Universidade Estadual de Campinas
Instituto de Computação

Emanuel Felipe Duarte

Arte Factus: Study and Socially Aware Co-design of Socioenactive Digital Artifacts

Arte Factus: Estudo e Co-design Socialmente Consciente de Artefatos Digitais Socioenativos

CAMPINAS
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Tese apresentada ao Instituto de Computação da Universidade Estadual de Campinas como parte dos requisitos para a obtenção do título de Doutor em Ciência da Computação.

Thesis presented to the Institute of Computing of the University of Campinas in partial fulfillment of the requirements for the degree of Doctor in Computer Science.

Supervisor/Orientadora: Profa. Dra. Maria Cecília Calani Baranauskas

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All doing is knowing, and all knowing is doing.

– H. R. Maturana & F. J. Varela
The Tree of Knowledge

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Resumo

Atualmente, a tecnologia computacional tornou-se cada vez mais pervasiva por meio de computadores de diferentes tamanhos, formas e capacidades. Mas avanços tecnológicos, embora necessários, não são suficientes para tornar a interação com tecnologia computacional mais transparente, como preconizado pela computação ubíqua. Sistemas computacionais atuais ainda exigem um vocabulário técnico de entradas e saídas para serem utilizados. No campo da Interação Humano-Computador (IHC), a adoção da teoria da cognição enativa pode lançar luz sobre um novo paradigma de interação que preenche a lacuna entre ação e percepção. Sistemas computacionais enativos são um promissor tema de pesquisa, mas seu design e avaliação ainda são pouco explorados. Além disso, sistemas enativos, como já proposto na literatura, carecem de consideração do contexto social. O objetivo desta tese de doutorado é contribuir para o design de tecnologia computacional dentro de uma abordagem da cognição enativa, além de também sensível à aspectos sociais. Portanto, esta tese investiga os conceitos de sistemas enativos e socioenativos por meio do co-design de arte interativa e instalações. Para atingir esse objetivo, é proposto um arcabouço teórico-metodológico chamado *Arte Factus* para apoiar o estudo e o co-design socialmente consciente de artefatos digitais. O arcabouço *Arte Factus* foi utilizado em três estudos de design relatados nesta tese: InterArt, InstInt e InsTime. Esses estudos envolveram a participação de 105 estudantes de graduação e pós-graduação em Ciência da Computação e Engenharia de Computação no co-design de 19 instalações. O processo envolveu o uso de tecnologia pervasiva do tipo Faça-Você-Mesmo (*Do-It-Yourself, DIY*), e algumas dessas instalações foram estudadas em oficinas de prática situada que ocorreram em cenários educacionais (escola e museu exploratório de ciências). O arcabouço *Arte Factus*, como a principal contribuição desta tese de doutorado, mostrou-se eficaz no apoio ao co-design socialmente consciente de instalações interativas que materializam o conceito de artefatos digitais socioenativos. Além disso, através do estudo dos artefatos criados no contexto desta investigação, esta tese também contribui para a construção teórica do conceito de sistemas socioenativos.

Abstract

Currently, computational technology has become more and more pervasive with computers of different sizes, shapes, and capacities. But technological advancements, although necessary, are not enough to make the interaction with computational technology more transparent, as preconized by the ubiquitous computing. Current computational systems still require a technical vocabulary of inputs and outputs to be interacted with. Within the field of Human-Computer Interaction (HCI), the adoption of the enactive cognition theory can shed light on a new interaction paradigm that bridges the gap between action and perception. Enactive computational systems are a promising subject of research, but their design and evaluation are still hardly explored. Furthermore, enactive systems as already proposed in the literature lack a social context consideration. The objective of this doctoral thesis is to contribute towards the design of computational technology within an enactive approach to cognition, while also being sensitive to social aspects. Therefore, this thesis investigates the concepts of enactive and socioenactive systems by enabling the co-design of interactive art installations. To achieve this objective, a theoretical-methodological framework named *Arte Factus* is proposed to support the study and socially aware co-design of digital artifacts. The *Arte Factus* framework was used in three design studies reported in this thesis: InterArt, InstInt, and InsTime. These studies involved the participation of 105 Computer Science and Computer Engineering undergraduate and graduate students in the co-design of 19 installations. The process involved the use of pervasive Do-It-Yourself (DIY) technology, and some of these installations were further studied in workshops of situated practice that took place in educational scenarios (school and exploratory science museum). The *Arte Factus* framework, as the main contribution of this doctoral thesis, has shown effective in supporting the socially aware co-design of interactive installations that materialize the concept of socioenactive digital artifacts. Moreover, through the study of the artifacts created in the context of this investigation, this thesis also contributes towards the theoretical construction of the concept of socioenactive systems.

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List of Abbreviations

ACM	Association for Computing Machinery
API	Application Programming Interface
CSS	Cascading Style Sheets
DIY	Do-It-Yourself
FAPESP	São Paulo Research Foundation
GOMS	Goals, Operators, Methods, and Sections rules
GSR	Galvanic Skin Response
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HTML	Hypertext Markup Language
IDE	Integrated Development Environment
IoT	Internet of Things
JIS	Journal on Interactive Systems
LDR	Light-Dependent Resistor
LED	Light Emitting Diode
MOOC	Massive Open Online Course
MQTT	Message Queuing Telemetry Transport
NFC	Near-Field Communication
OS	Organisational Semiotics
PAD	Pleasure, Arousal, Dominance
PAM	Problem Articulation Methods
RGB	Red, Green, Blue
SAC	Socially Aware Computing
SAM	Self-Assessment Manikin

SBC	Brazilian Computer Society
SIG	Special Interest Group
TUI	Tangible User Interface
UI	User Interface
Unicamp	University of Campinas
USB	Universal Serial Bus
UX	User Experience

Contents

Chapter 1

Introduction

When Weiser [171] proposed his concept of ubiquitous computing in the year 1991, he exemplified his predictions for future devices with what he named “tabs” and “pads”, concepts that much resemble current pervasive devices such as smartphones and tablets. Although the accuracy of his predictions was remarkable, his most substantial contribution is not a description of devices, but rather the introduction of the abstract concept of ubiquity in computing. Weiser argues that ubiquitous computing is not only about technology (*e.g.*, making computers readily available anywhere), as technology alone does not make computers a natural part of the environment. Ubiquitous computing, the author argues, is about making the computer “disappear”, to integrate it seamlessly into everyday life until it becomes unnoticed while still always present.

From a technological perspective, it is clear how the concept of ubiquitous computing has been inspiring the development of a wide range of technological products. Currently, computational technology comes in varied sizes, shapes, and even embedded into “things” of everyday life. Besides being a tool for common tasks and entertainment, some of these computers also collect information and make autonomous decisions, aligned with the concept of an Internet of Things (IoT) as described by Ashton [8]. Furthermore, supported by a Do-It-Yourself (DIY) philosophy, the phenomenon of the maker culture empowers an ever-growing number of people to form communities of practice and independently develop their own hand-made technological products [126]. Weiser [171], however, argued since the beginning that the “disappearance” of the computer into the background of everyday life “is a fundamental consequence not of technology, but of human psychology”. Even with different sizes, shapes, and capacities, current computational technology still have what Weiser named at the time as an “arcane aura”, and it can also be argued that current computational technology is still “approachable only through complex jargon that has nothing to do with the tasks for which people actually use computers” [171].

Taking into account how Weiser [171] refers to how humans cease to be aware of something when they learn it sufficiently well, it can be inferred that what the author meant by “human psychology” in the sentence “is a fundamental consequence not of technology, but of human psychology” may be more accurately described as human cognition. The fact that the author mentions different sources related to cognitive science (*e.g.*, computer science, psychology, and philosophy) corroborates with this interpretation. In this subject, the Human-Computer Interaction (HCI) field of research, in which this doctoral thesis is situated, has a long-standing interest in human cognition. Classic HCI literature features a significant amount of cognitive models (*e.g.*, Fitts' law [83], the Goals, Operators, Methods, and Sections rules (GOMS) model [33, p. 139-192], or Norman's model of gulfs of execution and evaluation [139, p. 45-52]). These classic models are concerned with aspects such as ergonomics, interaction steps, and describing the human mind in terms of information processing, therefore well aligned with what is considered first or second-wave HCI (these characteristics contrast with the more recent third-wave HCI, which goes beyond work-related and "purposeful" interaction to emphasize more aspects of life and open-ended contexts [21, 99]). Although HCI researchers have shown an interest in human cognition for quite some time, the adoption of models that traditionally represent human cognition in terms of information processing has yielded little progress towards making the computer "disappear". This outcome may be a consequence of how these models feature the computer not only as a very present entity, but also having its own non-human vocabulary in terms of input and output. Therefore, it is plausible that an approach aligned with the more recent third-wave HCI, and consequently with a different approach to human cognition other than information processing, may yield better results towards seamlessly integrating computational technology into everyday life.

Similarly to the HCI's three different waves of thought, Varela, Thompson, and Rosch [168, p. 3-14] argue that Cognitive Science can also be categorized within the three different approaches of cognitivism, emergence and enactivism. In the view of Varela, Thompson, and Rosch [168, p. 172-173], advocates of the more recent enactive approach, cognition cannot be explained exclusively in terms of representation, be it in the form of the recovery of a pre-given outer world (realism), or the projection of a pre-given inner world (idealism). The authors describe cognition as *embodied action*. *Embodied* means that cognition is dependent on the experiences that emerge from having a physical body with varied sensorimotor capacities, and these sensorimotor capacities, in turn, are embedded in a more encompassing biological, psychological and cultural context. *Action*, in this context, means how sensory and motor processes (*i.e.*, perception and action) are fundamentally inseparable in a co-origination and co-dependence relation. With *embodied action* in mind, the authors define the concept of enaction based on two central ideas:

> 1. Perception consists in perceptually guided action; and
> 2. cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided. [168, p. 173]

In summary, the enactive cognition theory does not view cognition as a process contained entirely inside one's brain (nor entirely outside, for that matter), and therefore cognition cannot be described only in terms of information processing in the brain, analogous to a computer. In the enactive cognition theory, cognition is better described as the emergence of cognitive structures that comes from having a physical body with specific sensorimotor capacities, and sensing and acting are not two separate operations, but rather something simultaneous and inseparable. Therefore, there is a clear contrast between classic cognitive models used in HCI and cognition as understood in the enactive cognition theory. In Norman's model of gulfs of execution and evaluation [139, p. 45-52], for instance, there is an emphasis on the accomplishment of well-defined tasks, and more prominently, there is a clear-cut distinction between action (input) and perception (output) in what the author named as evaluation and execution gulfs.

As an attempt to bring the perspective of the enactive cognition theory to HCI, the work of Kaipainen *et al.* [112] represents an approach towards a more coupled interaction paradigm named by the authors as enactive systems and enactive media. The control of the computational system does not occur through a classic interaction mode oriented by tasks and well-defined goals, but instead through a dynamic coupling between body and technology. For instance, instead of deliberate inputs, the computational system can use sensors to collect psychophysiological data from a person (*e.g.*, heart rate, facial expressions *etc.*) and constantly produce dynamic responses based on those readings. The authors illustrate this approach with a movie theater that collects psychophysiological data from a person watching a movie and then uses this data to dynamically generate the following scenes of the movie, generating new psychophysiological data. Therefore, in this "enactive movie theater", the person affects the movie as much as the movie affects the person, and no specific vocabulary is necessary to take part in the interaction, being present is enough. Notwithstanding being valuable and innovative in many ways, there is one important limitation in Kaipainen *et al.*'s [112] example of an enactive system: it is ultimately a one-person experience. In the form it was presented, this example does not address how watching a movie is often a social activity, and a conventional movie theater is usually occupied by dozens of people that also affect each other's experience, be it by laughing together or being annoyed by the sudden brightness of a smartphone screen. Taking into account how Varela, Thompson, and Rosch's [168] enactive cognition theory emphasizes how sensorimotor capacities are embedded in a more encompassing cultural context, and even how Weiser [171] contrasts ubiquitous computing with virtual reality arguing that the latter is conclusively alienating, any computational system that does not actively acknowledge humans as social beings can also be alienating to some degree, failing to be faithful to the enactive cognition theory regardless of how "coupled" its interaction may be.

To achieve computational systems more faithful to the enactive cognition theory, it seems necessary to equally balance theory and practice. From a theoretical and conceptual perspective, the interaction should go beyond tasks and well-defined goals, and the very concept of an interface between a person and computer should be reconsidered not as an interface that mediates the interaction through a pre-defined language, but as a coupling between person and computational technology. From a practical and technological perspective, the interaction should go beyond a common Graphical User Interface (GUI) that is manipulated through conventional input devices (*e.g.*, mouse, keyboard, and touch-screen), the interaction should be embedded into the physical environment through the use of sensors and actuators. Ultimately, it can be argued that no computational system can be truly enactive in the way described by Varela, Thompson, and Rosch [168], because a computer is no living being and it discreetly separates sensing (input) and acting (output). The enactive cognition theory, however, can still be used as an analogy to inspire computational systems in which the interaction occurs in a more coupled and transparent way, contributing towards making the computer "vanish into the background" as Weiser [171] predicted. In this context, this doctoral thesis is part of a more encompassing project titled "Socio-Enactive Systems: Investigating New Dimensions in the Design of Interaction Mediated by Information and Communication Technologies" (São Paulo Research Foundation (FAPESP) Thematic Project #2015/16528-0). This doctoral thesis, therefore, is not only interested in investigating the concept of enactive systems, but also in contributing towards the conceptualization and materialization of the original concept of socioenactive digital artifacts with the following hypothesis and research questions:

> **Hypothesis**: The enactive cognition theory can support the socially aware co-design and study of computational technology to create digital artifacts that evoke an experience that is both enactive and social.
>
> **Research Question 1**: How can we construct interactive digital artifacts in a way that they make emerge a socioenactive experience?
>
> **Research Question 2**: How can we formally understand and characterize a socioenactive experience evoked by an interactive digital artifact?

