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Design for and with visual impairments through 3D printing: a case study from the covid-19 pandemic

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Abstract

This work aims to investigate the contribution of the design practice and 3D printing to improve the learning experience of visually impaired students through a collaborative design case study. The collaborative development of "IO", a multifunctional tool for visually impaired students in distance learning contexts, is presented in this work together with the results from the user tests of the experimentation. Thanks to the open design principles and the flexibility of 3D printing, these assistive tools can improve the learning experience during the whole school career regardless of disruptive events i.e., the Covid-19 pandemic.

Keywords

Open design, Covid-19, Additive manufacturing, Collaborative design, Inclusive design.

1. Introduction

The covid-19 pandemic has been affecting several aspects of human life since its outbreak in late December 2019. This event led to a global crisis that changed the daily habits of millions of people. Different countries have been imposing lockdown to tackle the pandemic situation and to reduce the virus spread ratio, generating new socio-economic problems (Nicola et al., 2020). The global medical community experienced a severe resource shortage due to the overloads caused by SARS-CoV-2. Digital technologies and additive manufacturing played a crucial role at the beginning of this pandemic thanks to their flexibility compared to the traditional processes (Irfan Ul Haq et al., 2020; Oladapo et al., 2021). The local and global actions of citizens and fab labs mitigated this supply chain crisis thanks to distributed manufacturing strategies (Kieslinger et al., 2021; Longhitano et al., 2021; Pearce, 2020).
Several people had to quickly adapt their lifestyles in response to this disruptive event. The activities of people with physical impairments have been strongly affected by the lockdown restrictions (Lebrasseur et al., 2021; Senjam, 2021; World Health Organization, 2020). For instance, the closures of the education institutions forced students to online classrooms, adding further barriers for those living with visual disabilities (Balkist & Agustiani, 2020; Battistin et al., 2021). Recently, some projects have been developing new tools for the learning experience of visually impaired students. However, these solutions are still focused on in-presence activities or offer limited haptic feedback to the users (Castilho et al., 2020; Ciano et al., 2021; Krahe, 2020; Samonte et al., 2019; Somma et al., 2021).
How can design practice and 3D printing processes contribute to improving the learning experience of students with visual impairments in distance learning contexts (Buehler et al., 2015; D'Olivo et al., 2020; Romani & Levi, 2020)? How can their contribution be actual even beyond a disruptive event for the daily habits of visually impaired students?
This work investigates the potential contribution of open design and 3D printing to improve the learning experience of visually impaired students. This paper presents the collaborative development of *"IO"*, a tangible assistive technology tool for visually impaired students in distance learning contexts (Mattiuzzo,

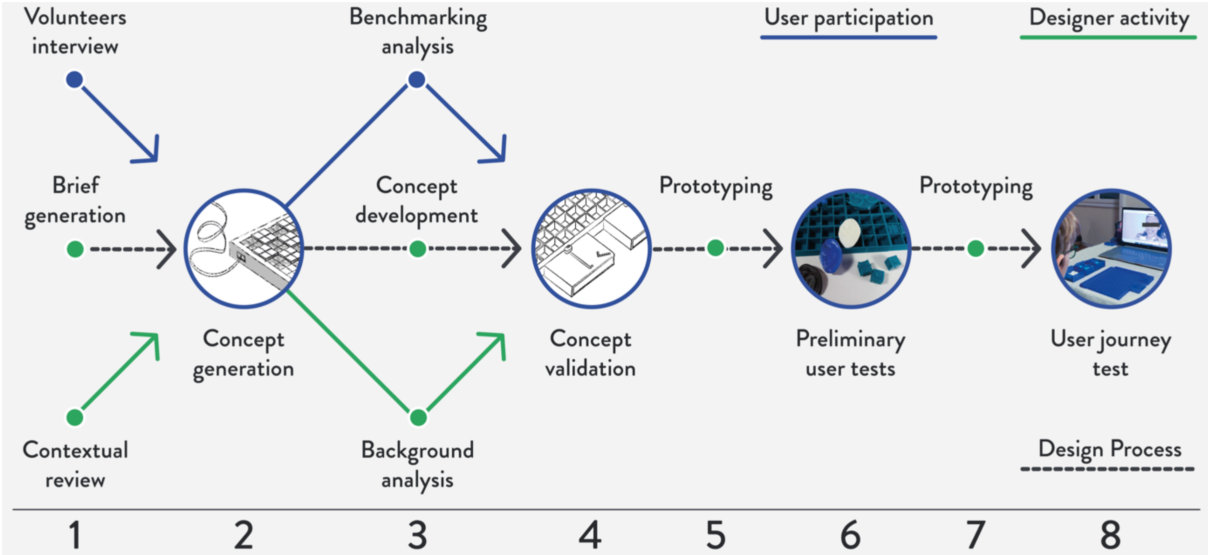

Fig 1. Steps of the research: 1. Preliminary phase with the generation of the brief, the contextual research, and the interviews. 2. Main ideas/concepts generation. 3. Project research to develop the concept. 4. Selection and validation of the concept. 5. Development and prototyping of the mock-ups. 6. User tests with the mock-ups. 7. Definition and prototyping of the final proposal. 8. User journey test with the final prototype.

