Makerspaces for Inclusive Education

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Abstract. Academic makerspaces have been shown to foster creativity and innovation, as they provide conditions for novel thinking to challenging problems. The capability to foster rich discussions, robust ideas, and unique cross-discipline collaborations and approaches stems directly from the diversity of people, their backgrounds and perspectives, as well as their interests, which become lively in the makerspace. This project leverages the creativity and communities of two makerspaces located in two major higher education institutions, to address the need for educational tools and materials for STEM education of students with visual disabilities. Higher education students who participated in this challenge formed multidisciplinary teams to create novel accessible, affordable devices containing inclusive technology to foster inclusive learning environments. This work is an example of how educational innovation and engineering can merge in a project mediated by makerspaces, culminating not only in the generation of the products expected, but also in valuable outcomes for higher education students who participated in this challenge-based experience.

Keywords: Educational innovation · Higher education · Inclusive education · STEM education

1 Introduction

1.1 Makerspaces in Universities

Makerspaces, also known as fablabs or hackerspaces, serve as gathering points for creation where skills, knowledge, resources, and community merge [1]. They act as platforms to promote creativity and innovation, encouraging the free flow of ideas through hands-on prototyping and open collaboration practices. Such spaces are becoming ever more relevant in the support of engineering and design programs that promote innovation and entrepreneurship [2]. Rooted in its philosophy, a makerspace is a place where anyone can learn about and use digital fabrication technologies to make almost anything [3].

Research carried by Webb [2] suggest that makerspaces are largely student focused, for the promotion of technological skills by showing people how to make things. In particular, universities worldwide have implemented them in a variety of forms to

M. Antona and C. Stephanidis (Eds.): HCII 2020, LNCS 12189, pp. 246–255, 2020.
https://doi.org/10.1007/978-3-030-49108-6_18

support education in STEM fields [4]. In the process of making, students develop STEM skills and knowledge to solve challenges through creative solutions [1].

Users of these spaces are commonly called "makers" and are recognized as being part of the "Maker Movement" [2] and can vary according to the vocation a given makerspace has. For instance, in their study of Norwegian makerspaces, Jensen et al. [5] identified six different categories of makers, varying from children looking for educational experiences to established companies looking for industrial and commercial solutions. They also divided user profiles into two categories based on their expertise level: novel users with limited experience or trying the technological tools for the first time, and extreme users with advanced experience building complex projects.

The maker movement conveys more than lab spaces and tools for creation, it portraits a philosophy in which imagination, creativity, engineering, arts, and an insubordinate mindset merge in the creation of novel functional devices. Hlubinka et al. [1] described a philosophy in which:

- Makers believe that, if it can be imagined, it can be made.
- Makers are more than consumers, they are an active part of a creative process.
- Everyone can be a maker.
- Makers seek out opportunities to learn to do new things, especially through hands-on, DIY interactions.
- Makers surprise and delight with their projects, no matter the state they are (rough-edged, messy and, at times, over-stimulating).
- Makers comprise an open, inclusive, encouraging, and generous community of creative and technical people that help one another do better.
- The economic benefit is not the primary focus of the Maker movement; however, makers are not against it. Entrepreneurship blooms naturally.
- Makers celebrate other makers, their drive, enthusiasm, passion, and skills.

Makerspaces do not operate locally and in isolation, instead they tend to connect to a global network of like minded people and spaces [3]. The concept of community is strongly associated to makerspaces, studies has shown how volunteer contributions by a wide community of enthusiasts are becoming structural to the functioning of the culture and high-tech industries [6].

In academic makerspaces, community members formally and informally learn from one another in a variety of formats: classroom, workshop, or open-studio [7]. Along with this philosophy, inclusion appears as an intrinsic component of makerspaces that are open to an enthusiast community of makers where richer discussions, more robust ideas, and greater interdisciplinary collaborations naturally arise due to the diversity of people, perspectives, and interests. This openness and multi-disciplinary character of makerspaces have also encouraged participation of female students, and thus created inclusive environments in a broader sense.

1.2 Academic Makerspaces in Latin America

In Latin America, several major universities have joined the maker movement in recent years and now have functional academic makerspaces in their facilities. Although the exact number of makerspaces in general is unknown, it is clear that the maker movement is incipient in this region (about 30), and numerically, those in the US (between 240 and 600 registered) surmount at least 10 times those in the entire Latin America, according to Web directories from well-known organizations in this field [8, 9]. Similarly, a recent search for publications about makerspaces in Latin America informed there are few articles that can give us a closer look on how makerspaces perform in the Latin American context. Due to this fact, we extended the search to Iberoamerica, and one of the few reports situated in this context is the paper by Saorín et al. [10], who address the importance of a makerspace as a place to improve the creative competence of engineers in training at a university in Spain. Most recently, de León et al. [11], present ideas on how a classroom can be converted into a makerspace in a school in Tenerife, Spain.