To investigate the concept of socioenactive digital artifacts, a theoretical and methodological framework named *Arte Factus* (Latin for "artifact", meaning made by art) is constructed in this thesis. The framework, illustrated in Figure 1.1, is composed of three main components: (1) design studies, (2) situated practices, and (3) socioenactive conceptualization. In design studies, a process is proposed and followed using pervasive technology to create socioenactive digital artifacts. In situated practices, the artifacts created in design studies are experienced in real-world settings and the experience is evaluated to create empirical knowledge. The socioenactive conceptualization, in turn, consolidates acquired knowledge into theories and methods that can be applied in design studies, completing a full circle. Although the overview implies a sequence to be followed within the framework, each component is also a complex entity in itself rather than an input/output black box, with its own rhythm and internal cycles. With inspiration from the enactive cognition theory, each of these components is autonomous, but at the same time, they are part of each other's environment, mutually affecting and being affected by its neighbors (*e.g.*, a formal understanding of the concept of socioenaction is equally affected by empirical knowledge on current artifacts as much as current artifacts are affected by an understanding of the concept of socioenaction). Additionally, it should be noted that the cyclical nature of the framework does not mean that the conceptualization and materialization of the original concept of socioenactive digital artifacts occurs through a simple accumulation of artifacts, knowledge, and methods, but rather through a continuous reframing and reconstruction of the understanding of socioenaction.

While the *Arte Factus* framework can be used in other contexts, in this doctoral thesis it was investigated in the context of interactive art installations. According to Muller, Edmonds and Connell [135], the act of "experimenting" any work of art is already an active and fundamentally interactive process, but it is the advent of art with computer-based interactivity that started what is now widely referred to as interactive art. Interactive art, especially in the form of installations that occupy or permeate the physical environment, represents a suitable investigation context for the *Arte Factus* framework. This suitability stems from how interactive installations often intrinsically value a different relationship

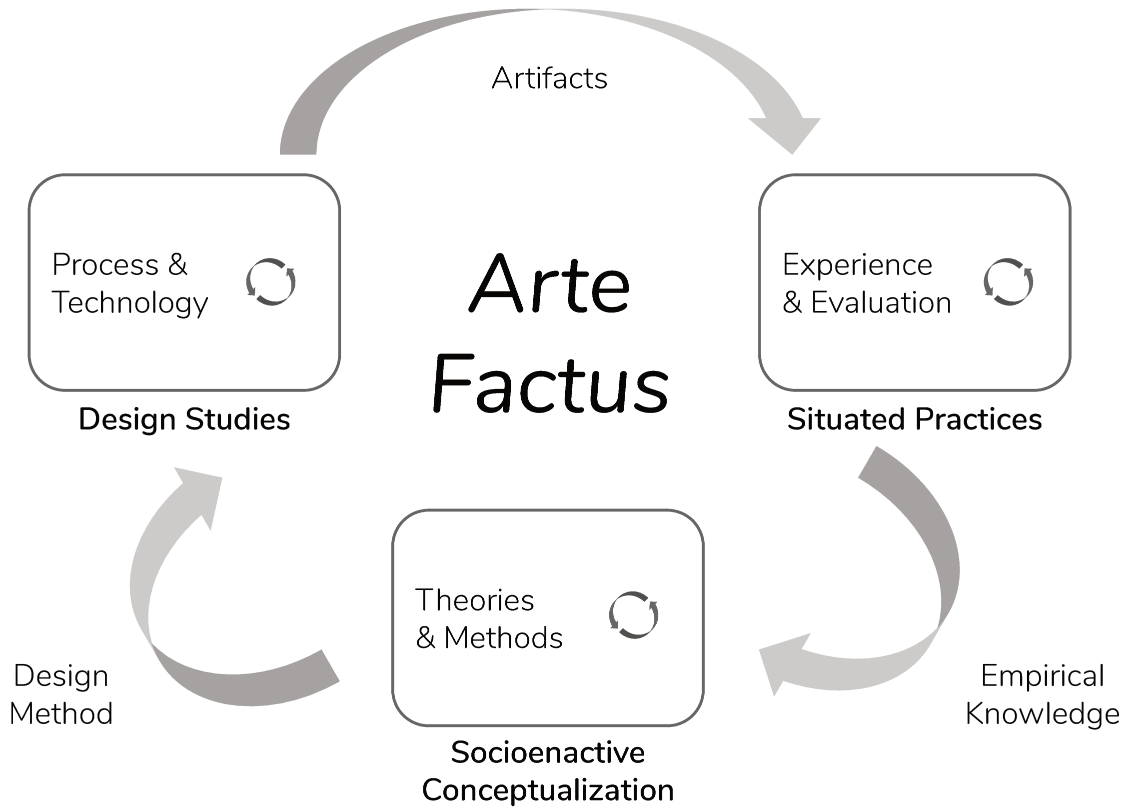


Figure 1.1: Overview of the *Arte Factus* framework.

between person and computational technology other than tasks and well-defined goals, and sometimes even bring this relationship to the spotlight. Moreover, interactive art installations often explore novel forms of interaction with computational technology (*e.g.*, creative uses of the body to interact with installations, or immersive interactive environments) that can serve as inspiration for computational systems with or without artistic intent, including socioenactive digital artifacts. Lastly, while the terms interactive art and interactive installations are used to describe the digital artifacts created in the design studies of this doctoral thesis, it is important to emphasize that this thesis has no intention of defining what is and what is not art.

1.1 Objectives

This doctoral thesis has the main objective of contributing to the HCI field by investigating a new paradigm for the design of interactive systems. Drawing on the enactive cognition theory from Varela, Thompson and Rosch [168], and the concept of enactive system from Kaipainen *et al.* [112], this thesis aims at contributing towards the design of computational technology within an enactive approach to cognition, while also being sensitive to social aspects. Therefore, this thesis investigates the concept of socioenactive digital artifacts by enabling the co-design of interactive art installations. The concept of a socioenactive digital artifact should not only contribute towards the design of more transparent computational technology, but also towards interactive artifacts that take the social dimension into account. With an alignment of theory and practice, this doctoral thesis has the following more specific objectives:

- Construct the *Arte Factus* theoretical and methodological framework to support the design of socioenactive digital artifacts;
- Design and develop, in a socially aware manner and with the use of DIY pervasive technology, digital artifacts in the form of interactive installations that materialize aspects of the concept of socioenaction; and
- Study digital artifacts that take the social dimension into account in its construction, alongside an enactivist view of interaction design, to support the ongoing characterization of socioenactive digital artifacts.

1.2 Methodology

In a high level of abstraction, the methodology of this doctoral thesis follows Baranauskas' [11] semioparticipatory approach to design. Using Organisational Semiotics (OS) [127] as a theoretical frame of reference, the semioparticipatory approach adopts a systemic view of the role of technology in society, and the design of computational technology is not viewed as an exclusively technical activity. Figure 1.2 illustrates this systemic view in which not only technical, but also formal and informal aspects are also considered, and a socially aware design process should permeate all layers of this semiotic "onion" in a continuous cycle that cuts through the three layers. In this representation, the outer layer of the onion contains the *informal* interactions between people within a society, such as culture and values. The middle layer has the *formal* meanings and intentions through which society is organized, such as laws, models, and regulations. Lastly, the inner layer represents the *technical* artifacts that mediate the interactions from the other layers, such as software and other computational systems. Consequently, this approach assumes that technical systems not only depend on their formal and informal contexts when they are designed, but once materialized they also affect these contexts back by being situated within them, characterizing the continuous cycle shown in the figure. The semioparticipatory approach is adequate to the objectives of this doctoral thesis because it welcomes and encourages a plurality of worldviews and experiences to be brought into the design process, likely avoiding the creation of alienating digital artifacts.

Regarding our methodological approach for more specific parts of the *Arte Factus* framework, a brief description of the methodology adopted in the three distinct components of the framework is presented in the following sections: (i) socioenactive conceptualization, (ii) design studies, and (iii) situated practices.

1.2.1 Socioenactive Conceptualization

An evolving conceptualization that represents a live understanding of the concept of socioenactive digital artifacts is the product of two complementary efforts: the conduction and monitoring of situated literature reviews, and the analysis and interpretation of

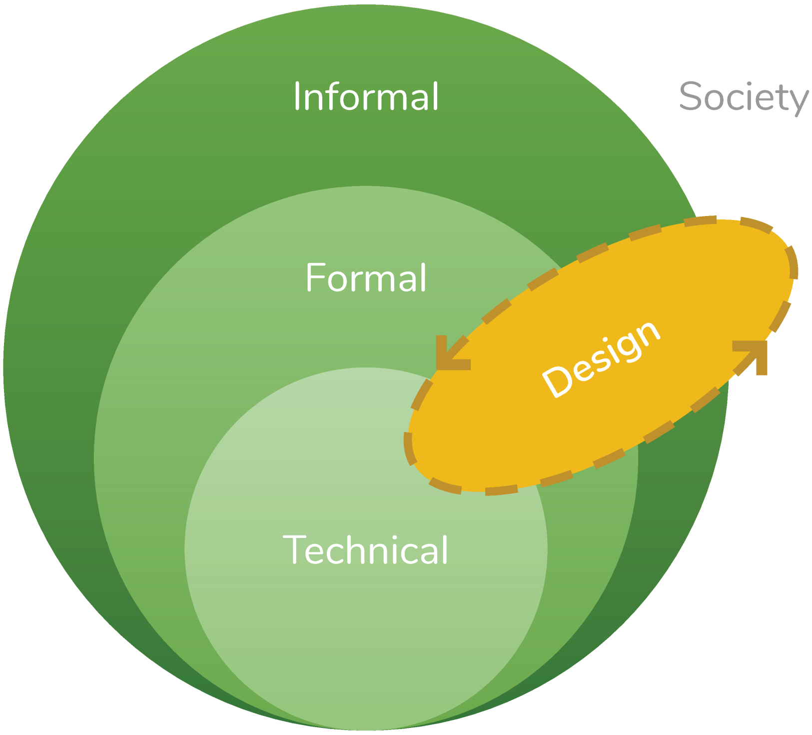


Figure 1.2: Design in the semiotic "onion". Adapted from Baranauskas [11].

empirical data regarding the design, construction and situated use and evaluation of socioenactive digital artifacts. By the monitoring academic publications related to at least one of the main topics of this doctoral thesis (*e.g.*, enaction, enactive systems, interactive art installations, and co-design processes), it is possible to create and evolve an understanding of how these subjects can be articulated to enable the design of socioenactive digital artifacts. Although some of the efforts of this doctoral thesis are more directed towards design studies or situated practices, they all involve a situated literature review within the scope of the study. On the other hand, empirical data from the experience of interacting with socioenactive digital artifacts validates (or transforms) the understanding of the concept of socioenaction and its encompassing theories and methods.

1.2.2 Design Studies

The *Arte Factus* framework was used in three design studies reported in this thesis: InterArt, InstInt, and InsTime. These studies involved the participation of 105 Computer Science and Computer Engineering undergraduate and graduate students from the University of Campinas (Unicamp). The students co-designed a total of 19 installations with the use of pervasive DIY technology. Each design study has its particularities, but they all followed an original and constructionist-inspired [141] process containing the following activities:

1. a hands-on exploration of existing artifacts for inspiration;

2. participatory ideation for generating original ideas;

3. clarification of the problem and involved stakeholders;
4. participatory sketching of design proposals;
5. physical and digital co-construction of artifacts; and
6. peer evaluation of artifacts.

These design studies provided the students with creative freedom, meaning that they were free to choose the direction they wanted to take and what they wanted to construct. The design process, in turn, favored co-authorship and social awareness. Furthermore, to support the technical aspect of these design processes, the students were provided with the Pincello electronics kit, which is accompanied by original online documentation (Pincello, an original contribution of this doctoral thesis, is described in detail in Appendix A).

1.2.3 Situated Practice

The design studies conducted within the scope of this doctoral thesis were responsible for the creation of a substantial collection of promising interactive artifacts. This, in turn, creates the opportunity to explore these artifacts in situated practices in the educational contexts of a school and an exploratory science museum. These practices involved an activity to be conducted within a specific time-frame (between one to three hours) and following a specific narrative aligned with the artifacts involved (*e.g.*, a workshop with technology that feels like magic follows the narrative of making the participants become magicians by mastering the technology). Each situated practice in this doctoral thesis have its particularities, but they all roughly contain the following activities:

1. Free, hands-on and instructionless exploration;
2. Guided reflection about the involved technology; and
3. Evaluation of the experience.

