation [37]. In this FabLab, interactive design helped to support the knowledge modelling in preliminary design, considering the needs and perspectives of participants, and allowing them to have an active role in the pursue of their personal objectives. Thus, the input of the customer's needs was taken into account, from the design stage, to the final real physical product [38].

Mazur [39, 40] argues that modern engineering education should reflect on the professional world in general. This vision relates to this FabLab in the sense that it is important to create educational opportunities that propel interactive design, either in formal or non-formal pedagogical contexts. This space became an opportunity for children, community service students, teachers and researchers, all from different ages, different socio-economic backgrounds and experiences, to interact between each other. The Fab Lab itself represented a collaborative learning context that incited, supported, and extended possibilities for the design of prototypes based on participants' interests and needs. They developed competences such as communication, intercultural awareness, and consideration of different positions, which in the professional world will translate in engaging different stakeholders as part of the design or manufacturing processes.

In this space of interactive design, the dialogue that was possible was productive as it helped participants from different institutions and backgrounds to collaborate in the search of common goals and the use of tools for achieving them. In contrast to other formal settings where curriculum is compulsory and testing is the measure of progress, the freedom and openness of a space such as the FabLab Campana affords meaningful learning in STEM education as it connects with more genuine interests of participants to solve problems creatively. This, in turn, affords more genuine identities where participants grow in skills to use tools in an informed way and to be recognized by others for the expertise developed. It also helps to create a sense of belonging to a social group and thus to be sensitive to the needs of others. This is certainly a higher objective that we could all aim as educators.

The implementation of FabLab Campana resulted in lessons learned related to the process of operating a FabLab in a marginalized community. These lessons include:

1. The need for funding to start collaboration with different sectors of society, such as university students, scholars, students from basic education schools, as well as members of marginalized communities.

2. A carefully initial diagnosis about the needs of participants, ensuring an opportunity to empathize with them in order to identify what their circumstances are for everyday living.

3. In order to transmit the spirit of STEM education, it is important to design creative ideas with an open mindset when addressing problems faced by community members.

4. Allow for a phase of prototyping the setting, its spaces, machinery, furniture, services, possible relationships, and users.

5. The need of funding for setting up the site. The funding might come from national or international agencies with an agenda involving social innovation, digital fabrication and transformative learning.

6. The need for a long-term sustainability plan. In the case of this project, we have found it very valuable to join interests and strengths from several audiences to help sustain the FabLab. In particular, the time provided by university students as part of their communitarian social service to interact with other members of the Campana-Altamira district was very instrumental to achieve a sustained activity with children and CBTIS students. Also, the time provided by scholars and administrative staff from Tecnológico de Monterrey was crucial for coordinating the efforts of participants. Sustainability was not only about money, but more crucially about time (see [41]).

7. The importance of international help and academic support. For this project, one of the key features of success was the international attention received from the British Council and other English universities, which became very interested in the academic work we were developing, as well as in the circumstances of the participants in marginalized settings and the possibility to co-design a different future for them.

8. A plan for disseminating findings through conferences and publishing academic papers, which also are a way to be part of a wider community of scholars conducting research linked to real scenarios and educating students in addressing real challenges as part of their university education.

9. Funding support is needed in order to disseminate results and expand the network of researchers addressing social innovation problems and digital fabrications, as well as for renewing machines, furniture, and covering the expenses of the site and their participants. We are also in this stage, trying crowdsourcing platforms.

10. The importance of connecting the concepts of educational innovation and interactive design, as these two areas help to develop a sense of identity with the activities and mission of the fabrication laboratory. In this process, dialogue was a key practice, because it assisted participants to express their needs and work actively in achieving their personal and professional objectives.

Thus, these learnings might serve as an opportunity to guide new projects in this field. Furthermore, it opens the discussion for identifying the requirements that makerspaces need to cover in order to promote collaboration with the participants and help them to achieve a more promising future.

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