Situated in a setting closer to the Mexican context is a study analyzing the role of 3D printing technology for inclusive innovation in Brazil [12]. In this paper, the authors conclude that "3D printing encourages design thinking in marginalized communities and the open access nature of the technology makes it more accessible to marginalized groups" (p60). In Mexico, the study reported by González-Nieto, Fernández-Cárdenas and Reynaga-Peña [13] details to what extent the sense of belonging, collaborative learning and networking are fundamental aspects for creating an innovative ecosystem in an academic makerspace.

With that into consideration, the work we present in this paper aims to contribute to a general appreciation of how academic makerspaces can foster inclusive STEM education in the Latin American context.

2 Background

2.1 Inclusive STEM Education (Our Project)

A main interest of our work group is to foster inclusive STEM education at the different school levels. For this project, we elected to work with blind and visually impaired (BVI) students as an example of a group in situations of vulnerability. Previous research on the analysis of science education for mainstreamed visually impaired children at the middle school level in Mexico [14] revealed that, even if the implementation of the curriculum is a multi-factorial situation, there are two key aspects where more need is required for improving the educational quality for this population. On one side, there is a noticeable deficit of inclusive STEM educational materials and resources for students with visual disabilities, and on the other, specialized teacher training and teacher professional development is a requisite for successful STEM education. For the work we describe in this paper, we address the first aspect, mainly, the existing deficit of inclusive educational materials. We approached this task in the form of a challenge-based pedagogy with the involvement of higher education students from two major universities, one in Mexico and one in the US, so the process would involve an educational scenario for them too.

In order to achieve that, we developed a novel collaboration between the fields of educational innovation and engineering, mediated by the key participation of the Innovaction Gym at Tecnologico de Monterrey in Mexico and the CITRIS Invention

Lab at UC Berkeley, being both examples of academic makerspaces immersed in leading universities in the field of engineering. Consistently with the concept of an academic makerspace, both laboratories promote invention and innovation by providing each other, mentoring and the infrastructure and/or equipment required for materializing ideas. Everyday processes in a makerspace include iterative prototyping, testing and solving challenges in order to obtain a functional product. A common and flexible thread for both laboratories is that the user range goes from students who are just beginning to explore the processes of making and craftsmanship, to those who are fully immersed in the culture of making as a global movement.

2.2 Inclusive Technologies for STEM Education

Elsewhere, we have elaborated on the shortage of accessible and affordable inclusive technologies for STEM education of students with visual impairments [15], starting from the premise that inclusive educational materials are those that fully support participation of all students, with the same level of engagement and at the same time in a mainstream classroom. Some examples of basic inclusive materials are Braille texts holding color illustrations and regular printed text, or three-dimensional objects with tactile resolution plus attractive visual information.

Technology, used as a support tool, is a potent agent to reduce differences between people with disabilities and without them; technology also helps build up on the autonomy of youth with such condition. However, to the best of our knowledge, few technology-based educational resources utterly comply with the characteristics of being accessible for BVI users, while they are also attractive and inclusive for sighted individuals. Some of those available are multisensory and provide auditory information [16], while others have evolved to be part of more sophisticated contexts, such as museums [17].

In the last decade, 3D printing technology has allowed to materialize three-dimensional representations of objects in a selection of science subjects, including Biology and Astronomy, to support the education of blind learners [18, 19]. Using 3D printed objects is an advancement over the traditional use of 2D tactile thermoformed graphics, and their cost is still affordable; however, simple 3D printed objects usually are single-colored, and do not include interactive technology.

It is well known that Universal Design for Learning (UDL) [20] is the framework of choice for developing inclusive technologies. Implementation of UDL in classrooms benefits students with disabilities who major in STEM fields, as it provides them with alternatives in the materials, content and resources they use for learning [21]. The use of UDL designed educational resources also increase the opportunities for interaction of BVI users with their sighted peers, as both can use the same learning materials. Thus, we proposed that the challenge would be addressed following UDL principles, so the products would be engaging and useful to all learners.

3 Methodological Approach

3.1 Participants

College students who participated in this project belonged to diverse majors, including engineering, mechatronics, biotechnology, business, physics, humanities, technology and computer science, among others. Participants were recruited at both universities through an open call, considering all majors, and the best profiles were invited to join the project, based on their interest in education and their previous experience on projects with social impact, as well as their abilities for making or desire to become makers. Once students were selected, they organized into interdisciplinary teams.