These practices were recorded in video and audio for further analysis of actions, dialogue and other relevant aspects that may emerge from the participants during the exploration of the selected artifacts. The analysis of the recordings may be conducted in an *ad-hoc* manner, or follow a more strict methodology such as the grounded theory [93], depending on the quality of the collected data and the specific objectives of the investigation. The evaluation, in turn, is focused on the self-reporting of emotional state and qualities of the experience during the activity, with the use of instruments such as the Self-Assessment Manikin (SAM) [24] and AttrakDiff [100].

1.3 Organization

Aside from the introduction and conclusion, this doctoral thesis is organized in 6 chapters. Each chapter is already published or is being submitted as conference proceedings, book chapters, or journal articles. Additionally, Appendix A is composed of a book chapter accepted for publication, and Appendix B presents the technical specifications of an interactive artifact named Lobo-Guará. With the exception of the additional Appendix C, which presents publisher authorizations for using published works in this thesis, a summary of the contents of each chapter and appendix is presented in the following sections.

1.3.1 Chapter 2: The Interface Between Interactive Art and Human-Computer Interaction: Exploring Dialogue Genres and Evaluative Practices

This chapter is composed by an article published on the Brazilian Computer Society (SBC) Journal on Interactive Systems (JIS) [64]. The article is an extension of the previous paper "Revisiting Interactive Art from an Interaction Design Perspective: Opening a Research Agenda" [56], published in the proceedings of the 17^{th} Brazilian Symposium on Human Factors in Computing Systems (IHC 2018), and awarded with second place among the best full papers during the symposium. The article that composes this chapter has the following abstract:

> **Abstract**: In this article, we investigate the relatively common origins, differences, and similarities between the Interactive Art and Human-Computer Interaction (HCI) areas of knowledge. We also investigate what kind of human-computer interactions are sought by artists or emerge in Interactive Art examples, as well as what kind of frameworks, evaluation criteria or methodologies are reported in the literature to support the design and evaluation of Interactive Art. As a result of our analysis of Interactive Art examples found in the literature and beyond, we derived four genres of dialogue that emerge naturally or are stressed by authors: visual, embodied, tangible and social. These genres, albeit not comprehensive, can inspire the design of novel forms of interaction in computational systems with or without artistic intent. Moreover, frameworks, evaluation criteria, and methodologies may allow a cross-pollination between Interactive Art and HCI. While interactive artists may provide novel ways to look at the design and evaluation of interactive systems, these artists may also benefit from appropriating traditional HCI methods, tools, and technologies for new purposes. Lastly, we draw on our findings and learned lessons to outline a research agenda with the main objectives of 1) encouraging Interactive Art research, 2) studying Interactive Art examples, 3) practicing Interactive Art design and evaluation, and 4) designing Interactive Art for all.

This chapter investigates the subject of interactive art from an HCI perspective. It narrates how these two distinct fields have similar origins and a latent synergy, but only recently are being brought together in academic literature. The chapter presents an overview of dialogue genres and evaluative practices found in the literature and other non-academic examples that are relevant to the scope of this thesis, and concludes with a research agenda for the study of interactive art within the field of HCI.

1.3.2 Chapter 3: InterArt: A Constructionist Approach to Learning Human-Computer Interaction

This chapter is composed of an article submitted for peer review [57]. The article is an extension of the previous paper "InterArt: Learning Human-Computer Interaction Through the Making of Interactive Art" [55], published as a book chapter in "Human-Computer Interaction. Theories, Methods, and Human Issues: 20^{th} International Conference, HCI International 2018, Las Vegas, NV, USA, July 15–20, 2018, Proceedings, Part I". The article that composes this chapter has the following abstract:

> **Abstract**: As new ubiquitous and pervasive technologies constantly change what we understand as a computer, Human-Computer Interaction (HCI) educators are required to not only stay updated but prepare their students to work with state-of-the-art technology and an ever-growing number of socio-technical situations. This phenomenon constitutes a challenge for HCI syllabuses and practices, demanding new approaches to HCI education. In this article, we present InterArt: a constructionist approach to teaching/learning HCI. We report and discuss a case study with 55 Computer Science and Computer Engineering undergraduate students engaged in the design and construction of physical interactive artworks that go beyond the computer screen. Results suggest that our approach made possible for the students to creatively express themselves through the construction of nine different interactive artifacts that they were interested in. Furthermore, our design process allowed the construction to be the result of participatory and socially aware practices. Overall, our students reported an expanded view of HCI at the end of the course, as well as a developed competence to appropriate new methods and artifacts in the design of interactive systems.

This chapter presents InterArt, a design study conducted in the scope of this doctoral thesis. The chapter narrates how the creation of interactive art can be used to learn HCI, describing a design process and resulting artifacts. Following the open-endedness of the theme, emphasis on the use of pervasive technology, and the adoption of a co-design process, the featured interactive installations showed qualities relevant to the concept of socioenaction, such as going beyond the computer screen and traditional input methods (*e.g.*, mouse, keyboard and touchscreen) through the use of sensors and actuators, while also being aware of social aspects and promoting empathy.

1.3.3 Chapter 4: InstInt: Enacting a Small-scale Interactive Installation Through Co-design

This chapter is composed of a paper published in the proceedings of the 30^{th} Australian Conference on Computer-Human Interaction (OzCHI '18) [59]. The paper that composes this chapter has the following abstract:

> **Abstract**: As interaction moves away from the screen into physical space, research on design techniques and practices is of central importance to cope with

novel interaction possibilities. Participatory approaches are a viable strategy for the design of ubiquitous systems, however, going beyond early design phases is usually a challenge. In this work, we propose a design process that integrates technical and creative abilities of participants, promoting a more holistic involvement in the co-design of interactive artefacts. The design process is illustrated in the InstInt case study. We detail the co-design process, from ideation to construction, of a small-scale interactive installation for public spaces. This process was conducted with Human-Computer Interaction (HCI) students. Results of the study indicate that participation reached the physical prototyping stages of design and the final artefact emerged from the materialisation of participants' different ideas and purposes, illustrating what we call a socioenactive design process. Our design process can be useful for HCI educators and practitioners seeking for new activities and approaches for open-ended scenarios.

This chapter presents InstInt, a design study conducted in the scope of this doctoral thesis. The chapter reports the enactment of a small-scale interactive installation through co-design. The design process is closely investigated, highlighting how participatory design techniques can be used to allow everyone within a design team to equally participate and be responsible for the resulting artifact in a co-authorship relationship. The resulting small-scale interactive installation showed qualities relevant to the concept of socioenaction, such as needing multiple people interacting at the same time to achieve a complete experience, ultimately encouraging strangers to notice each other.

1.3.4 Chapter 5: InsTime: a Case Study on the Co-design of Interactive Installations on Deep Time

This chapter is composed of a paper accepted for publication in the proceedings of the 2020 Designing Interactive Systems Conference (DIS 2020) [65]. The paper that composes this chapter has the following abstract:

Abstract: New technologies and practices are constantly transforming our interaction with computational systems. These transformations bring challenges to the Human-Computer Interaction (HCI) field, along with a constant need to better understand and describe how the design of interactive systems is changing. Currently, movements and theories such as speculative design and embodied cognition present unconventional perspectives and bring debate into the field. We investigate what kind of artifacts and attitude towards the design of interactive systems emerged in the InsTime project, in which 9 interactive installations were co-designed addressing the concept of deep time. Our discussion draws on a juxtaposition of backgrounds in philosophy of science, speculative design, and embodied cognition to analyze and characterize the empirical data from the InsTime project. As contributions, besides presenting the 9 interactive installations from InsTime and their co-design process, our

> discussion leads to a characterization of an attitude towards design that we named socioenactive design.

This chapter presents InsTime, a design study conducted in the scope of this doctoral thesis. The chapter narrates the design of interactive installations with the more specific theme of "deep time". The design approach taken in the study is framed against the concept of speculative design [67] and aspects from the philosophy of science. This framing, alongside the qualities of the resulting interactive installations, allowed the characterization of a socioenactive approach to design. This characterization is composed of stances towards the design of interactive systems concerning paradigm, methodology, ontology, axiology & rhetoric, and epistemology.

1.3.5 Chapter 6: "Maned Wolf in the Museum:" a Case Study on Learning Through Action

This chapter is composed of a paper published in the proceedings of the XXIV Workshop de Informática na Escola (WIE 2018) [60]. The paper has the following abstract:

> **Abstract**: Newer theories of cognition, together with novel ways of interacting with computers, allow us to revisit the idea of learning through action. In this paper, we explore, in an educational context, the use of the "maned wolf" interactive artifact. The artifact promotes a learning experience about the real animal, through the action of actively exploring its digital tangible replica. Our study included 5 teachers and 15 children, who independently discovered the (not initially obvious) artifact features. We discussed the technologies involved and applied an evaluation instrument of their emotional response. Results indicate that the activity was generally well-received and that our study informs a discussion that can revisit the long-standing concept of learning through action.

This chapter presents the "Maned Wolf in the Museum" workshop, a situated practice that took place in a school and involved the exploration of the interactive artifact Lobo-Guará from the InterArt design study. The chapter revisits the concept of learning through action, linking with the enactive cognition theory. The activity was well-received by both teachers and students, and it contributed with valuable empirical data of multiple people interacting with the digital artifact (often at the same time), while gradually exploring the mysterious wolf and socially discovering how it works.

1.3.6 Chapter 7: "The Magic of Science:" Beyond Action, a Case Study on Learning Through Socioenaction

This chapter is composed of a paper published in the proceedings of the XXV Workshop de Informática na Escola (WIE 2019) [63]. The paper has the following abstract:

Abstract: Recent advances in Human-Computer Interaction (HCI) can significantly affect technology-enhanced educational contexts. Our evolving relationship technology is a challenging topic of investigation, but alternative theories to cognition and socially aware empirical studies can shed light on the subject. In this paper, we explore "The Magic of Science" workshop, conducted in an educational museum context. With a background on learning through action and enactivism, our objective is to observe how people can individually and socially experience pervasive digital technology in educational contexts. Our study included 15 participant children and adolescents, who explored an exhibit of three interactive artworks and then built an interactive artifact from scratch during the workshop. We observed how these interactions took place and collected feedback on the experience of the workshop. Our results indicate that new ways of interacting with pervasive technologies allow us to expand the concept of learning through action, towards learning through socioenaction.

This chapter presents the "The Magic of Science:" workshop, a situated practice that took place in an exploratory science museum and involved the exploration of three interactive artifacts from the InterArt design study. This chapter expands the concept of learning through action, towards the original concept of learning through socioenaction. The activity was well-received by the participants, and its empirical data was analyzed with the grounded theory methodology to obtain deeper insights about the interactions of the participants with the interactive artifacts and among themselves.

1.3.7 Appendix A: Pincello: An Affordable Electronics Kit for Prototyping Interactive Installations

This appendix is composed of a paper accepted to be published as a book chapter in a book containing the proceedings of the 22nd International Conference on Human-Computer Interaction (HCI International 2020) [58]. The article that composes this chapter has the following abstract:

Abstract: Interactive artifacts and environments that involve more aspects of life other than work (*e.g.*, social relations, entertainment, art *etc.*) are gaining more attention within the Human-Computer Interaction (HCI) field. This includes interactive art and installations. Do-It-Yourself (DIY) technologies, such as Arduinos with sensors and actuators, are often used in interactive installations. These technologies, however, are often oriented towards hobbyists and engineers. Moreover, easy-to-use commercial kits have a relatively high cost and a lack of flexibility. In this paper, we present Pincello: an affordable electronics kit for prototyping interactive installations. Pincello is not a commercial product, but rather a recommendation of components accompanied by meaningful hands-on documentation. We present and discuss the main components of the kit, including suggestions on how they can be used to allow

> different forms of interaction. We also present three case studies in which Pincello was used, involving 105 HCI students. Considering how the kit received positive feedback in the three case studies, and how it was successfully used to create 18 installations of varied themes, Pincello has shown to be a promising tool for the design and construction of interactive installations.

This appendix presents the Pincello electronics kit. It narrates the importance of DIY pervasive technology in the creation of interactive installations and presents Pincello as a tool that is relatively affordable, flexible and accompanied by practical documentation. The components in the kit are described with an emphasis on their possible uses in interactive installations, and InterArt, InstInt, and InsTime are presented as successful cases of the creation of interactive installations with Pincello.

1.3.8 Appendix B: Lobo-Guará's Technical Specifications

This appendix presents the technical specifications of an interactive artifact named Lobo-Guará, which is representative of the installations featured in this doctoral thesis. The technical specifications include an overview of what is the artifact and how it behaves, a circuit & wiring diagram with a list of hardware components used to build it, the microcontroller programming and wireless communication source code, and lastly the source code for the web page responsible for displaying information.

Chapter 2

The Interface Between Interactive Art and Human-Computer Interaction: Exploring Dialogue Genres and Evaluative Practices

2.1 Introduction

The articulation of art and science has been an important source of innovation and contributions in many fields throughout history. In the Renaissance, for example, the search for knowledge often led to a blurred line between art and science. The work of Leonardo da Vinci is an exemplary illustration of this interdisciplinarity. According to Wilson [174], throughout Leonardo's many intellectual accomplishments, engineering inventions, and artistic creations, he was also successful in incorporating scientific approaches and theory into the practices and reflections of his creative process (*e.g.*, conducting a careful observation of phenomena and developing grounded theories of understanding). There were no gulfs among the aesthetic, scientific, and technological dimensions of his works or accomplishments, they intermingle each other.

