Design and Development of Tangible Artifacts for Participatory Design for All

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Abstract

This technical report documents the design and development of efforts that were made in the direction of proposing digital versions of artifacts and techniques used in participatory practices, with the goal of making them accessible to all. Therefore, we aim to allow that any person, regardless of ability, literacy, age, culture or any other special condition, is able to actively contribute and be a part of ideation and participatory practices, used during the design process of new computer systems. In order to accomplish our goal, we adopted the Universal Design (UD) philosophy, so that the artifacts we propose in this work do not require special adaptations for specific groups of users. We also followed the Tangible User Interface (TUI) paradigm, so that our designs can be familiar representations of their original non-digital counterparts, but with an underlying computer system. The artifacts we have redesigned come from Organisational Semiotics (OS) and Participatory Design (PD), and we have done our best to preserve their original essence while making them more inclusive.

1 Introduction

The current technological scenario has brought us closer to what Weiser (1991, p.1) [15] envisioned as ubiquitous computing: "*The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*" However, the technological advances do not eliminate the necessity of Universal Access, which "*aims to enable equitable access and active participation of potentially all people in existing and emerging computer-mediated human activities by developing universally accessible and usable products and services. These products and services must be capable of accommodating individual user requirements in different contexts of use, independent of location, target machine, or runtime environment.*" (Emiliani and Stephanidis, 2005, p. 607) [2]. In fact, as information becomes more embedded into the environment, it is crucial that everyone has access to it, regardless of ability or special conditions.

Considering such relevant and challenging scenario, this Technical Report presents a work that is part of a five-year project, called "*Socio-Enactive systems: Investigating New Dimensions in the Design of Interaction Mediated by Information and Communication Technologies*"[1]. Enactive Systems, as proposed by Kaipainen et al. [4], do not follow a goal-oriented paradigm of interaction; instead, the body and the human's spatial presence are a part of the system. In this case, physiological readings, for instance, may act as a way of unconscious control of the system, in a feedback loop where the readings have an effect on the system behavior, which in turn has an effect on the human side. Particularly in this work, our focus is in aiding Participatory Design (PD) practices within the project, making them accessible to all. Therefore, we report the efforts of designing and

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[1]São Paulo Research Foundation (FAPESP) #2015/16528-0.

developing artifacts that follow both the Tangible User Interface (TUI) paradigm and the Universal Design (UD) philosophy, to make inclusive some participatory techniques and tools that are usually not usable, for instance, to people with disabilities. More specifically, we have worked on the design of tangible artifacts based on a technique called BrainWriting [14], and on three artifacts from Organisational Semiotics (OS) [6]: the Stakeholders Identification Diagram (SID) [7], the Evaluation Frame (EF) [1], and the Semiotic Framework (SF) [11].

This report is organized as follows: Section 2 describes the theoretical foundation for this work. Section 3 provides the results of the designs, with technical specifications. Finally, in Section 4 we present our concluding remarks.

2 Theoretical Background

The following subsections present the explanation for the basic concepts behind this work.

2.1 Universal Design (UD)

Universal Design (UD) can be defined as "*the design of products and environments to be usable to the greatest extent possible by people of all ages and abilities*" [13]. Also known as "Design for All", this philosophy respects the difference between people, and intends to promote inclusion for everyone, in all activities of life. This comes from the principle that an "average" user does not exist, i.e., each person is unique, and diversity is a trait of the human race. However, UD accepts that it is improbable that a single design solution will fit everyone, under any condition. Hence, it is better to look at UD as a process of reaching everyone.

Universal Design has its roots on changes of social and demographic nature that emerged in the 20th century [13]. However, UD also applies to nowadays, the era of *information society* [12], that is based on the production and exchange of information. This entails a variety of computer-mediated activities, that everyone should have access to. Hence, UD applied to this context implies providing access to high quality interaction and information to the widest possible range of people.

There are seven UD principles – each accompanied by a set of guidelines – that can be applied to guide the design process, or to evaluate existing designs [13]. They are the following:

1. Equitable Use: "*The design is useful and marketable to people with diverse abilities.*"

2. Flexibility in Use: "*The design accommodates a wide range of individual preferences and abilities.*"

3. Simple and Intuitive Use: "*Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.*"

4. Perceptible Information: "*The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.*"

5. Tolerance for Error: "*The design minimizes hazards and the adverse consequences of accidental or unintended actions.*"

6. Low Physical Effort: "*The design can be used efficiently and comfortably and with a minimum of fatigue.*"

7. Size and Space for Approach and Use: "*Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.*"

In summary, Universal Design – or Design for All – is the core philosophy behind our work. The idea of turning traditional paper-based tools and techniques into digital artifacts is based on the premise that technology provides means for including people, due to its flexibility and pervasiveness. Hence, we are both including people to create new technologies, and designing new technologies that promote the inclusion of people.