3.2 The Challenge

Explicitly, the call was to create inclusive educational materials based on Universal Design for Learning (UDL) with suitable tactile and auditory features that would also make them multisensorial, through the incorporation of low-cost technology. Technology was considered to support autonomous learning by potential users.

As mentioned in the previous sections, this challenge emerged from a current deficit of STEM educational materials accessible to blind and visually impaired (BVI) learners. The focus on BVI learners was decided under the premise that this group is an example of underserved, vulnerable population. Additionally, the resources to be produced, if complying with the requirements listed below, could be useful for other vulnerable groups as well. This means that the materials to be generated would have the potential to be used by everyone in a mainstream classroom, in equal conditions, in contrast to traditional materials for BVI, which are not attractive for sighted students, and therefore are non-inclusive.

The objective was ambitious, but feasible given the intrinsic resources of both makerspaces, which played a central role in the process. Thus, the challenge for participants was to design and construct prototypes with the following desirable features: the products had to be accessible and inclusive (UDL designed), engaging, scientifically accurate, interactive, multisensorial (with tactile, audio and/or video components), affordable, and reproducible. An ideal product would also have the capability of providing auditory information in various languages. Scientifically precise language would have to be academic, using a horizontal discourse [22], so that marginalization due to social class will be addressed as well.

Maintaining a low production cost is an important feature, as we aimed to produce a repository of files with open licensing, available at no cost, either to print or assemble objects, and therefore, the idea is that they will be available to educators worldwide. The reasoning behind those requisites is that the products could be used in formal and informal environments, and replicated in any place with access to a makerspace (or a digital fabrication lab), or even in a regular fabrication facility.

3.3 Developing Empathy with Target Users

To undertake the task, higher education students were sensitized to the condition of visual impairment through activities that included, among other, conversations with adults with visual impairment, who shared their experiences as blind learners. Some teams also visited local or international associations for the blind, or centers for development of educational resources for students with disabilities, as well as a technology center for the blind. All activities had the intention of creating empathy, but also helping participants understand the needs of the target users and know what was currently available and in use in those places.

3.4 Making Together

A second goal of the project was that participants from each institution interacted with fellow participants at the other university. To facilitate this interaction, communication occurred through remote group meetings and chats, and mutual visits took place in order to exchange ideas and form an extended, bi-national, community of makers. Monterrey students participating in the project visited Berkeley for a week, then Berkeley students visited Monterrey.

Within the first weeks of the project, one activity to build collaboration between participants of both countries and between teams took place. This activity consisted on teams designing a unique chair that would represent an aspect of the culture or context of each of both universities; instructions for building the chair were exchanged between mirror teams at the other university, under the command that the original design could be hacked by the builders. The purpose was that participants would get to know each other, would discover the skills of their teammates, but also to realize what was needed for the instructions to be universal. For example, to take into consideration the differences in measuring systems, availability of materials and clarity of descriptions, in order for the product (in this case, the chair) to be replicated anywhere. Once participants completed the general activities described above, the ideation stage formally began and they focused on the design and development of their educational prototypes.

3.5 International Mentorship

Mentors for the higher education students participating in the project included specialists in engineering, prototyping, technology, programming, educational innovation and inclusive education for the blind. The role of mentors was to offer support and advice, but also to guide participants to do research and build the knowledge needed to materialize their ideas. Mentorship occurred both ways in the international collaboration, and complemented one another. While at Berkeley the major input was on boosting creativity, ideation and problem solving, the group at Monterrey mentored in aspects of science education for BVI students and other vulnerable populations.

Participants from both universities met with mentors on a regular basis throughout the duration of the project, to share advances on their developments and to receive feedback, in order to run several cycles of iteration before functional prototypes were fabricated. The design and development processes also included conversations with end users (blind individuals), with special education teachers, and with accessible technology experts at different stages of the project.

4 Results

Results were tangible in at least two venues: 1) the generation of prototypes of educational materials accessible to blind youth; and 2) valuable learning outcomes for the college participants after the challenge-based experience.

4.1 Prototypes

To date, there are four educational products in the stage of functional prototypes generated by interdisciplinary teams of college students, some of those are in the process of being tested with users.