Around four centuries after Leonardo da Vinci, during the late eighteenth hundreds and early twentieth century, both science and art were revolutionary. Science had revolutionary breakthroughs that still shape contemporary research. Einstein's relativity, Heisenberg's quantum mechanics, and Gödel's incompleteness theorems challenged the universal worldview, showing it contingent to the point of view. Art, on the other hand, broke conventions about perspective, representation, the role of the self and the unconscious, starting movements that still influence contemporary artists. Some examples, among a myriad of other ones, are: modernism challenged perspective and classical rules of composition; cubism questioned the solidity of objects and explored relativistic concepts of time; dadaism brought everyday objects to the artistic scene, questioning art itself.

According to Wilson [173], artistic traditions such as iconoclasm (constantly challenging or rejecting the *status quo*) and a greater appreciation of subjectivity allows artists to be more likely to pursue lines of inquiry devalued by others. By applying these artistic traditions in scientific research projects, it may allow scientific discoveries that would otherwise probably not happen or be overlooked. Furthermore, the author argues that through a closer relationship between artists and scientists, artists may be able to employ their critical thought and become an active part of the creation of new technologies.

Still on the subject of articulating art and science, John Maeda [131] argues that "For those of us involved in either field today [art and science] (and many of us have a hand in both), we know that the similarities between how artists and scientists work far outweigh their stereotypical differences". However, there is also a growing need to better specify what is meant by "art" and "science". Candy and Edmonds, for instance, open the first chapter of Explorations in Art and Technology [31] with an epigraph from Roy Ascott, an artist with a long-standing contribution to the relation between the arts and computing, which says "It is no longer enough to speak of the convergence or reciprocity of art and science [. . .] but to specify which art and which science, and, by what means they might fruitfully interact." [31, p. 4].

In this article, we explore the subject of articulating art and science under the lens of Interaction Design in the HCI and Interactive Art fields. Both HCI and the Interactive Arts are broad, diversified, and relatively recent fields. They subsume interdisciplinary practices and perspectives. HCI includes computing, among other fields such as psychology, anthropology, language studies, philosophy, communication. The Interactive Arts, in turn, relaxed the compulsory roles attributed to other stakeholders, such as the audience, bringing them to the forefront of the processes of art-making. Early examples of the explorations of computations in the arts are the Cybernetic Serendipity exhibition held at the Institute for Contemporary Art in London in 1968 [31, p. 5], and Giorgio Moscati and Waldemar Cordeiro's works, who explored computers and printers in the 1960s [134].

Edmonds [70] stresses that some artists give great importance to what the audience feels or the ways it responds. Moreover, in Interactive Art, in particular, experience and participation are not only important but key aspects. Similarly, participation and experience, and shifts in their understanding are also challenging and often enriching what the HCI community conceives as encompassing "User Experience (UX)" design. Benford *et al.*'s "Uncomfortable UX" concept [18], for instance, employs an annoying form of interaction as a strategy to deliver entertaining, enlightening and socially bonding cultural experiences. Therefore, the articulation between art and science in HCI should be further encouraged, and this may be accomplished through the study and practice of Interactive Art. Weiley and Edmonds [170], for example, argue that HCI researchers can incorporate art approaches to (1) make some types of decisions more explicit by documenting not only results but also the ideation process, (2) support stronger hypothesis generation by fostering divergent thinking and informed intuition, and (3) enrich evaluation methods by adopting a more reflective practice. Furthermore, Edmonds [71] argue that HCI researchers, especially those interested in experience design, could benefit from incorporating the concerns of interactive artists (*e.g.*, hedonic qualities and different forms of engagement) into the study of interaction design and user engagement.

In this article, we present a brief and modest introduction to the intersection between the Interactive Arts and HCI, as well as some examples and criteria of evaluation of interactive works. We revisit the concept of Interactive Art grounded on our Interaction Design perspectives and practices. We bring a subset of the material production of joint efforts between HCI and the Interactive Arts, to reflect on their design processes, following the two main questions:

1. What kinds of human-computer interactions are sought by artists or emerge in Interactive Art examples in the literature and other non-academic sources?
2. What kinds of frameworks, evaluation criteria or methodologies are reported in the literature to support the design and evaluation of Interactive Art?

This article is structured as follows: we begin Section 2.2 by presenting a brief background on the connection between Interactive Art and HCI. In Section 2.3 we present an initial categorization of dialogue genres from Interactive Art examples found in the literature and other non-academic sources (Question 1). Then, in Section 2.4 we explore different frameworks and methodologies found in the literature that support the design and evaluation of interactive works of art (Question 2). Afterward, in Section 2.5 we discuss our main findings and contributions, as well as their implications for the design processes, leading to the outline of a research agenda. Lastly, in Section 2.6 we summarize our main considerations and present directions for further work.

2.2 Background

The cross-pollination between the arts and HCI is not new, as some knowledge and methods related to art have been used in HCI for quite some time. For example, Gestalt psychology, color theory, and other visual principles have been applied with relative success in the design of interfaces, bringing visual balance, consistency and harmony, when desired or employed. Furthermore, the methodology described by Frayling as Research through Art and Design [85] has been gaining attention within the HCI community in recent years [178, 90, 16]. Among many possible approaches to understand and articulate art and science through computational works of art, in this article, we focus on something that has been inhabiting the worlds of the arts, the sciences and the technologies for some decades, but somehow always manages to reinvent itself and retains a feeling of novelty and innovation: the theory and practice of Interactive Art itself.

It is worth noting that interactivity in art does not necessarily involve computational technology. According to Muller *et al.* [135], the act of "experimenting" any kind of work of art is always an active and fundamentally an interactive process. In this case, the interaction occurs in the processes of perception and creation of meaning by the audience. For instance, Hélio Oiticica and Lygia Clark, Brazilian artists, are recognized as rather important to the initial development of the field of Interactive Art, with artworks developed between the 1950s and 1970s. These early works are valuable in their pioneering and other aesthetic qualities.

As argued by According to Muller *et al.* [135], it was the advent of art which explored computer-based interactivity, material-wise, that brought forth what is now broadly recognized as Interactive Art. Therefore, due to our field of inquiry being HCI, for practical reasons we consider interactivity in art that does not involve computers to be beyond the scope of this article. Furthermore, considering the way our investigation is focused on HCI and Interaction Design, in this article we consider Interactive Art to be any form of art enhanced with computer-based interactivity. It is important, however, to emphasize that it is not our intention to define what is and what is not Interactive Art. Even though we give some examples in the next section to suit our needs, we encourage readers to explore the concept of Interactive Art to construct their own understanding of what is (and what is not) Interactive Art.

In Interactive Art, interactivity is not restricted to the cognitive, narrowly understood as within the realm of the mind, the symbolic. It engulfs and demands and includes the embodied, the situated, the historical throughout its frameworks of understanding. It ceases to be conceived solely as a mental abstract process, which would happen in the mind of each spectator. Contrastingly, each participant handles the work of art, in a two-way embodied and intentional sensory-motor-mindful exchange, forming an interactive dialogue that has the potential to be unique for each person.

England [75] points out that Interactive Art and HCI share common origins. During the 1960s and 1970s, several artists explored video and computing technology and created the first digital interactive experiences. Krueger's GLOWFLOW and VIDEOPLACE projects [120], for instance, date from 1969 and 1974 respectively. In Brazil, Waldemar Cordeiro [130], worked in the same period, but also added political-social commentary during the controversial years of the Brazilian military government. Regarding fundamental differences, Edmonds [70] discusses the way Interactive Art is not exactly concerned with task analysis, error prevention or task completion times, recurrent themes in mainstream HCI. Goals may not be well defined, and the focus tends to be on pleasure, play, experience, and engagement. The works of Dunne and Raby [67], which mingle art, design, and computing, are examples of design not for efficiency or usability, but as a catalyst for "design fiction" or "social dreaming". As the authors say, designers can aspire for more than making technology easy to use and consumable.

Though Interactive Art was already on track during the 1960s, the field of computing was still emerging and in process of consolidation as a recognized academic field. Engelbart developed the computer mouse during that decade and published his "Augmenting Human Intellect: A Conceptual Framework" [74] already in 1962. At the Association for Computing Machinery (ACM), people interested in computing and people gathered within the Special Interest Group on Social and Behavioral Computing, renamed as Special Interest Group on Computer-Human Interaction in 1982. Xerox Alto, which is considered the first computational machine designed to embed an operating system and a graphical user interface had its first unities delivered in 1973.

These common interests and themes among interactive artists and interface professionals and researchers, however, fade out during the 1980s, when HCI was formalized as an academic field, and somehow restricted its interests mainly to professionals from areas such as cognitive psychology and computing as its predominant voices. People with other interests went elsewhere because there was no substantial space for more subjective or social aspects of interaction. Later, HCI has seen the sprout and growth of distinct trends or schools, sometimes described as waves. They differ among commentators. Based on

Duarte and Baranauskas [54], they can be described roughly as:

1. First-wave HCI is more concerned with ergonomic universals, task modeling, and experimental methods. It relies heavily on task analysis, cognitivism and information processing models of human behavior. Its methods focus on how subjects, usually in laboratory conditions, process information displayed by a computer and communicate back through a user interface, making use of both experimental methods and more naturalistic inquiries to derive "universal laws", such as Fitt's law [83], Card, Newell and Moran's GOMS [33], and Norman's gulfs of evaluation and execution [139].

2. Second-wave HCI stems from the so-called cognitive science revolution. Around the mid-1980s, divergent researchers and movements questioned the universal validity of such generalizations commonly found in first-wave HCI. Authors such as Winograd and Flores stated the situated, historical, and mediated nature of human cognition [175]. Other examples are Suchman's work on planning and action [162], as well as Bødker's work on human activity [20]. However, the context was still mostly circumscribed around the work environment.

3. Third-wave HCI brings forth previously under-recognized and marginalized topics such as culture and values. As computing reached out [96] across a manifold of human endeavors, affecting the everyday life of a significant parcel of the privileged population, a richer set of phenomena fell under the umbrella of HCI, transcending work in uncountable ways. As such, third-wave HCI concerns go beyond production-related and "purposeful" tasks (*e.g.*, to study how to reintroduce humanities in HCI to stimulate emancipatory or social change-oriented approaches [15]). It relies on experimental methods and more naturalistic inquiries to understand different facets of everyday life.

According to England [75], since the first years of the 2000s, a community effort was made to bring HCI and art closer together. This is illustrated by panels & Special Interest Groups (SIGs) (*e.g.*, [156, 76, 77]) and workshops & art exhibitions (*e.g.*, [3, 78, 79]), mainly at the CHI conference, but there are also contributions in smaller, but no less important conferences, such as Creativity & Cognition [30]. Without exhausting the subject, there have been academic discussions regarding hybrid evaluation methods that can potentially contribute both to new media arts and HCI practitioners [3]; cataloging the digital arts and reported curatorship experiences [77, 78, 79]; possible articulations of lines of research in digital arts and HCI through intersections and cross-fertilization [156, 81, 76]; the relationships between the Interactive Arts, audience engagement and experience design [73]; how can HCI research be aligned with socially engaged arts practices that encourage debate around societal challenges [40]; how art and HCI discourses can both inform and be informed by innovation policies and initiatives [80]; and how art and HCI can investigate together the shifting role of the former "user", who can now become, for instance, an author, collaborator or performer [124].

With the growing number of contributions at the intersection between art and HCI, it is our understanding that interaction designers could benefit from the unconventional thinking and the creative efforts that arise from the creation of Interactive Art in its many forms. This can be achieved by studying dialogue genres found in Interactive Art examples, both in scientific literature and other sources, as well as design and evaluation approaches employed in the creation of Interactive Art artifacts, as we will present in the two following sections.

2.3 Interactive Art: Examples

Interactive Art is well covered by the academic literature, as well as within online communities. In this section, we bring some examples of Interactive Art. Our aim in choosing this subset is to illustrate both distinct trends we identified within the literature and the possibility of analyzing the cross-fertilization between HCI and the arts. By analyzing examples of interactive works of art from the perspective of both art and computing, we derived some types of emphasis they stressed, mostly based on the genre of dialogue they enable or stress when handled. A dialogue genre is defined at the SIGCHI Curricula for HCI [103] as “the conceptual uses to which the technical means are put.". The identified genres are (A) Visual, (B) Embodied, (C) Tangible, and (D) Social.

Our focus on the dialogue genre or theme of the artifacts restricts the kind of analysis we carry and is somehow naïve, from the perspective of the cultural, situated, and historical dimensions of the artworks we picked. However, though limited, they have enabled us to illustrate the types of technological environments works of art have been exploring, the means they explore, and some of their uses. In the following subsections, we present these four dialogue genres and provide examples to illustrate them.