2.2 Tangible User Interface (TUI)

Proposed by Ishii & Ullmer [3], Tangible User Interface (TUI) is an interaction paradigm meant to push beyond the of Graphical User Interfaces (GUIs) and their restriction to flat displays, mouse and keyboard. Inspiration came from the work of Weiser [15], who described ubiquitous computing as a new paradigm where computers were everywhere, invisible. TUIs, however, intend to "*augment the real physical world by coupling digital information to everyday physical objects and environments*" [3, p.2], representing a shift from the desktop to, for instance, our skins, bodies, everyday graspable objects like books or cards, and ambient media like sound and light.

There are three main concepts behind TUI [3]: (1) **Interactive surfaces**, i.e., to make active interfaces out of surfaces from the environment, such as walls, windows and doors; (2) **Coupling**, i.e., to embed digital information into graspable objects like books and cards (the information should be appropriate to the object, and vice-versa); and (3) **Ambient media**, i.e., to make background interfaces out of surrounding media such as sound, light and airflow. Hence, TUI covers both interactions on the foreground, with a visual and *hands-on* approach, and on the background, with a seamless and ambient approach.

In essence, TUI provides a new interaction paradigm, that intends to create a closer relationship between the physical and the virtual worlds. For our purpose of bringing artifacts and techniques from the paper to the physical and digital, this paradigm provides a good middle-term.

2.3 Participatory Design (PD)

Participatory Design (PD) is an approach to the design of computer systems that brings people who are prospective users of the system into the design process, as active participants. PD started out in Scandinavia and the main principle behind it is that the people who will use the system are the experts in their domain [10], so they hold the knowledge about their tasks and how to perform or improve them. Then, according to the PD philosophy, designers should act as technical consultants, creating cooperation in the sense of a "mutual learning" [5], so that users can learn about the technical possibilities, and designers can learn about the application domain.

Considering that, within an organization, different groups have their own interests and visions of what a system or product should do, and how it should do it [10], PD activities usually involve group negotiation and cooperation. For instance, Muller et al. [9] describe sixty-one PD practices, applicable within different moments in the design process, and adequate for varied objectives and group sizes. However, they are not meant to be linear step-by-step guides towards predictable and safe outcomes. Instead, they should be seen as scaffolds for complex, non-linear group processes.

One common type of practice in PD is based on *brainstorming*, a method for the raising of ideas by a group of people. An example of this is the BrainWriting technique [14], which follows a round-robin dynamics (Figure 1), where each participant starts by writing their own idea on a piece of paper and, after a predetermined amount of time, they pass the paper to another person and receive someone else's sheet. Then, they must complement the other person's idea until time runs out. The procedure is repeated until at least one cycle is completed, i.e., until everyone receives their sheet back. This style of brainstorming solves some problems of having an influencer among the participants, and leads to a more distributed discussion and proposition of ideas. BrainWriting is usually done in a silent manner, using pen and paper, which makes it less accessible to people with disabilities, like people with visual or motor impairments.

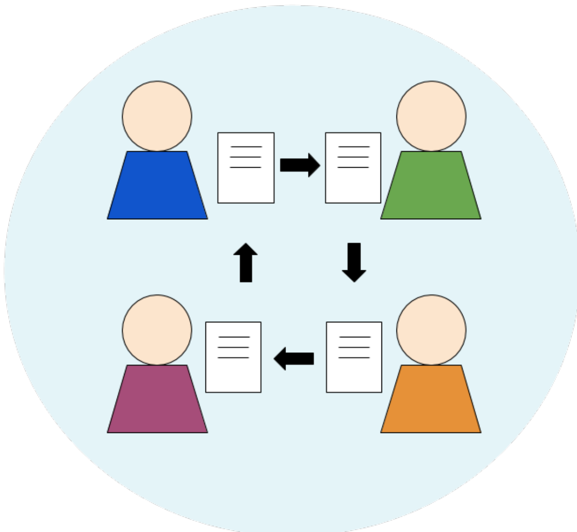

Figure 1: Representation of the BrainWriting round-robin dynamics.

2.4 Organisational Semiotics (OS)

Organisational Semiotics (OS) involves the application of Semiotics to the study of organizations [6]. In this context, organizations can be seen as information systems, i.e., they can create and convey information, as well as define and change meanings. Looking at organizations as information systems and using the lens of Semiotics to their design, might improve the decision-making process by allowing that accurate and quality information gets to the right people. In this sense, there are three OS artifacts that help in the design process by allowing stakeholders to discuss and organize ideas regarding a product.

The first artifact is the Stakeholders Identification Diagram (SID), which consists of a sequence of five layers, where the inner ones contains stakeholders that are closer to the direct operation with the product, and the outer layers hold stakeholders that are affected by the product, but in less direct ways. Its graphical representation is shown in Figure 2.

The second artifact, the Evaluation Frame (EF), is represented as a table, with a column for raising issues, a column for solutions or ideas, and five rows, one for each SID category. Hence, it is used to support the reasoning of problems and solutions associated with each stakeholder identified in the SID [1]. Therefore, this artifact allows the identification of requirements, as well as the anticipation of issues that may affect the design. EF's graphical representation is shown in Figure 3.