2020). After the explanation of the research workflow, the tool is briefly described together with its use, potential distribution, and customization. Although further work should be done, these kinds of assistive tools may significantly improve the quality of life of the users during their daily habits, regardless of disruptive events such as the Covid-19 pandemic.

2. Methodology

This work shows collaborative experimentation based on a Research through Design approach (Buur & Matthews, 2008; Friedman, 2008) carried out with two Italian associations of visually-impaired people (Unione Italiana dei Ciechi e degli Ipovedenti ONLUS, Fondazione Istituto dei Ciechi di Milano Onlus). Fig. 1 resumes the general development workflow of *"IO"*. The activities were organized as it follows:
1. Brief proposals from the contextual research and the interviews with the associations' volunteers.
2. Generation and selection of the ideas/concepts according to the previous interviews.
3. Project research through a benchmarking and context analysis of the existing learning tools for visually impaired students starting from the volunteers' experience.
4. Validation of the most promising concept thanks to the feedback of the volunteers.
5. Product development phase and prototyping of the first mock-ups for the user tests.
6. Preliminary user tests on the haptic perception of the 3D printed parts with the volunteers.
7. Product definition thanks to the previous step and prototyping of the final proposal.
8. User journey test in a simulated distance learning context with a blindfolded student (primary school).

Two lockdowns were imposed in Italy during the experimentation of this work (2020). A preliminary interview was carried out with five volunteers to understand the daily habits of a person with visual impairments during the Covid-19. 3D printed mock-ups were used as the main communication tool and facilitated the collection of feedback on users' experience and haptic perception (Hartcher-O'Brien et al., 2019; Karlsson & Velasco, 2007; Metatla et al., 2015; Sanders & Stappers, 2008). The prototypes were made with a desktop-size 3D printer and commercial PLA and PETG filaments.

A user journey test was carried out with a blindfolded student at the primary school in a simulated distance learning context (late Fall 2020). The simulation focused on the use of *"IO"* before, after, and during the learning activity. The tests were done with a videoconferencing app. One author acted as the educator, while the other researchers and the child's parents gathered information, pictures, and videos.