2.3.1 The visual dialogue genre

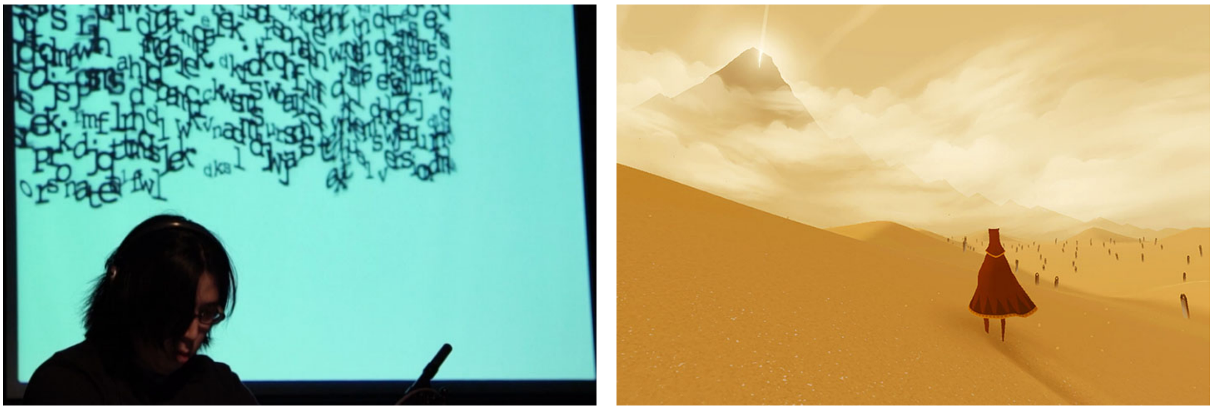
People gaze, view and look at GUIs, interactive artworks and installations. An interface where the visual is predominant is an example of a visual HCI dialogue genre. GUIs usually stressed the visual representation of something, such as an environment, a landscape, a map, a product, in two or three dimensions. The desktop metaphor enables users to tackle with distinct documents, and later on, as windows, representing distinct applications. As computers and associated displays became cheaper and more affordable, smaller (to be used in headsets) and larger (to engulf us), they enable users to fall in an environment, where we can look, view and sail around, either to design products (computer-aided design and manufacturing) or institutions (virtual museums, digital libraries), or large and complex data sets (geographical information systems).

When stressing the *visual interaction* qualities or perceptions, the artwork has been sometimes labeled as virtual (*i.e.*, have a digital representation). In many cases, it is experienced through a set of display screens or a virtual reality headset, usually correlated eye tracking or head position, together with more traditional input devices, such as a mouse, keyboard, touchscreen, or joystick.) Usually, these artifacts are designed with a significant degree of aesthetic interest when compared to everyday counterparts. Some examples of Interactive Art with a focus on visual interactions are:

- Live Writing: Gloomy Streets[1], illustrated in Figure 2.1a and created by Sang Won Lee, is an application in which the experience of writing a poem is enriched with a real-time audio-visual performance on top of what was written. As a person writes in a blank screen with a typeface and sound effects, which resemble those of a typewriter, the text may start to blur and ripple while an enigmatic sound effect plays in the background. The writer's own emotions emerge through keystrokes and letters that seem to be alive [123].

- Journey[2], illustrated in Figure 2.1b and developed by thatgamecompany, is originally a Playstation 3 digital game in which the player controls a character roaming in a vast desert towards a distant mountain. Although it is an online multiplayer game, the player has limited interaction with other players, relying only on communication through character movement and a musical chime. It was not the gameplay that made it very well received by both critics and players alike, but the strong emotional and aesthetic experience, as can be seen in the aggregated reviews available at Metacritic[3] [165].

- Additional examples of visual interaction include but are not limited to: This Is Not Private [46], idMirror [109], and Fukushima Audio Census [117].



(a) Live Writing: Gloomy Streets [123, p. 1389]. (b) Journey [165] (PlayStation Europe, CC BY-NC 2.0).

Figure 2.1: Visual dialogue genre examples.

2.3.2 The embodied dialogue genre

People are present, move and wander in physically immersive interactive artworks and installations. An interface where the embodiment is predominant is an example of an embodied HCI dialogue genre. As a wide range of sensors and computer vision algorithms

[1]Live Writing: Gloomy Streets, by Sang Won Lee `https://livewriting.github.io/`
[2]Journey, by thatgamecompany `http://thatgamecompany.com/journey/`
[3]`http://metacritic.com/game/playstation-3/journey`

are created, become more efficient, affordable and easier to use, computing artifacts became more diluted and distributed across and around the user's physical space (a trend labeled as ubiquitous or pervasive computing). These ubiquitous or pervasive computational technologies can surround the places we live and work in, and embodied computer interfaces enable us to interact with them by being within a physical environment, present with our full bodies.

When stressing or incorporating *embodied interactions*, the artwork reaches out to the physical world to receive embodied methods of input that go beyond traditional everyday interaction. Usually, it involves sensors capable of identifying psycho-physiological indicators, and the person's own body is used for conscious, or even unconscious, interaction with the artwork, as in the concept of an Enactive System proposed by Kaipainen *et al.* [112], drawing upon the enactive approach proposed by Varela *et al.* [168]. Some examples of Interactive Art with a focus on embodied interaction are:

- iMorphia[4], illustrated in Figure 2.2a and created by Richard Brown, is an art installation in which a person has its body tracked by sensors so that a computer connected to a projector can project a virtual character over the person's body. Body tracking allows the projected character to follow the person's movements in real-time. It can be used, for instance, to project fictional characters such as *anime* or cartoon protagonists, allowing the tracked person to physically impersonate the character, challenging basic conventions of screen-based interaction [25].

- CAVE[5], illustrated in Figure 2.2b and created by Domingues *et al.*, is an art installation in which the audience can experience an interactive ritual related to Afro-Brazilian popular religions. Sensors are used to detect physiological indicators and walking patterns to, accordingly, control projections on the walls and other interactive resources, such as ambient sound. The goal is to "enhance the sensorial experiences and amplify kinesthesia by adding the sensations that are formed in response to the physical world, which aesthetically constitutes the principle of synaesthesia" [51, p. 1].

- Additional examples of embodied interaction include but are not limited to: Distractions [27], Avian Attractor [53], and BrightHearts [115].

2.3.3 The tangible dialogue genre

People touch, handle and manipulate tangible interactive artworks and installations. An interface where tangibility is predominant is an example of a tangible HCI dialogue genre. As interactive devices transcended the graphical output (representation or spectacle) and computational technology is somehow embedded into physical objects, they enable a person to physically handle these objects. This physical handling has immediate feedback, be it haptic or not, and provide an improved sense of being-in-a-world. This improved

[4] iMorphia, by Richard Brown `http://mimetics.com/`

[5] CAVE, by Diana Domingues *et al.* [51]

(a) iMorphia [25] (Art.CHI 2016 Archive). (b) CAVE [51].

Figure 2.2: Embodied dialogue genre examples.

sense of being-in-a-world effect, in turn, is not only abstract but concrete, as tangible interfaces enable the manipulation and use of physical tools that are ready-to-hand, enabling a richer set and sense of attitudes and actions contained within these tangible computational objects.

Drawing from the concept of "Tangible Bits" by Ishii and Ullmer [105], in the *tangible interaction* approach, the interactive works of art go beyond the virtual and is somehow embedded in real-world objects, by enabling their manipulation. It usually involves sensors capable of tracking these objects and sensors in the objects themselves to capture interaction data, as well as actuators that constraint or facilitate the manipulation. They may also involve networked and distributed devices commonly known as IoT. Some examples of Interactive Art with a focus on tangible interaction are:

(a) Crafted Logic [148]. (b) Breaking AndyWall [113].

Figure 2.3: Tangible dialogue genre examples.

- Crafted Logic[6], illustrated in Figure 2.3a and created by Irene Posch and Ebru Kurbak, is an interactive installation situated within a larger project focused on

[6]Crafted Logic, by Irene Posch and Ebru Kurbak `http://www.ireneposch.net/crafted-logic/`

handcrafting simple electronic components from scratch. It consists of handcrafted hardware created with textile-crafting techniques, such as crochet. The hardware is connected forming basic logic gates controlled through electromagnetism and can perform designed logical operations. According to the authors, this installation "[...] challenges the aesthetics, interactions, and technology creation scenarios we take for granted in the field today" [148, p. 3884].

- Breaking AndyWall[7], illustrated in Figure 2.3b and created by Leo Kang, is an interactive installation where participants are invited to "destroy" pieces of art that are socially considered what the author calls "great art", such as Andy Warhol's Marilyn Diptych. The chosen famous artwork is projected onto a canvas that can be hit by the audience with a provided wooden hammer. Sound sensors capture the impact of the hammer on the canvas, and with each hit, the projected artwork is gradually broken down into shattered pixels. According to the author, the objective is to provide an experimental space to discuss the dynamic roles of users in art and Design [113].
- Additional examples of tangible interaction include but are not limited to: Endless Ripples [98], eBee [145], and Dichroic Wade [155].

2.3.4 The social dialogue genre

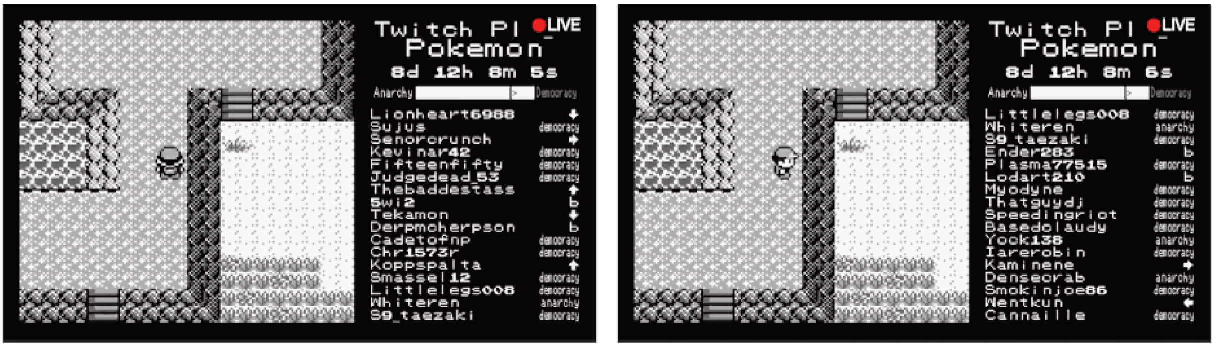
People share, communicate and dialog within social interactive artworks and installations. An interface where the social is predominant is an example of a social HCI dialogue genre. As computer networks continuously connect privileged people in separated geographical and social landscapes, the sharing, collective, and participatory nature of knowledge are also constantly targeted. This happens not only computationally, but also culturally, politically, and historically. When some social or geographical and spatial boundaries become obsolete through computational technology such as social networks, people with similar or complementary knowledge and skills can create large groups (or, sometimes, "bubbles") to share stories, be part of something bigger, and collaborate or compete among each other.

When stressing or incorporating some kind of *social interaction*, an artwork may not necessarily excel in its degree of aesthetic interest and neither provide any novel form of interaction with computational technology in the traditional sense; on the other hand, they may somehow allow and/or encourage people to interact with each other in unconventional ways through its provided resources. They may encourage people to collaborate and achieve highly complex levels of self-organization. Some examples of Interactive Art with a focus on social interaction are:

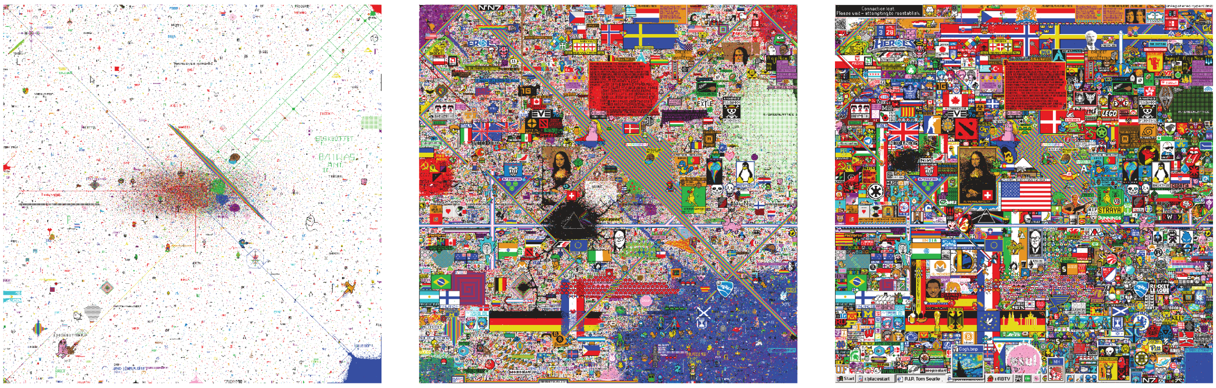
- Twitch Plays Pokémon[8] is a social experiment created by an anonymous programmer, still active by the time we write this article. Its most memorable moment was

[7] Breaking AndyWall, by Leo Kang `http://leokang.com/portfolio/index.php/hciart/breaking-andywall/`

[8] Twitch Plays Pokémon, anonymous `https://twitch.tv/twitchplayspokemon`



(a) Snapshots of Twitch Plays Pokémon.



(b) Snapshots of Reddit's r/place canvas from beginning to end. Reconstructed from Albini's Archive [5].

Figure 2.4: Social dialogue genre examples.

during the very beginning of February 2014, when thousands of players could simultaneously issue commands to control the character of a live stream play-through of the classic game Pokémon Red [88], as illustrated in Figure 2.4a. Oscillating between democracy and anarchy, ultimately the players could collaborate to the extent that they surprisingly were able to finish the game in precisely 16 days, 9 hours, 55 minutes and 4 seconds.