The third and final artifact is the Semiotic Framework (SF), which has six levels of knowledge stacked on top of each other, in a progressive manner, similarly to a ladder. From bottom to top, they are the following: Physical, Empirical, Syntactic, Semantic, Pragmatic and Social World. The bottom three levels are related to the structure of signs, how they are organized and transmitted. In turn, the upper three levels are related to how signs are used, in terms of meanings, intentions, and

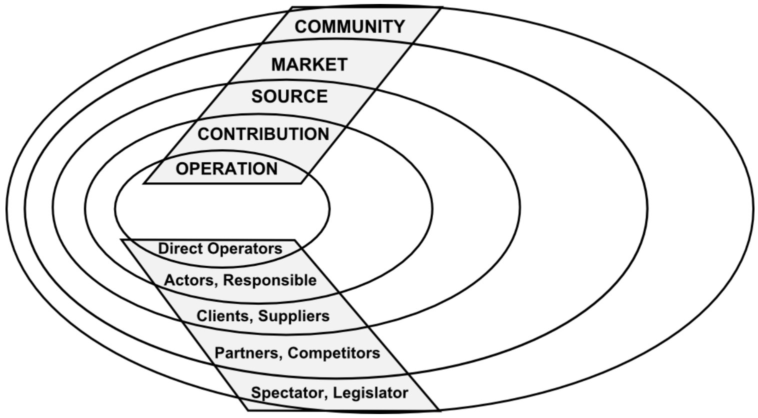

Figure 2: Graphical representation of the Stakeholders Identification Diagram (SID).

STAKEHOLDERS	QUESTIONS & PROBLEMS	IDEAS & SOLUTIONS
OPERATION (Direct Operators)		
CONTRIBUTION (Actors, Reponsible)		
SOURCE (Customers, Suppliers)		
MARKET (Partners, Competitors)		
COMMUNITY (Spectator, Legislator)		

Figure 3: Graphical representation of the Evaluation Frame (EF).

social impact they have. In the context of our work, this artifact is used for identifying and organizing requirements, viewing them from their technical infrastructure (bottom), to their information system (top). The graphical representation of the SF is shown in Figure 4.

In participatory practices, we regularly use these three artifacts in poster format, so that participants – preferably, representatives from the stakeholders – can freely place post-its where they see fit, to fill the artifacts with information. The goal is to promote discussion, so during the participatory practice, participants are encouraged to talk to each other to decide what to write on the post-its and where to place them. This way, they can all contribute to the decision-making process, and collectively reach an understanding of the problem at hand. This way, however, people with disabilities (e.g. with visual impairments) cannot participate with autonomy, since they would need someone else's help to write on the post-its and place them on the poster.

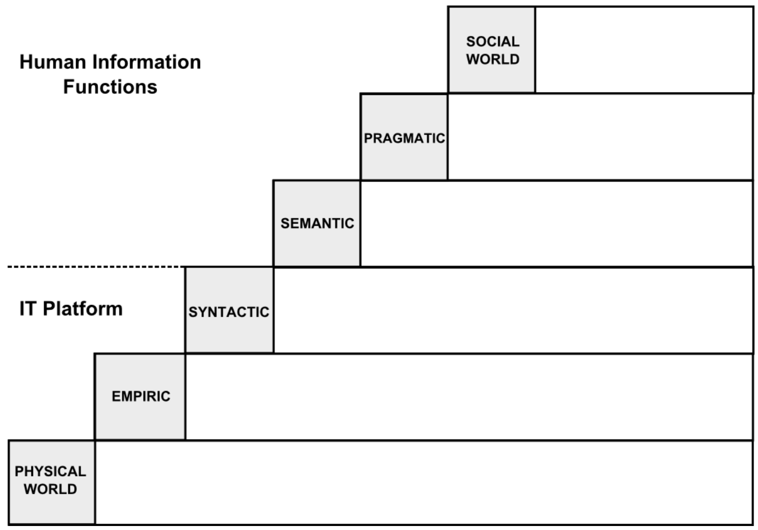

Figure 4: Graphical representation of the Semiotic Framework (SF).

3 Results

The main goal of our work was to design tangible artifacts – inclusive for all – based on the BrainWriting PD practice, and on the three OS artifacts, the SID, the EF and the SF. The results from this design process are separated into four stages, explained in the following subsections: tangible interfaces, hardware, web interface and interaction design.

3.1 Tangible Interfaces

For the three OS artifacts, the starting point for this stage was their graphical representations. Therefore, we built a cardboard version of each artifact. First, for the SID, its five elliptical layers were cut out so that one fits inside the other, as shown in Figure 5. Purposely, there is a gap between each layer, for two main reasons: (1) so that the layers can move independently when they are pressed, becoming "interactable"; (2) to differentiate between them by touching the artifact. The latter is important for Universal Design, since it favors people with visual impairments. In this sense, there is also a difference in height between the layers, such that the closer to the center, the taller the layer is. These features are in line with UD principle of "Equitable Use" [13], which recommends making the design useful and marketable for people with diverse abilities, without segregating or stigmatizing users.