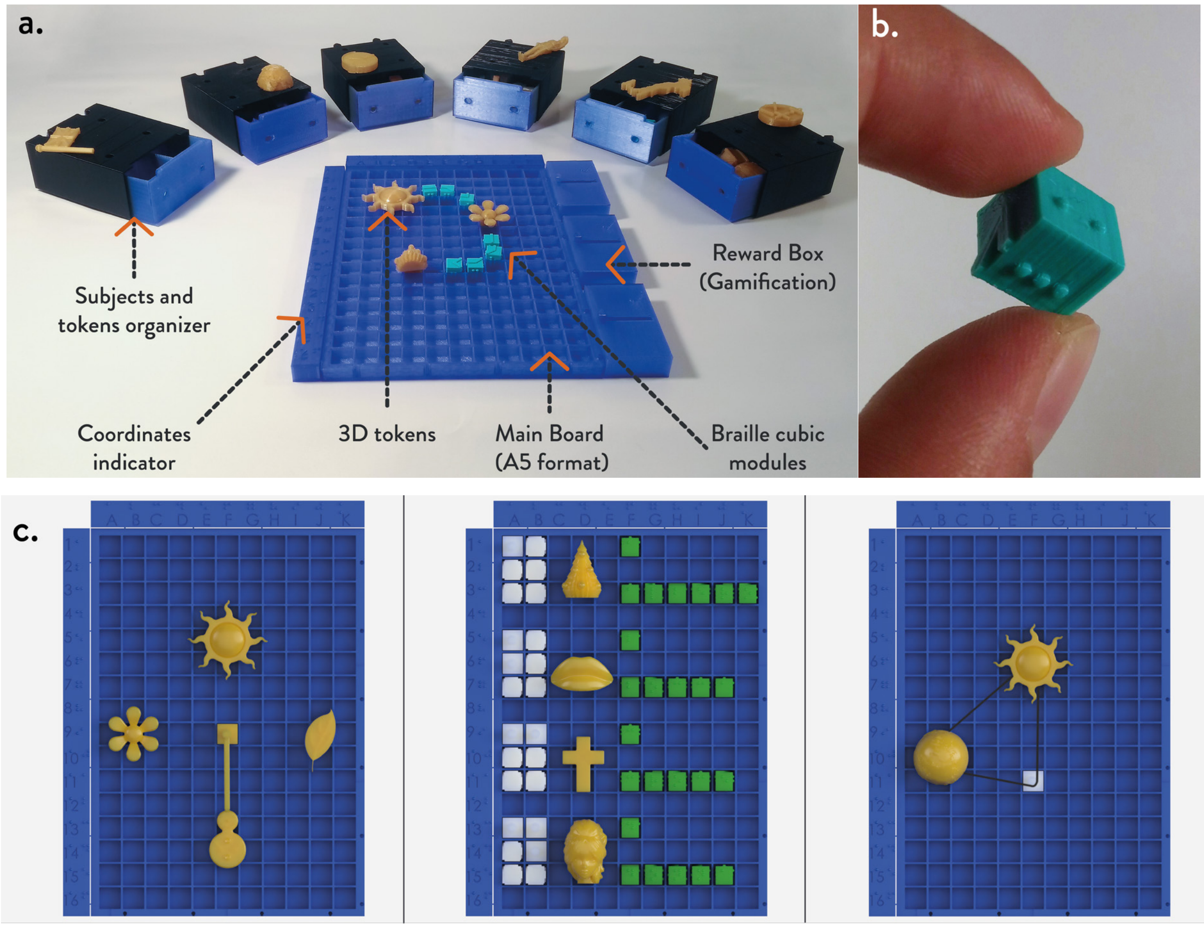

Fig 2. "*IO*" Multifunctional tool: (a) main components; (b) a braille cubic module; (c) three use configurations (from left to right: primary school activity on the four seasons, primary school braille and alphabet activity, and high school activity on the orbital rotation).

3. Results and discussion

"IO" aims to translate, through haptic feedback, specific learning concepts that are difficult to explain without visive support. It can be used autonomously in distance learning contexts through the coordinate system and the storytelling of the educator. This tool can be customized according to the user's needs, i.e., different school subjects, new learning modules, or leisure activities. The educators, caregivers, other classmates, and friends can interact with *"IO"* as secondary users. Moreover, *"IO"* can engage the students through gamification strategies, i.e., game rewards for primary school activities.

Fig. 3a shows the main components of *"IO"*. In detail:

- The main board is used to place the braille modules and 3D tokens. It corresponds to the A5 standard and can be combined with other boards to enlarge the user space, i.e., A4 format.
- The two coordinates' indicators (one sequence of letters and one sequence of numbers) help the users to place and read the braille modules and 3D tokens.
- The organizers collect the different braille modules and divide the different subject school 3D tokens.
- The braille cubic modules are the basic alphabet of *"IO"*. Each module has four faces with braille letters and tactile graphic signs for graphs and schemes [fig. 3b].
- The 3D tokens represent specific signs and can have different meanings according to the activity, i.e., "sun" as summer or as solar system star.
- The reward boxes can be used for the gamification of the learning activities by inserting a reward.

Some school activities were designed to validate the overall idea [fig. 3c]. Other modules can be added