One team developed a game-like device with sound display designed to help blind students practice math operations through play. A second team produced a device to learn the Braille alphabet, which is suitable and engaging for young learners. A third team developed an educational prototype to learn about the female reproductive system. A fourth team is currently testing an interactive device that provides auditory information on any three-dimensional representation of choice on STEM subjects. This product has the flexibility that the information to be displayed can be recorded and played in any language. A description of this device is available elsewhere [23].

A further goal of this project is the creation of an open repository of the resources generated by participants; this ultimate product will have the potential to benefit an unlimited number of users. To the best of our knowledge, this could be the first repository in Latin America to hold STEM educational materials with technology to foster inclusive education of students with visual disabilities in mainstream classrooms or other formal and non-formal educational settings.

4.2 The Social Part of Innovation Through Making

Students reported that through participation in this project they learned to solve problems in innovative ways, searching for more alternatives than originally thought, in terms of design and use of materials:

"I realized that we are doing a good project in order to help people that are really in need, and to join forces with others who are interested in helping this type of participants" (Log 14-14).

Higher education students also realized the value of collaboration, as they worked in teams to develop solutions for the education of BVI participants. The process of getting to know each other was possible as part of the everyday group work at the makerspaces, but also as a result of the trips they did visiting the other university teaming with them:

"In relation to our interaction as a group, [at the beginning] we didn't know each other well and that made difficult to build trust… after visiting each other, I realize that now we are a team, we know each other's names, likes, jokes, but also we have found the real purpose to continue with this project" (Log 1516-2050).

Teams also were approached by other researchers and makers in different moments when they were presenting their prototypes, who offered help and support to build prototypes:

"We were approached by a scholar from the Faculty of Engineering (Log 7-7), [and] we did networking with Okdo and Arduino, which were very interested in supporting our projects (Log 3-3).

Students also had the opportunity to compare and value strengths in both institutions. Berkeley, located in the Silicon Valley, offered a fertile business atmosphere and Tec de Monterrey was identified as a place for creativity and craftsmanship aimed at the local needs of BVI participants.

Empathy with the needs of users, blind and visually impaired, was crucial: "Talking to them [BVI] helped me to understand aspects that we hadn't considered, that our product needs to have" (Log 2-2). "We learned to become more aware, empathic and humble to accept that we don't know without the sense of sight, and it is our duty to search for information from the right people in order to try our product" (Log 5-5).

Finally, creativity was crucial for developing prototypes that can have a real impact in the life of users: "With this project I have learned that you do not need to be and engineer to be in a makerspace and do things which can help others, everybody, despite your area, age, or interests, you can start learning about the use of tools which make a makerspace a valuable space" (Log 3-3).

4.3 Participant's Engagement and Motivation

Information obtained from observations and student interviews taking place half-way during the project indicate that participants fully engaged in the generation of inclusive STEM education materials accessible to blind youth. They also expressed that the challenge was highly motivating to them and acknowledged that the accompaniment of mentors was crucial to find creative solutions. Within the mentoring process, they appreciated the freedom given to develop their ideas, in contrast to other spaces where they feel they are being limited.

According to the participants themselves, a highlight of the process was the networking of experts who were available to support them on the different stages of their developments. For many of them, this was the first opportunity to apply their knowledge and skills to solve an educational challenge. Some mentioned that they learned how to combine innovation in both fields, their major and education. An excellent example is one participant, majoring in Innovation and Design, who declared that through this experience he found a vocation for his future.

Among the areas that participants identified as most challenging, they mentioned the communication with other participants during the process, understanding disabilities, how to design for teaching/learning at the middle school level, and making ideas tangible.

Most interestingly, participants clearly situated their contribution to solve a pressing challenge in education and understand the social approach of their work.

5 Concluding Remarks

In a process where educational innovation is the main axis of all outcomes, the experience we describe in this work is an example of how a project centered in the use of a makerspace, involved higher education students from different disciplines to contribute to equitable and inclusive STEM education for disadvantaged groups, such as youth with visual disabilities.

The value of craftsmanship in materializing ideas was very relevant to communicate possible solutions and alternatives to different audiences, but also to develop further their own understanding of the challenges faced by BVI youth in school settings and BVI individuals in general.

Finally, the international experience of having students from Mexico and the United States working together in understanding the challenges of BVI educational processes helped university students in both countries to develop a shared community of practice for comparing and testing ideas for STEM education with a UDL perspective.

Acknowledgments. This project was supported by CITRIS-ITESM funds granted to the authors. We thank the advice of Alejandra Díaz de León, from Tecnologico de Monterrey, during early stages of the project.We thank Writing Labs, TecLabs, from Tecnologico de Monterrey for their financial support to present this work at the conference.