Then, for the EF, we decided to make a simplification by reducing the amount of cells. By not including the vertical and horizontal headers, instead of the 18 cells shown in Figure 3, we made 10. Therefore, the tangible EF focuses on the areas where content is placed, i.e., the parts that in fact need to allow interaction. This is also an important factor for Universal Design, since one of its principles is "Simple and Intuitive Use", which recommends eliminating unnecessary complexity [13]. The resulting cardboard interface is shown in Figure 6.

For the SF artifact, we transformed its lateral view of a ladder into a three-dimensional ladder, where each step is interactable. This decision can also be related to the UD principle of "Simple and Intuitive Use" [13], which states that the design is easy to understand, regardless of the user's previous experience. Therefore, by translating the SF (which is also known as "Semiotic Ladder") into an actual ladder, we are making the artifact's intentions easier to grasp by all users. The result

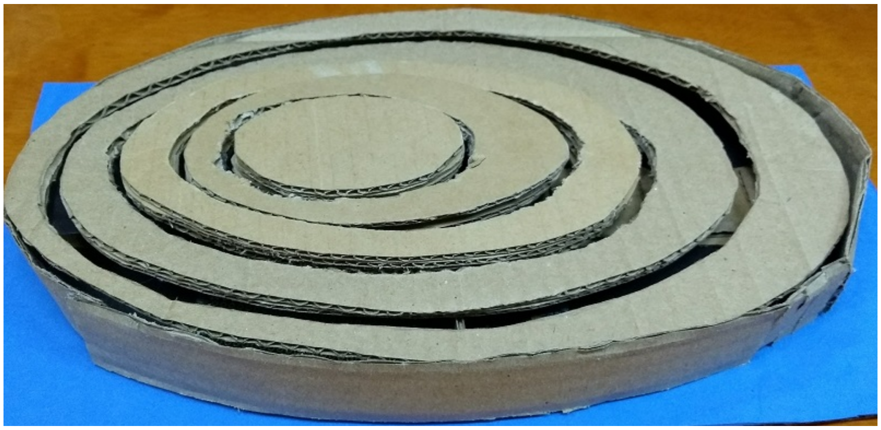

Figure 5: Cardboard version of the Stakeholders Identification Diagram (SID).

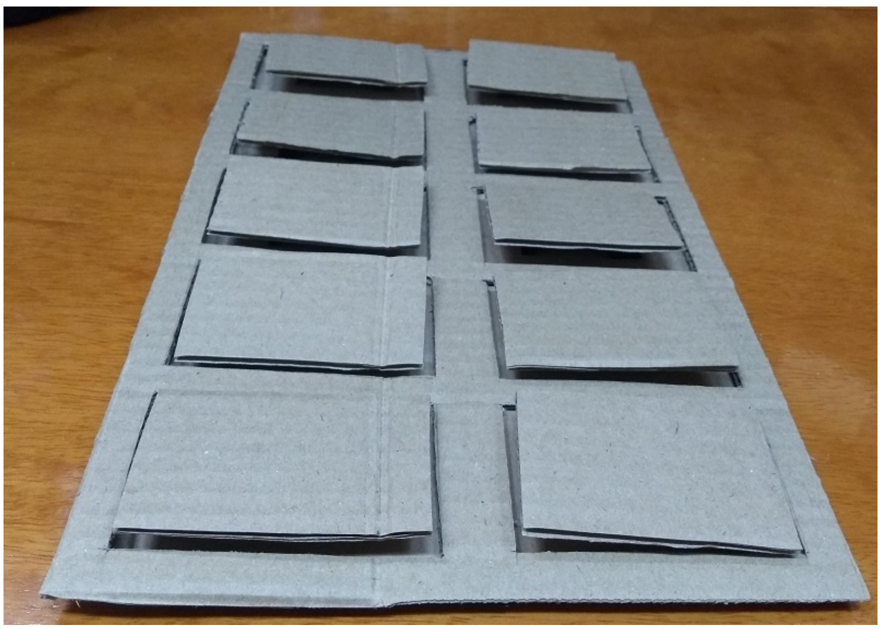

Figure 6: Cardboard version of the Evaluation Frame (EF).

is shown in Figure 7.

Finally, for the BrainWriting, we conceptualized the design as a simple voice recorder, with two buttons: play and record. This decision was based on the results of a previous exploratory activity [8], where we redesigned the traditional BrainWriting to use speech instead of writing. Therefore, we named the new technique *BrainSpeak*, and so its accompanying artifact requires ways to record and to play audio. In order to do so, as we can see in Figure 8, there is a sound speaker on the top left corner of the interface, with a triangle-shaped play button below it. On the right side of the artifact, there is a circle-shaped record button, with a hole for a microphone above it. Therefore, the tangible interface for this artifact, much like the EF, has followed the "Simple and Intuitive Use" principle, by focusing on the essential functionalities.