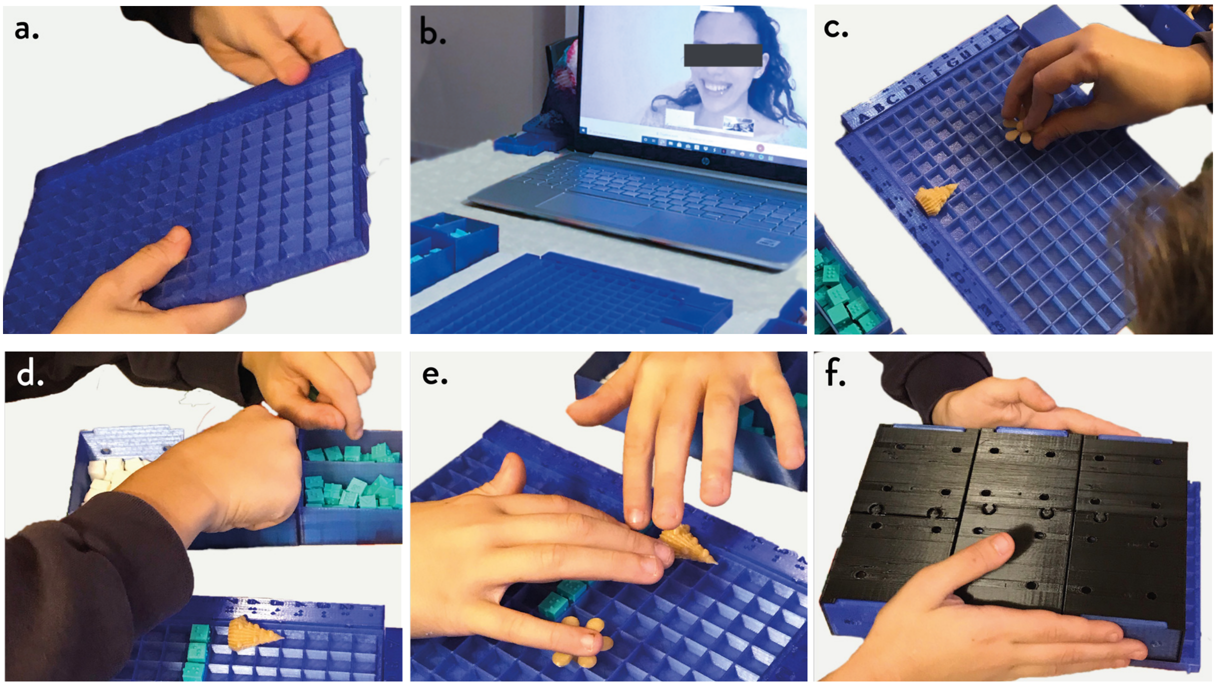

Fig 3. Use of *"IO"* in distance learning contexts: (a) spatial organization of the components by the student; (b) explanation of the learning activity; (c) positioning of the 3D tokens and braille modules guided by the educator; (d) identification of the braille letters for the correct selection; (e) reading of the resulting spatial order and explanation from the educator; (f) removal of the pieces and reorder of the components.

or customized with low-cost desktop 3D printers, i.e., new 3D tokens.

The user journey test simulated an online activity of primary school students with visual impairments during a lockdown, helping in defining the use of *"IO"*. Before the class activity, the student can organize the components of *"IO"* on the table, i.e., connecting the coordinate system to the mainboard. The class activity begins with the educator's explanation of the learning activity. The student detects and places the 3D tokens and/or braille modules thanks to the educator's guide and the coordinate system. The student can then read the braille modules and understand the 3D tokens by touching the components. Finally, the student can reorder the components of *"IO"*.

"IO" can be also used in conventional school environments, i.e., in-presence classrooms. The primary and secondary users can interact and design new activities to improve the learning experience and create more inclusive class environments. Hence, these assistive technology tools allow users to actively customize their products. Users can become "prosumers" by prototyping and modifying *"IO"* according to their needs. This specific practice falls under the umbrella of the open design concept, i.e., Do-it-yourself, and encourages sharing new designs, promoting their use, and collaborating for their implementation (Boisseau et al., 2018). Different levels of customization may be achieved depending on the specific users, the specific environment, the different activities, and the age of the student. This freedom should encourage the real use of *"IO"* by focusing on the long-term learning experience regardless of a specific disruptive event, i.e., the Covid-19 pandemic.

3D printing represents a way to make a specific tool accessible to a wider audience. *"IO"* and similar tools can be distributed with Open-Source licenses through online repositories (Thingiverse, Github, Zenodo) encouraging distributed collaborative networks of individuals (Buehler et al., 2015; Rayna & Striukova, 2021). Hence, users can purchase *"IO"* in different ways, i.e., at home with a personal 3D printer, in a fab lab, in a physical 3D printing shop, or from an online 3D printing service.

4. Conclusions

This work investigated the contribution of collaborative open design and 3D printing to improve the learning experience of students with visual impairments in distance learning contexts. The results provided an overview of how *"IO"* can be used in online classrooms and other scenarios regardless of specific disruptive events, i.e., the Covid-19 pandemic. This tool grows together with the student according to their specific needs, encouraging collaborative work for its customization. Design practice and 3D printing can contribute to the distribution and customization of *"IO"* and similar tools thanks to the collaborative approach fostered by open design and the Open-Source distribution.

Further efforts should be done to deepen this study. Due to lockdown restrictions, user interviews and tests were limited to a little group of volunteers, and user journey tests were carried out with a single user. Additional tests should be done with different users and in other contexts. Furthermore, this promising collaborative approach may be extended to different assistive tools and users' needs.

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