- Reddit's /r/place[9] is a social experiment by the Reddit social network conducted in April 2017. Users of Reddit, also known as Redditors, were given a shared empty canvas with 1000×1000 pixels, and each Redditor could place or paint only one pixel on the canvas every 5 to 20 minutes. The experiment, illustrated in Figure 2.4b, lasted only three days, but it was enough to show a fierce competition between different groups of people for the limited pixels, as well as complex levels of self-organization and collaboration between people with shared interests. As an attempt to catalog everything that was created during the three days of the Reddit's /r/place event, the /r/place Atlas[10] has 1493 entries.

- Additional examples of social interaction include but are not limited to: Tango

[9] Reddit's /r/place, by Reddit `https://www.reddit.com/r/place/`

[10] `https://draemm.li/various/place-atlas/`

Apart: Moving Together [72], Whorl [132], and Sprung! [42].

Concerning common interests of HCI and Interactive Art, both assume many forms and can be analyzed from many perspectives, beyond the limited scope of the analysis of this article. Our proposed categorization of dialogue genres and respective examples illustrate only some of these angles. Besides the humanistic value that may or may not be intended, these examples provide a basis to understand further research on important topics for both HCI and Interactive Art. The provided examples encompass, for instance, properties that led to high levels of immersion and engagement; novel forms of interaction with computer systems based on alternative technologies and sensors; and social behaviors of collaboration (or competition) and self-organization through computer systems.

It is important to emphasize that these different dialogue genres are not mutually exclusive, and they are not intended as a strict nor comprehensive categorization of Interactive Art. The Twitch Plays Pokémon and Reddit's /r/place examples, for instance, could also be considered examples of visual dialogue genres due to their computer screen emphasis and interaction through traditional peripherals, while embodied and tangible genres can easily become intertwined.

2.4 Interactive Art: Design and Evaluation

Bannon and Ehn [10] and Kostakos [119] argue that HCI communities often focus on results, products, and services, while the design processes and practices often lack thorough presentation and discussion. However, besides analyzing Interactive Art examples, we may also benefit from studying how these artifacts are created. In this section, we aim to address our second research question, concerning how to evaluate joint HCI and Interactive Art efforts. We briefly present some methods and frameworks that we have considered relevant during our study, without exhausting the subject. We will emphasize evaluation processes, as it is one of the central aspects of HCI practice and research. The evaluation also often informs design in a formative manner.

Evaluation processes in HCI can significantly differ from one another as they have different criteria regarding distinct interests, values, objectives, and methodologies from researchers and practitioners. Leaning on a summary of the three HCI waves previously presented in Section 2.2, we have:

1. First-wave HCI evaluative criteria appear to be more concerned with finding ergonomic universals and quantifying interaction metrics, relying on experimental methods. They are focused on tasks and intend to improve the fit between human and machine to avoid human error, improve performance, and reduce strain. They are usually conducted in controlled laboratory conditions.

2. Second-wave HCI evaluative criteria are also focused on improving production in work-related activities. However, they go beyond short-term tasks, focusing on long-term human action or work, as well as their outcomes. They are usually carried out in work settings. It is usually conducted in contextualized actual work settings.

3. Third-wave HCI evaluative criteria rely on both experimental methods and more naturalistic inquiries to understand different facets of life and reality. They are mostly conducted in everyday life conditions and way beyond restricted, work-related environments.

In summary, evaluation criteria in HCI spans from short-term controllable settings, all the way to long-term uncontrollable situations. On the one hand, short-term controllable settings enable some generalization, such as production metrics in the evaluation of a simulated workstation on a shop floor. On the other hand, long-term uncontrollable situations, are more subjective and unpredictable, such as the more naturalistic study of any kind of life activity, not necessarily work-related.

In art, in turn, reception and evaluation tend to be uncontrollable, as in third-wave HCI. Candy [29] argues that evaluation is usually an unfamiliar practice, and sometimes even a rejected notion among artists – even though some form of evaluation may implicitly occur in the art-related activities of critique and curatorship. According to the author, however, there are pioneer practitioners and researchers that are exploring forms of evaluation that impact how art is made and exhibited. For example, drawing on Dewey's notion that "[...] art is complete only as it works in the experience of others than the one who created it." [49], we could say that interactive artists could opt to give away control of their creation to allow other people to "complete" their work by experimenting with it, similar to what Eco [69] has called "the open work", later in 1967. This experience-focused approach supported by evaluation methods may allow not only the discovery of new knowledge on engagement and UX but also the creation of new artworks altogether.

It is our understanding that the cross-pollination between the arts and HCI can be explored as a two-way process. As HCI tends to move towards undetermined purposes and uncontrollable settings, and as art intends to explore the constraints and implications of computational media, which still demands the specialized technical skills of programming and testing, it is possible to envision space for mutual contribution between the fields. Even though HCI researchers and practitioners have had decades to propose, design, study and put into practice a wide range of evaluation methods, the use of these methods in different artistic contexts, and with unorthodox objectives, has the potential of shedding light on aspects not yet considered, possibly further improving such evaluation methods and contributing to HCI research.

In the following subsections, we present some examples of design and evaluation frameworks in Interactive Art. They are illustrative of evaluative practices of interactive systems, mostly developed in the realm of the arts. A larger and more comprehensive set of examples can be explored in [32]. Afterwards, we briefly discuss the use of participatory approaches to the design of Interactive Art.

2.4.1 Candy's Model

Candy [29, 28] proposes a generalized design and evaluation model which aims to support higher-level problem clarification regarding the development of Interactive Art. Candy's evaluation model is designed to clarify the elements of a design and/or evaluative process and the features to be designed and/or evaluated, along with applicable criteria, qualities or values. It includes four categories, which are: (1) Participants (people, creators); (2) Experience (process, interactions); (3) Outcomes (products); and (4) Environment (context). It may be summarized as follows:

1. Participants: it may include artists, technologists, audience, curators, organizers or even funding agencies; which may lead to the evaluation of features such as imagination, expertise, skill, experience, intention, reputation, success or failure; with criteria considering levels or degree of motivation, skill, education, expertise, engagement, curiosity, commitment or resources.

2. Experience: may encompass audience engagement, art practice, curatorship or system development; which may lead to the evaluation of features such as response, attitudes, risk-taking, interaction, innovation, design quality or performance; with criteria considering levels or degree of the experience being positive, negative, opportunistic, adventurous, curious, cautious, experienced or transcendent.

3. Outcomes: may include artworks, installations, exhibitions, performances or compositions; which may lead to the evaluation of features such as novelty, originality, impact, adaptability, aesthetics, effectiveness or appropriateness; with criteria considering levels or degree of qualities such as leading-edge, engaging, purposeful, enhancing, exciting or disturbing.

4. Environment: may comprise a studio, laboratory, museum, gallery or public space; which may lead to the evaluation of features such as physical spaces, facilities, costs, time, resources, effort, constraints or support; with criteria considering levels or degree of qualities such as design quality, convincing, adaptable, effective, innovative, sufficient, sustained, damaging or copious.

Candy's model shows a heavy emphasis on knowing beforehand and planning for the different parts who influence or are influenced by the design or evaluative process. Even though it is exemplified with stakeholders or aspects that are historically not common in HCI (*e.g.*, art practice, performances, and disturbing or damaging qualities), we believe that there is a common ground to be explored here, especially when research more aligned with third-wave HCI is concerned.

2.4.2 Costello and Edmonds' Pleasure Framework

Aiming at identifying what constitutes pleasure in what the authors refer to as "playful interaction", Costello and Edmonds' pleasure framework [41, 42, 43] is composed of thirteen categories of pleasure that can be experienced when interacting with Interactive Art. According to the authors, the framework can be used both to support the design, as well as to evaluate playful interactive experiences. The framework's categories, with some considerations of our own in parenthesis, are:

- *Creation* is the pleasure from being able to create and express yourself creatively, obtained from the aesthetic qualities of the creation or simply from being in control (for an artwork to excel in this category it seems plausible that it must not only be interactive, but also participatory, elevating the audience to the status of co-authorship).

- *Exploration* is the pleasure of exploring something or an unfamiliar situation. It is often linked with Discovery, but sometimes it may also be self-contained.
- *Discovery* is the pleasure obtained from making a discovery, like discovering relationships between performed actions and respective responses from an artwork or even finding a solution to a problem (the amount of pleasure for finding a solution to a problem seems correlated with the next pleasure category: Difficulty).
- *Difficulty* is the pleasure from developing or exercising a physical or intellectual skill to do or achieve something, as an activity may often be more fun if it is not too easy (there may, however, be a fine line between achieving this pleasure and being frustrated with a too high difficulty).
- *Competition* is the pleasure of achieving a system or self-defined goal. This goal may or may not involve working with or against another physical or virtual entity (when Competition is between people and not a virtual entity, it may be even a harder task to adjust Difficulty without frustrating one or both competitors, as Difficulty cannot be explicitly controlled anymore).
- *Danger* is the pleasure from feeling scared, in danger or as taking a risk. This feeling may vary between simply feeling a mild sense of unease, to a strong feeling of fear, and may occur indirectly through empathy for another entity, *e.g.*, a fictional character.
- *Captivation* is the pleasure from feeling mesmerized, like being in some way controlled by another entity. It may happen, for instance, through an immersive experience that leaves the audience unconscious of its surroundings.
- *Sensation* is the pleasure from feeling a sensory physical action, *e.g.*, touch, hearing *etc.* (besides a category on its own, the multisensory nature of Sensation leads us to think of it as also an underlying aspect of the other categories, as our senses are directly related to them).
- *Sympathy* is the pleasure from sharing physical or emotional feelings (as we understand, Sympathy is inherently reciprocal, as sharing feelings in the terms of simply exposing them may not be enough to achieve pleasure from this category. Reciprocity seems to be essential).
- *Simulation* is the pleasure from perceiving a copy or representation of something from real life (in our understanding, the Simulation category may not be limited to representations from the real, physical world; a physical or virtual representation of something virtual may also invoke the described pleasure).

- *Fantasy* is the pleasure from perceiving a fantastical creation of the human imagination, like the representation of peculiar fictional worlds and creatures.
- *Camaraderie* is the pleasure from developing a sense of friendship, fellowship or intimacy with someone (this category seems highly likely to be linked with Competition and Sympathy, and it seems fundamental to achieve behaviors of collaboration and self-organization).
- *Subversion* is the pleasure from breaking rules, subverting the meaning of something or watch someone else do it (in doing something not allowed or predicted by the system, this category may be linked with Exploration, Discovery, and Creation, as well as Danger in some circumstances).

According to Costello and Edmonds, it is not feasible for an interactive artwork to excel in all categories they propose simultaneously. This should not be the goal or the purpose of the framework altogether. The authors are more concerned with surfacing and understanding possible aspects of playful interaction that may or may not lead to some form of pleasure for people interacting with an artifact, as well as identifying which categories stand out in an artwork.

In contrast with Candy's model, which is more generalized and concerned with planning, Costello and Edmonds' pleasure framework is much more concerned about the very specific and complex qualities of playful interaction. Although the design of "pleasurable" user interfaces can be argued as a goal of UX design, we believe that the depth to which Costello and Edmonds explore the subject makes it a promising tool to be used by HCI researchers and practitioners, especially regarding categories of pleasure that traditionally can be considered unconventional (if not completely undesired) in traditional interaction design, such as difficulty, danger or subversion, with the exception of digital games design.

2.4.3 Participatory Approaches

The use of participatory approaches in the design of Interactive Art or installations has been reported in the scientific literature for over fifteen years. Frecon *et al.* [86], for instance, reported on how a museum installation about visualizing sound perception in submarines was redesigned with participatory activities to collect design suggestions with invited stakeholders. There is a significant amount of publications in the literature that present interactive installations designed with some kind of participatory design approach (*e.g.*, [45, 23, 138, 157]). However, these studies tend to have their contributions oriented towards showing the created product qualities, while details of the design process are often absent or briefly discussed.

For studies that do give greater emphasis to the design process, many of those highlight the use of participatory approaches in early design phases to generate ideas and concepts. Some studies present the benefits of conducting fieldwork at the intended environment for an interactive artifact or installation [37, 36]. Some studies present a variety of early phase approaches to design, such as a rapid ethnographic study in a museum setting [144], integrating stakeholders into the design team to open-endedly generate design ideas, or developing early prototypes to gather feedback from users to lead the design from there [110, 39], and showing the feasibility of including children in the process to generate ideas for a virtual reality exhibit [159]. In a more holistic approach, Ciolfi *et al.* [38] describe a co-design process that iterates phases for the generation of new concepts (divergent activities) with phases for the selection of concepts to pursue (convergent activities). The authors describe the use of practical, embodied activities such as sketching in hardware, in-situ scenario building, bodystorming and combining technology and content.

Perhaps the most controversial aspect of it, participatory approaches may challenge traditional understandings of the concept of authorship, leading to the concept of co-authorship of Interactive Art. Jacucci *et al.* [107], for instance, compare the dichotomy between designer and users in HCI to artist and audience in artworks. It is argued that the growing interest in participatory approaches to both art and design can blur these dichotomies. Artists may invite people to contribute within a given conceptual framework, or they may encourage the artwork to be ultimately appropriated and extended by the joint participation of audience and artist.