It is important to note that we have highlighted a specific UD principle for each artifact, but,

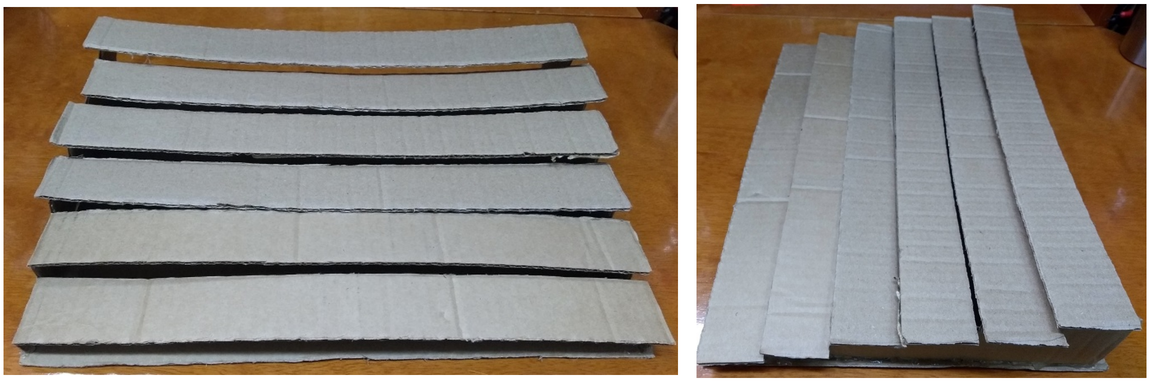

Figure 7: Cardboard version of the Semiotic Framework (SF).

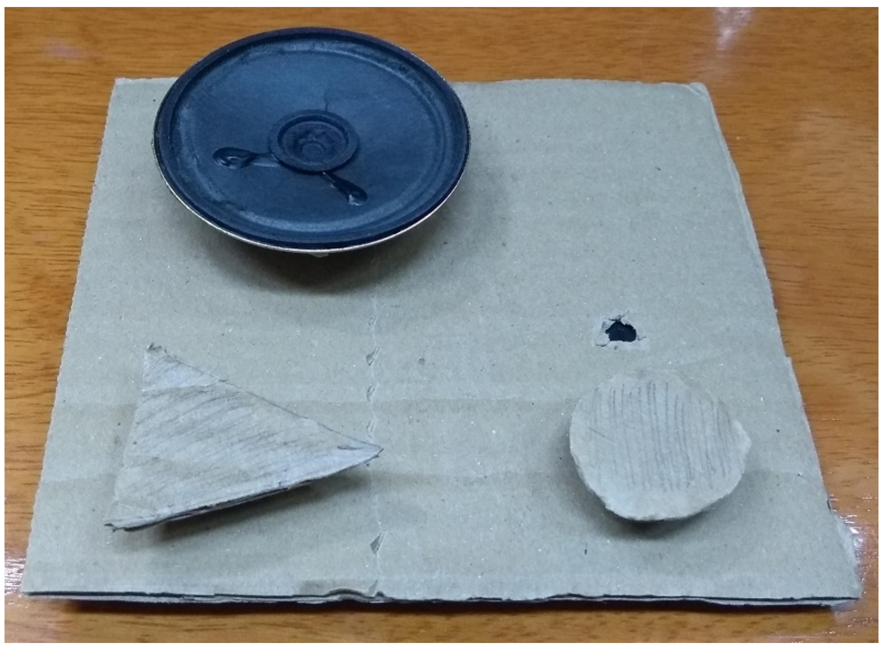

Figure 8: Cardboard interface of the BrainSpeak tangible artifact.

in fact, we can safely say that all seven principles guided the entire design process. For instance, the choice for cardboard is not only because the material is cheap, but also because of principle “Low Physical Effort”, since cardboard is light. In addition, more than weightless, the artifacts must have an appropriate size, to be comfortable to hold and to pass around a group of people during a participatory practice. Therefore, the principle “ Size and Space for Approach and Use” is also present here.

Furthermore, the interactable parts of the artifacts and how they are easily perceived, both visually and through touch, is part of the “Perceptible Information” principle. Also, all tangible artifacts have an elevated base (as shown in Figure 5), to make them easy to handle, and also to have room to store and protect the hardware in a way that hides what the user does not need to see or touch. This means minimizing hazards and accidental or unintended actions, which is part of the “Tolerance for Error” principle.

Finally, the principle "Flexibility in Use" permeates the rest of the design rationale, described in the following subsections. In particular, the guideline"*Provide choice in methods of use*" is what motivated us to have both tangible cardboard and software interfaces. The reasoning is that the tangible and the software bring their own interaction possibilities, which allows us to make the artifacts even more inclusive.