References

1. Hlubinka, M., et al.: Makerspace playbook. School edition. Maker Media (2013). www.makerspace.com
2. Webb, K.K.: Makerspaces. In: Publishing, C. (ed.) Development of Creative Spaces in Academic Libraries, Greenville, NC, USA, pp. 37–40 (2018)
3. Hielscher, S., Smith, A.: Community-based digital fabrication workshops: a review of the research literature. SPRU Working Paper Series, SPRU-Science and Technology Policy Research, University of Sussex, Brighton (2014). www.sussex.ac.uk/spru
4. Webb, K.K.: Case studies in the literature. In: Development of Creative Spaces in Academic Libraries, pp. 65–78. Chandos Publishing, Greenville (2018)
5. Jensen, M.B., Semb, C.C.S., Vindal, S., Steinert, M.: State of the art of makerspaces—success criteria when designing makerspaces for norwegian industrial companies. Proc. CIRP **54**(2016), 65–70 (2016)
6. Söderberg, J.: Automating amateurs in the 3D printing community. Work Organ. Lab. Glob. **7**(1), 124–140 (2013)
7. Wilczynski, V.: Academic maker spaces and engineering design. Paper Presented at the 122nd ASEE Annual Conference and Exposition. American Society for Engineering Education, Seattle (2015)
8. The Fab Lab Network web page. https://www.fablabs.io/. Accessed 30 Jan 2020
9. Make Web page. https://makerspaces.make.co/. Accessed 30 Jan 2020
10. Saorín, J.L., Melian-Díaz, D., Bonnet, A., Carbonell Carrera, C., Meier, C., De la Torre-Cantero, J.: Makerspace teaching-learning environment to enhance creative competence in engineering students. Think. Skills Creat. **23**, 188–198 (2017)

11. de León, A.B., Saorín, J.L., De la Torre-Cantero, J., Meier, C.: The classroom as a makerspace: use of tablets and cutting plotter to create pop-up cards in educational environments. Int. J. Emerg. Technol. Learn. (iJET) **14**(10), 116–131 (2019)
12. Woodson, T., Torres-Alcantara, J., do Nascimento, M.S.: Is 3D printing an inclusive innovation?: An examination of 3D printing in Brazil. Technovation **80-81**, 54–62 (2019)
13. González-Nieto, N.A., Fernández-Cárdenas, J.M., Reynaga-Peña, C.G.: Aprendizaje y práctica de la innovación en la universidad: Actores, espacios y comunidades. IE Rev. Invest. Educ. REDIECH **10**(19), 239–256 (2019)
14. Reynaga-Peña, C., Fernández-Cárdenas, J.M.: La educación científica de alumnos con discapacidad visual: un análisis en el contexto mexicano. Sinéctica (53), 1–17 (2019)
15. Reynaga-Peña, C.G., López-Suero, C.D.: Strategies and technology aids for teaching science to blind and visually impaired students. In: Álvarez Robles, T., Álvarez Rodríguez, F., Benítez-Guerrero, E. (eds.) User-Centered Software Development for the Blind and Visually Impaired: Emerging Research and Opportunities, pp. 26–37. IGI Global, Hershey (2020)
16. Landau, S., Wells, L.: Merging tactile sensory input and audio data by means of the talking tactile tablet. In: Proceedings of EuroHaptics 2003, pp. 414–418. IEEE Computer Society (2003)
17. Touch Graphics Homepage. http://touchgraphics.com
18. Grice, N., Christian, C., Nota, A., Greenfield, P.: 3D Printing technology: a unique way of making hubble space telescope images accessible to non-visual learners. J. Blind. Innov. Res. **5**(1) (2015)
19. Horowitz, S.S., Schultz, P.H.: Printing space: using 3D printing of digital terrain models in geosciences, education and research. J. Geosci. Educ. **62**(1), 138–145 (2014)
20. http://www.cast.org
21. Izzo, M.V., Bauer, W.M.: Universal design for learning: enhancing achievement and employment of STEM students with disabilities. Univ. Access Inf. Soc. **14**(1), 17–27 (2015)
22. Bernstein, B.: Vertical and horizontal discourse: an essay. Br. J. Sociol. Educ. **20**(2), 157–173 (1999)
23. Cuellar-Reynaga, D.A., Mendoza-Córdova, M., Ramírez A., Granados U., Santamaría D., Reynaga-Peña, C.G.: Touch and learn: turning simple objects into learning materials. A system that turns simple materials into multisensorial experiences for learning. In: Proceedings of Congreso Internacional de Tecnologías Inclusivas y Educación (CONTIE), pp. 135–140 (2019)