2.5 Discussion

Because evaluation is a central aspect of HCI, there is already a vast amount of knowledge on the subject in the literature and among HCI researchers and practitioners. Nevertheless, the HCI community could always benefit from novel perspectives on the subject. On the other hand, there is a growing interest from Interactive Art practitioners in evaluating their work. This apparent alignment of interests may allow the evaluation to serve as a common ground for collaboration between the fields. Classical HCI evaluation methods, however, do not seem to be useful, neither well accepted, in the context of art. Their focus on well-defined goals and objective metrics seems indeed out of place in the evaluation of Interactive Art, which is noticeable as both presented frameworks are heavily focused on experience. In contrast, evaluation methods focused on aspects of UX and aligned with third-wave HCI methods are already being appropriated by artists and used with relative success in some contexts, such as the evaluation of audience interaction with a collaborative interactive music system [19]; evaluation in public art, including planning, preparation and different points of view by different stakeholders [4]; and evaluation in the collaborative creation of a public digital media exhibition [17]. How artists may appropriate, apply and evolve these methods is of high interest of HCI research as well, as it brings novel approaches and different views the HCI community alone could not be able to devise or envision.

Candy's model, for instance, seems aligned with problem clarification methods that already inhabit HCI research for quite some time. As an example, Organisational Semiotics' Problem Articulation Methods (PAM), commonly used within Baranauskas' Socially Aware Computing (SAC) approach [11], similarly makes use of specific artifacts to elucidate problems. With proper epistemological and methodological considerations, an articulation of these two approaches may yield novel insights into projects with or without artistic intent. This line of inquiry, however, may also lead to a possible conflict between the traditional individualism of the creative process in art against the participatory nature of the SAC approach, *i.e.*, authorship *vs.* co-authorship.

Costello and Edmonds' pleasure framework, in turn, could benefit from the Pleasure, Arousal, Dominance (PAD) emotional state model used in HCI practices. The pleasure framework's categories seem to be associated with the pleasure dimension in the PAD model; it also seems to encompass the arousal dimension, as the authors argue that some aspects of arousal act as modifying variables to the categories. This alignment with the PAD model may, perhaps, allow the use of well-established evaluation instruments alongside the framework, such as the SAM [24]. Also, understanding the role of pleasure in interaction design may be an important tool for encouraging engagement, collaboration, and other desired aspects in projects with or without artistic intent. For that, the study of Tan and Ferguson [164] on the role of emotions in art evaluation may also provide further insights. Furthermore, some categories from the pleasure framework may be correlated with aspects already familiar to some HCI researchers. For instance: certain levels of *creation* can be considered to elevate the audience to the status of co-authorship, resembling aspects of Participatory Design; the amount of pleasure from *difficulty* can be analyzed from a perspective that combines the often fragile balance between motivation and ability; *competition* and *sympathy* may both involve and shape cultural aspects and values from the people involved; *sensation* can be explored from a Universal Design perspective; and *simulation* has much potential in the field of virtual reality.

We have already explored Costello and Edmonds' pleasure framework in the contexts of HCI computer science and computer engineering undergraduate and graduate courses [55, 59]. In these courses, we experimented with the approach of inserting art as a context for the discipline's main project. As preliminary results, students expanded their understanding of art and HCI and explored novel forms of interaction by creating projects around the concept of Interactive Art or installations. Students were also able to make sense of Costello and Edmonds' pleasure framework while they used it to evaluate projects from colleagues in a peer review manner and to inform the design of their projects. To further report these case studies is beyond the scope of this article, but it shows both applicability of the framework and how the classroom may be a useful medium to promote the articulation of art and science, reaching not only the HCI community but perhaps widely and openly Computer Science itself.

Lastly, we did not find in the literature efforts in Interactive Art design and evaluation that emphasize accessibility or Universal Design. This seems to be a missed opportunity as Interactive Art has an excellent potential for multisensory approaches (*i.e.*, unlike a painting or a sculpture you are not allowed to touch, Interactive Art can be designed to not rely too heavily on sight by, for instance, also promoting other senses such as touch and hearing.) Some of the projects we designed and built with undergraduate and graduate HCI students already have higher attention to accessibility, but this remains an open opportunity for research. Furthermore, another possible direction to explore the subject of evaluation at the intersection between art and HCI is to revisit the practices of art critique and curatorship, which are usually not conducted by the artist itself, from an HCI perspective.

2.5.1 Towards a Research Agenda

Informed by what we presented and discussed so far in this article, we consider the following recommendations as essential steps towards articulating art and science in HCI through the concept of Interactive Art:

Encourage Interactive Art Research

There seems to be a steady increase in publications relative to the intersection between Interactive Art and HCI. However, there will always be numerous unexplored possibilities, and the potential mutual benefit for art and science seems to be a motivation to encourage further research on the subject. HCI communities could benefit from being open to works that permeate this frontier between the fields. Even though this could incur in some controversies regarding what is a valid scientific contribution in HCI (from conflicting ontological perspectives to different forms of rhetoric), these discussions could play an important role in contributing to the maturity of communities and openness to new ideas.

Study Interactive Art Examples

There are many Interactive Art approaches to be found in scientific literature and other sources from digital games to online communities, and this article only scratches the surface in this regard. Sometimes these artworks are not even intentionally designed as or named Interactive Art by their authors, but the lack of artistic intent does not prevent them from being perceived as art. Nevertheless, Interactive Art examples can provide useful insights that can inform the design of digital artifacts with or without artistic intent. Our examples of Interactive Art, for instance, show a varied collection of interaction approaches and desired qualities for interactive systems that, with proper study, may also be achieved to some degree in non-artistic contexts. The embodied ways in which we can interact with art, for instance, can be applied to the design of IoT systems for smart homes and other environments that go beyond a dashboard controlled from a smartphone, detecting and responding to our physical presence and actions.

Practice Interactive Art Design and Evaluation

Theory on Interactive Art cannot be considered complete without practice, and it is the very practice of Interactive Art that resonates well with the field of HCI, providing a mutual benefit relationship. Furthermore, Cressey [44] argues that we are entering the "age of the arduino", supported by data on how such devices are transforming science regarding automation and data collection. Besides their low cost, these devices are relatively simple, allowing its use by people without expertise on the subject, *i.e.*, there is no need to be an engineer or a computer scientist to use them successfully. Therefore, Arduino boards and the Raspberry Pi can serve as an inexpensive technical playground for people to explore interactive possibilities, whether they may be called Interactive Art or not. By exploring these technologies with a playful attitude, one can emerge significant learning experience and useful insights that could otherwise not be attained. Evaluation, in turn, complements the practice of Interactive Art with direct contributions to both Interactive

Art practitioners and HCI researchers, serving as a common ground between the fields. The extensive evaluation knowledge from HCI can be borrowed, employed and deconstructed by interactive artists, which in turn can contribute to unconventional insights and approaches to evaluation. One possible way to foster the practice of Interactive Art design and evaluation is to conduct design projects about the subject in undergraduate and graduate HCI classes, such as the InterArt [55] and InstInt [59] projects we have already conducted and reported on.

Design Interactive Art for All

People should be able to experience Interactive Art regardless of their age, size, ability or disability. The open-ended nature of Interactive Art can be explored to push the boundaries of our understanding of accessibility and universal design both in terms of social critique, as well as in making use of multisensory approaches with different technologies of sensors and actuators. Tactile and sound feedback, for instance, can be used to not only complement visual features but also to open entirely new ways and possibilities to experience Interactive Art artifacts altogether, artifacts, in turn, that can be experienced to the greatest extent possible of people. The design of Interactive Art for all can be approached both from “bottom-up” or “top-down” perspectives: you can make universal design a goal from the start, and conduct every design activity with universal access in mind, or, by exploring current technologies and prototypes, you may obtain insights about how these can be used to allow people with some limitation or disability to have a better experience.

2.6 Conclusion

The articulation of art and science can be an important source of innovation in the domain of interactive systems, and HCI can have a mutual benefit relationship with art through Interactive Art. Looking back at our first research question, Interactive Art can be considered a source of innovation regarding unconventional forms of interacting with a computer. We highlighted four distinct interaction approaches found in Interactive Art in the literature and other sources. These have stressed virtual, embodied, tangible and social forms of interaction, and are illustrated with examples that contain useful qualities that may also be desired in computational systems without artistic intent.

For our second research question, evaluation can be used as a common ground between HCI and Interactive Art researchers and practitioners. There are useful frameworks in the literature to support the design and evaluation of Interactive Art, such as Candy’s and Costello and Edmonds’. Although it is plausible that these could also be used in other contexts without artistic intent, there is still room for studies mixing them to some HCI practiced methods. Participatory approaches also provide unique ways of designing Interactive Art, providing a different perspective on the participatory design itself. It is noticeable how the potential issues raised by a combination of theory and practice on both art and technology design can have on reflection about political and social issues related to our being in the contemporary society.

The discussion on the results of the research questions addressed in this work leads to encouraging Interactive Art research, studying Interactive Art examples, practicing Interactive Art design and evaluation, and designing Interactive Art for all, as essential starting points in a research agenda.

Ongoing work involves the articulation of art and science in HCI by following the research agenda we outlined. More specifically, we are conducting work on the design of Interactive Art in a socially aware manner [11], and with a coupled relation between body and environment as described in the Enactive approach by Varela, Rosch and Thompson [168]. We expect this articulation to lead us towards the conception of what we may call socioenactive Interactive Art.

Chapter 3

InterArt: A Constructionist Approach to Learning Human-Computer Interaction

3.1 Introduction

Technological advances such as personal mobile devices, artificial intelligence, and IoT devices are substantially changing what we understand as a computer, as well as how we interact with it. When it comes to the field of HCI, technological advances also bring to researchers and practitioners the inevitable challenge of staying updated. The field of HCI, especially HCI education, has no option but to evolve alongside the changes in the technological landscape, infrastructure and the expanding capacities and contexts of technology use [97, 35, 95]. The power and impact of designers (to which we include interaction designers, user experience designers and other professional designations under the encompassing term of HCI practitioners) in our contemporary world is undeniable [166]. This profound and ever-expanding role that HCI practitioners are playing in our society raises the importance of formally discussing how these professionals may learn their craft.

Regarding formal discussion and practical approaches to HCI education in the literature, True *et al.* [166] argue that even though there are numerous approaches across existing programs worldwide, the inner workings of these programs are rarely discussed outside their own institutions. Grandhi [95], in turn, argues that most discussions regarding HCI pedagogy are informal and done through social networks or in conferences. To make things even more complicated, there is also no consensus in the literature about what topics constitutes the field of HCI to begin with. In 1992, when attempting to establish a curriculum, Hewett *et al.* stated that "There is currently no agreed-upon definition of the range of topics which form the area of human-computer interaction" [103]. Even though the field has considerably evolved and matured in the following decades, in Churchill *et al.*'s survey [35], the authors conclude that Hewett *et al.*'s observation was still valid in 2013. We find it plausible that this observation will remain valid indefinitely. To be clear, this is not necessarily a flaw in HCI education, but likely a sign of the diversity of thought in the field, as well as a response to the need of adapting HCI education to different socio-technical contexts, further highlighting the need to report and formally discuss these approaches.

Besides the lack of detailed reports and an agreed-upon definition of the encompassed topics of the field, it is a grand challenge for an HCI educator to constantly stay updated and properly prepare students to cope with the state-of-the-art technology, a vast amount of interaction possibilities, and an ever-growing collection of sociotechnical challenges. Furthermore, it is an even greater challenge to prepare a future generation of HCI researchers and practitioners for possibilities and implications that yet do not exist, cannot be precisely predicted, but will certainly happen at some point. It is our understanding that to better prepare HCI students to cope with current technologies, while also trying to prepare them for forthcoming technological advances, (1) students should be encouraged to creatively engage and tinker with novel tools and computational technologies, such as Arduinos and similar electronics gadgets, artificial intelligence Application Programming Interfaces (APIs), and IoT devices. Furthermore, following the well-accepted notion that HCI research and practice is no longer limited to well-defined and/or workplace problems [21, 99, 151, 22], (2) students should be encouraged to design for more elusive, open-ended scenarios. Building upon these educational challenges, as well as points (1) and (2), we devise our general and specific research questions:

> **General research question**: Can HCI students be prepared not only for current design problems, but also for those that will be faced in the next 5, 10 or 20 years?

> **Specific research question**: Can students learn HCI through a constructionist approach by exploring emergent technologies, such as Arduino and other devices, in the design of open-ended scenarios, such as the creation of interactive artworks?

In this article, we address a constructionist approach to the learning of HCI by promoting an articulation between art and science. Besides studying and practicing what can be considered traditional topics within the field, Computer Science and Computer Engineering undergraduate students also explored tools and technologies from the maker culture to approach an open-ended design problem presented to them: to design, implement and evaluate an interactive art project. Our primary objective was to engage our students by providing an HCI course that was challenging (the students had to step out of their comfort zones), and self-oriented (the students had the freedom to decide what to pursue and choose something meaningful to them). Taking advantage of the fact that HCI courses in Brazil are often offered within Computer Science or Computer Engineering programs, our approach also articulated several computing abilities beyond the traditional scope of HCI that were collaterally practiced during the semester, such as programming, electronic circuit making, and physical construction of artifacts. As results, we analyzed data collected throughout the course (*e.g.*, student feedback and the content of turned in assignments), as well as the resulting interactive artworks created by the students. We believe that our constructionist approach may lead to more versatile and open-minded

HCI practitioners, which in turn are better prepared to cope with novel technologies and emerging forms of interaction.