3.2 Hardware

For the three OS artifacts – SID, EF and SF – the circuit is very similar to the one in Figure 9. The main difference between them is the amount of buttons, since each artifact has its own number of interactable areas. In particular, the circuit illustrated in Figure 9 is for the SID artifact. It has one push-button for each SID layer – totalizing five – and an additional push-button to serve as control. The purpose behind the control button will be clarified in Section 3.4. Therefore, the other artifacts also have one push-button for each interactable area – ten for the EF, and six for the SF – and one more to serve as control.

Each push-button needs to be connected to a digital port in the microcontroller, which in this case, is the Arduino Uno. We have chosen this board due to its widespread availability, ease of use and compatibility with the software platform we selected, which will be explained in Section 3.3. Hence, the Uno is enough for the three OS artifacts because it offers thirteen digital ports, and the highest required amount for our designs is twelve, for the EF: eleven for the cells push-buttons and one for the Light Emitting Diode (LED). In fact, all three OS artifacts have an LED that will blink when one of the buttons is pressed. This serves as a visual feedback for the user to know the button press was recognized, which is useful for people without visual impairments, including the deaf. For those with visual impairments, the interface offers sound feedback, like voice instructions and the click of the push-buttons, which can be easily audible.

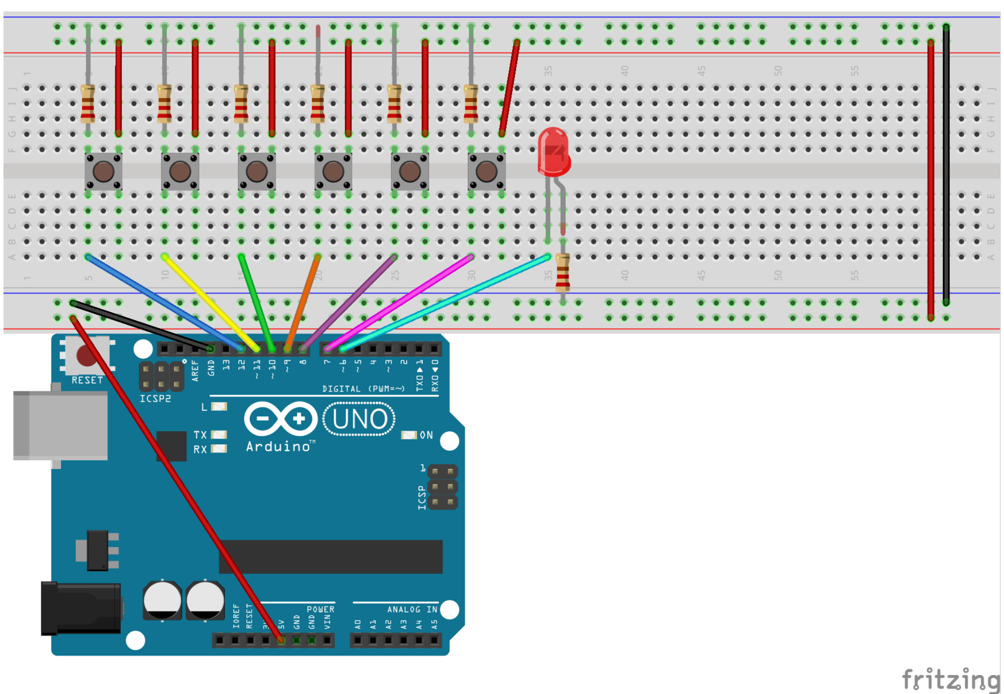

Figure 9: Circuit of the OS artifacts.

For the *BrainSpeak* artifact, we have decided to make use of an Arduino module named ISD1820, which records and plays sounds. As shown in Figure 10, the module has an embedded microphone (on the top left), a plug for a sound speaker (to the right, labeled “SP1”), and three push-buttons (on the bottom). The leftmost button is for recording, the middle button plays all the content stored in the memory, and the rightmost button plays the recording for as long as the button is pressed (i.e., the sound stops when you let go of the button). By default, the module records for a maximum duration of 10 seconds, but this can be altered either by hardware or by software.

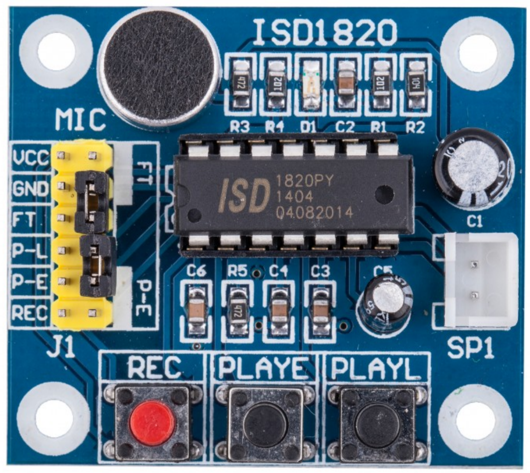

Figure 10: Module ISD1820, sound recorder and player.

This module was chosen because (1) it is more practical to use it than to build our own setup of microphone and speaker, and (2) it is relatively cheap (costs around 20 BRL), so we can make multiple *BrainSpeak* artifacts to use simultaneously during a participatory practice, if necessary.

3.3 Web Interface

The software for the tangible artifacts involves not only the programming of the microcontroller’s behaviors, but also a Web interface that is integrated with the tangible interface, following the TUI philosophy. We chose web technologies due to their cross-platform feature, i.e., for the possibility of integrating the tangible artifact with a wide variety of devices that can access web content, such as laptops, tablets, smartphones e smart TVs. Hence, the idea is that, during a participatory practice, while one person (or a group of people) is interacting with the tangible artifact, others can view on a TV screen or on their smartphones, the information that so far has been added with the artifact.

For instance, Figure 11 illustrates the behavior of the web interface for the SID artifact for when someone has pressed the innermost layer. Hence, this layer is shown highlighted, and to the right there are three types of relevant information:

- The name of the layer (at the top, in bold);
- The list of stakeholders that so far have been added to this layer;

- A clickable sound icon, to indicate that this information is also available in audio format.

The web interface for the other two OS artifacts works the same way, but obviously they have the graphical representations of their corresponding artifacts, instead of the SID.

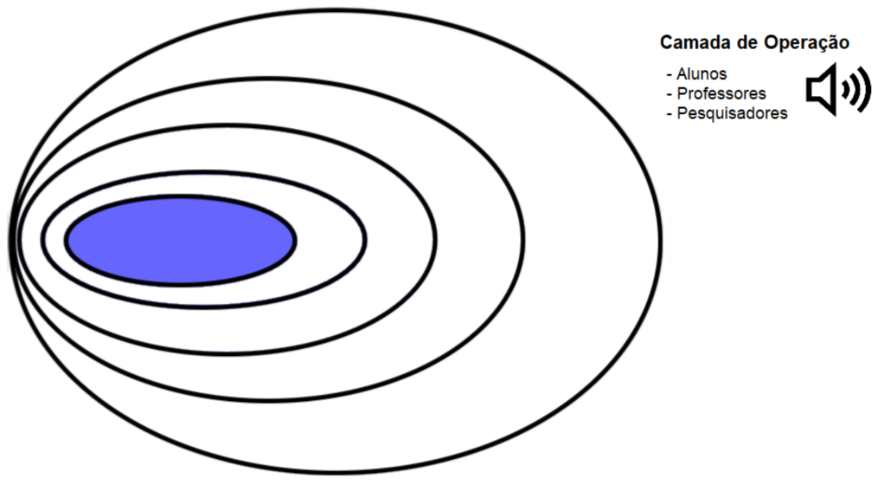

Figure 11: Software interface of the SID, to exemplify for the other OS artifacts.

For the BrainSpeak, the web interface would serve to make the artifact accessible for people with hearing impairments, which would be done in two ways. First, by translating into text information the sound participants without the hearing disability record. Second, to allow the users with the hearing impairments to input their own information, through text. Another purpose of the web interface for the BrainSpeak is to act like a "hub", where all the information is stored and distributed appropriately to the participants of the brainstorming session, automatically implementing either the round-robin dynamics or the adaptation we have proposed [8] – in case there is only one BrainSpeak artifact.

Therefore, the web interface helps us move towards Universal Design, allowing people to access the information in different formats, and to choose which format they want. This is in compliance with the UD principles "Equitable Use" and "Flexibility in Use".

Regarding specifically the web technologies, we have adopted HTML, CSS and JavaScript to design the interface. In addition, there are open source JavaScript libraries for speech recognition[2], and for Text-to-Speech (TTS)[3], so it is possible to do with JavaScript the translation of information from sound to text and vice-versa. Also, for the integration between Arduino Uno and JavaScript, we chose the Johnny-Five[4] platform. Furthermore, JavaScript allows us to store the data from participatory practices through a JavaScript Object Notation (JSON) or a Consumer Value Stores (CVS) file, which is small and can be easily ported to other tools, for data analysis or visualization. In the future, if considered necessary, the web technologies we have adopted can also be integrated with a more robust database.

[2] `https://github.com/TalAter/annyang`
[3] `https://github.com/Hagsten/Talkify`
[4] `http://johnny-five.io`

3.4 Interaction Design

For the three OS artifacts, the interaction design follows either one of two possibilities. First, if the user presses any button except for the control button, there will be a visual and audio feedback about the content that has already been added to that part of the artifact. Figure 12 illustrates this scenario, using the SID as an example.

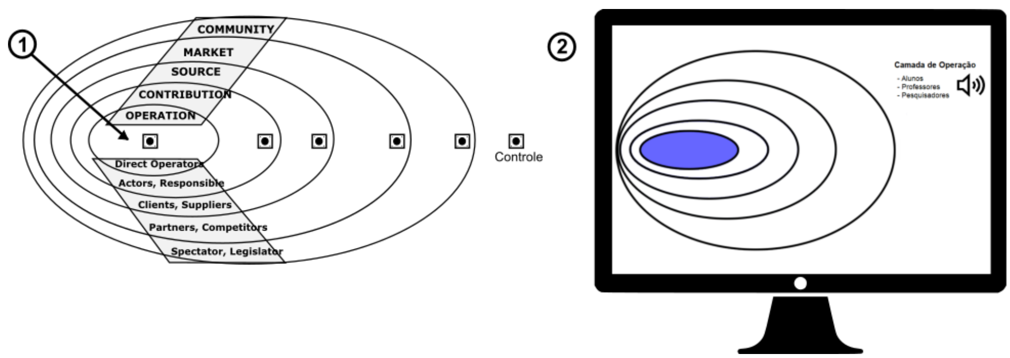

Figure 12: Interaction design for when one of the SID layers is pressed.

However, if the user presses the control button, there will be visual and audio instructions for her to press the part of the artifact to which she wishes to add information. This is step 1 in Figure 13. After the user presses a part of the artifact (step 2 in Figure 13), the display will highlight the layer in its graphical representation, and provide the name of the selected layer, through sound and text. Then, the user can add new information to this artifact, either through voice (which will later be converted into text using TTS), or using a keyboard if it is available along with the display device. This represents step 3 in Figure 13.

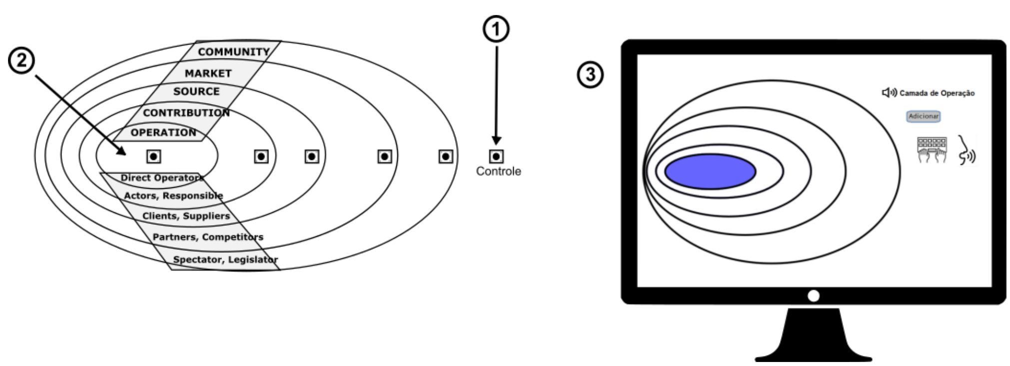

Figure 13: Interaction design for when the control button is pressed.

It is important to note how we are providing users the ability to choose how they want to receive and input information through the artifacts. Once more, the UD principles “Equitable Use” and “Flexibility in Use” show a strong presence in our interaction design.

4 Conclusion

In this technical report we have presented our efforts in the design and development of Participatory Design artifacts for all. To base our work, we have adopted the Universal Design philosophy and the Tangible User Interfaces interaction paradigm. We also chose three Organisational Semiotics artifacts and one Participatory Design technique as the subjects of our endeavor. The instruments we have selected are traditionally used in formats that are not accessible, for instance, to people with visual impairments. Therefore, in this report we have presented a design of their TUI versions, that is meant to be *for all*.

The three OS artifacts, although serving distinct purposes and having very particular representations, had their designs scaffold one another, since the way to interact is similar between them. In other words, their essence is the same: to promote discussion and to present the information resulting from such discussion. Therefore, although their visual representations (tangible and web) are very different, the interaction design for all of them can follow the same pattern.

In contrast, the Participatory Design technique we chose, BrainWriting, is not as simple to translate into a TUI artifact. We had to rethink its dynamics – as reported in previous work – and propose an interaction design different than the one for the OS artifacts. In particular, the software for the new BrainWriting – called *BrainSpeak* – has to implement the dynamics of the technique, in a way that can be adjusted to the amount of TUI artifacts we have available.

However, the four artifacts we have presented in this report have in common their concern for Universal Design. Specifically, the seven UD principles are evident in our designs, given the concerns for including diverse abilities, accommodating individual preferences, providing redundancy in information through different channels (auditory, visual and haptic), making information perceptible, and making the artifacts easy to handle.

In conclusion, the design and development results we have shown here are not final solutions; they represent a stepping stone to bring together Universal Design and Participatory Design. Future steps include applying the prototypes we have created into real participatory practices, preferably ones that have people in special conditions. In addition, we envision further studies on other artifacts or techniques that may take advantage of the designs we have proposed, and finding new instruments that present new interaction challenges like BrainWriting has.

Acknowledgements

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