The article is structured as follows: in Section 3.2 we present our theoretical background and some related work; in Section 3.3 we present the InterArt case study and its activities; in Section 3.4 we report our results from data collected throughout the course, including descriptions of the created interactive artworks; in Section 3.5 we discuss our results and main findings; and in Section 3.6 we present conclusions and directions for future work.

3.2 Background

The learning theory that underlies our study is the one developed by Seymour Papert in the early 1980s, now widely known as constructionism [141]. It may be tempting to describe the constructionist approach with short, catchy expressions such as "learning-by-making", or "project-based-learning". While these short expressions are not exactly wrong about important aspects of the approach, Papert and Harel [142] argue that constructionism can be much richer and more multifaceted, and also have much deeper implications than what can be conveyed by such expressions. Even the use of definitions is avoided when the goal is to convey the concept of constructionism, as the authors further argue: "[...] it would be particularly oxymoronic to convey the idea of constructionism through a definition since, after all, constructionism boils down to demanding that everything be understood by being constructed" [142].

Therefore, even though we cannot convey Papert's constructionism with simple expressions and formal definitions, it is our understanding that it encompasses at least two fundamental ideas [12]: First, it views the relationship between teaching and learning not as a transmission of knowledge from the professor to the student (described as an instructionist approach), but rather as a form of individual reconstruction, in which the learner is supported by the teacher in the effort of actively building his/her own knowledge structures. Second, there is an understanding that learning is most effective when the learner has the opportunity to experience the construction of an artifact that is somehow meaningful to him/her, and this construction process includes having the freedom to make his/her own decisions about what to construct and how. In a general sense, in the constructionist approach learners are not expected to achieve the same results (*e.g.*, finding the correct solution to a proposed problem). Instead, each learner can be viewed as an independent "*bricoleur*", someone with his/her inventiveness, constantly building their own knowledge as s/he explores and constructs artifacts of his/her interest.

In academic literature, constructionism is often associated with learning approaches for children, perhaps due to Papert's emphasis on childhood and his studies with children and computers. However, we have no reason to believe that the constructionist approach could not also be effectively explored with adults and in higher education. This is the focus of our study, to provide a constructionist environment to the learning of HCI at the undergraduate level, more specifically with Computer Science and Computer Engineering students. There are studies reporting HCI educational approaches with the intention of constructing things and going beyond software displayed in a computer screen (*e.g.*, [94, 163]). However, these reports do not focus on the underlying learning approach. Therefore, in the next subsection, we present a brief survey of works that explicitly use a constructionist approach with undergraduate Computer Science and Computer Engineering students, although without exhausting the subject.

3.2.1 Related Work

Regarding the explicit use of constructionist approaches to the teaching of Computer Science, the work of Korte *et al.* [118], with first-year Computer Science and Computer Engineering students, report a game-building method for teaching modeling skills in theoretical Computer Science. Even though the subject (finite-state and Turing machines) is initially abstract and theoretical, it obtains new meaning through a direct mapping between the games that the students are building and the models that they are trying to master. The authors argue that besides the benefit of learning by doing a practical task, which may help in understanding a hard to grasp content such as theoretical Computer Science, a significant element of customization and choice present in the assignment has the potential to increase both motivation and performance among students.

The work of Apiola *et al.* [7], in turn, describe a teaching experiment with LEGO Mindstorms robots for intermediate-level Computer Science students. With a focus on supporting creativity and intrinsic motivation among students, the learning objectives of the classes were not strict, in fact the students took part in defining those objectives by imagining and designing "future" uses for robots. The open-endedness of the objectives allowed the creation of playful projects, such as a tic-tac-toe playing robot, or a "guard" robot that shoots rubber bands. The authors argue that the robots were a powerful trigger of an initial curiosity and motivation in students, and even though the students faced a significant amount of technical challenges, they were able to self-direct the project while they creatively practiced computing skills.

Another explicit use of a constructionist approach to the teaching of Computer Science, but more specifically for the teaching of HCI within Computer Science, the work of Khoo [114] is concerned with learning user interface design. The author argues that traditional class lectures (*i.e.*, with textbooks, handouts, transparencies, and assignments) have the major limitation that students are often unable to "experience" user interface design. The author advocates for a constructionist approach to the learning of user interface design by letting students "do" or "construct" user interfaces with the use of HTML to better understand the subject. It is argued by the author that this was an effective approach for user interface design pedagogy.

The work of Nielsen and Majgaard [137], in turn, is concerned with merging interactive design processes and the development of interactive prototypes for first-semester software and information technology engineering students without prior programming experience. The authors make use of constructionism-inspired programming tools, most notably MIT's App Inventor, to support the students in the development of touch-based learning apps for children. The design process included specifying requirements, conceptual design, physical and interactive prototyping, and user evaluation. The authors argue that this approach allowed the students to have a "real-life experience", and even though the students did not have previous programming experience, the constructionism-inspired programming tools allowed them to create relatively complex applications with, to name a few examples, animations and sound, database connection, and with the use of integrated sensors in smartphones, such as the camera or an accelerometer. The use of "scaffolding" programming tools to create smartphone apps is also the subject of the work of Reardon and Tangney [149], even though the focus is on learning programming instead of interaction design.

Considering that interaction is no longer limited by classic peripherals (*e.g.*, touch-screen, mouse, and keyboard), it is our understanding that teaching/learning HCI and interface design should go beyond the classical projects with focus on the design of GUIs, and even beyond the conventional notion of the computer. There are a few studies in the literature that report the use of robots and other tangible or pervasive computational technologies in a Computer Science or Computer Engineering context of learning programming and related theoretical concepts, sometimes even with some relatively open-ended design problems. However, to the best of our knowledge, there is no reported use of an explicit constructionist approach to the learning of HCI through the open-ended theme of making interactive artworks. This distinction becomes especially more significant when we consider that our approach includes not only creating a conceptual design, fictional product or mock-up but actually going past this abstract stage and actually building and programming functional physical artifacts.

3.3 The InterArt Case Study

Our study was conducted in an HCI undergraduate course in the first semester of 2017, ministered by a professor and an intern teacher (second and first authors, respectively). A total of 55 Computer Engineering and Computer Science students from Unicamp, Brazil participated. As a first action, the students organized themselves in 9 teams of 6 or 7 members for the group activities to be conducted during the semester. Regarding the methodology, besides our general constructionist approach to teaching/learning, we adopted a sociotechnical perspective to the design of interactive systems, making use of inclusive and participatory practices [11, 127, 154]. Regarding the specific topics, the syllabus was based on Preece *et al.* [111], and Rocha and Baranauskas [150], and the students were proposed with pre-class "warm-up" activities between classes. The course program included:

1. History and evolution of the field of HCI;
2. Human factors in HCI (*e.g.*, perception, memory);
3. HCI paradigms and respective design and evaluation methods;
4. Introduction to Semiotics and Organisational Semiotics;
5. Accessibility and Universal Design theory and practice;

6. User Interface (UI) design tools and environments; and

7. Selected subjects (*e.g.*, IoT interaction design, cultural aspects).

Students were evaluated with two tests and two hands-on projects developed in groups and conducted in the classroom as the topics were presented along the semester. The first project was a more traditional approach to an HCI problem: students were asked to redesign, in the form of a mobile app, their university's current web app for managing classes, grades, and other academic matters. This first project included classic HCI techniques and methods that the students would likely apply in the industry right now, such as the creation of personas, heuristic evaluation, and paper and digital prototyping. The second hands-on project, however, is the one we will focus on in this article. The second project was entitled InterArt, and students were asked to design and build from scratch an original interactive artwork.

The articulation of art and science has been an important source of innovation and ground-breaking contributions in many fields throughout history [174]. Considering John Lasseter's quote that "[...] art challenges technology, and technology inspires art" [122], we take the perspective that there is a two-way path of influences between art and science, and articulation can be beneficial for both sides. In HCI, art and science may be articulated through the overlapping concept of interactive art [135, 70, 75, 56]. It is important to emphasize that we opted to not adhere to any precise or definitive definition of what is interactive art, as it would require equally precise definitions of what is both art and interaction, and every attempt to do so will always be subject of debate [2, 104]. For the practical purposes of this article, we consider interactive art to be broadly any form of artifact enhanced with any kind of computer-based interactivity. The creation of interactive artworks, in turn, brings us a fortunate consequence: it also represents an opportunity to explore novel technologies and interaction possibilities that could otherwise be overlooked in more traditional design problems. Concerning the importance of exploring novel technologies and materials, Löwgren [129] emphasizes the importance of the maker culture in interaction design research. According to the author, it can support the exploratory design of what he refers to as non-idiomatic interaction, a kind of interaction that is not yet inside the "established idiom", *i.e.*, not yet broadly known or understood. Posch [147], in turn, discusses how our tools, that we often take for granted, have the potential to shape our interaction with any kind of technology in a making process, and how we may appropriate our tools in new ways by reflecting and experimenting with them. Therefore, in this study, we opted to employ technologies and tools often associated with the maker culture phenomenon.

Before formally presenting the InterArt proposal, whenever possible, we articulated the course's content with the InterArt design context. Some of the proposed warm-ups and in-class activities allowed students to discuss aspects that might intersect with art, such as perception, and to form their own definitions of interactive art instead of adhering to an arbitrary one. In the following subsections, we list all the activities that were somehow connected to the InterArt project.

3.3.1 Introductory Questionnaire

The first warm-up activity was a questionnaire aimed at better knowing the students and their motivations, which would help us in tailoring the course to be more engaging and aligned with their interests. We asked open questions about their motivations for choosing Computer Science or Computer Engineering, and things they like and dislike in it. The last question, however, was our first approach towards the subject of art: we asked the students to "Indicate an artist or artwork that you admire." In the following week, when the teams for group activities were formed, the students named their teams after an artist or artwork of their liking.

3.3.2 Perception Warm-up

As a warm-up activity for a class on the topic of human perception, students were asked to openly state what they "perceive" in a picture of Lygia Pape's *Divisor* (1968). Without their knowledge, the class was randomly divided into two groups for this assignment: the first group answered without having access to the responses of colleagues, while the second group had access to previous responses from colleagues in the same group. The design of the warm-up, which is illustrated in Figure 3.1, was intended to discuss with students that perception is not only a physiological phenomenon but also a socially informed one.

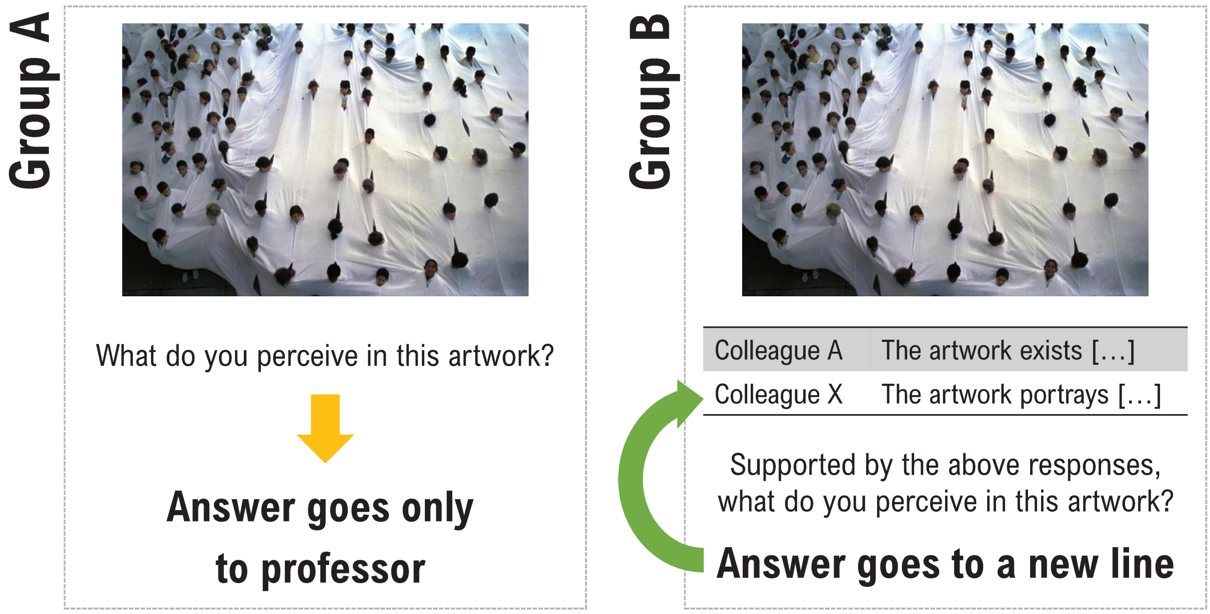


Figure 3.1: Illustration of the design of the perception warm-up.

3.3.3 Forming a Concept of Interactive Art

After a brief introduction about the theme of the InterArt project, we tasked students with researching the subject and coming up with an initial concept of what they understood as interactive art. Each team presented their initial concept in 10-minute seminars, including at least one illustrative example and describing their research process. After the class, we asked in an online form: “Did watching your colleague’s presentations somehow aggregate or modified your initial concept of interactive art? Please justify your answer.” Following our constructionist stance, instead of imposing some arbitrary definition, our objective was to have students construct their own understanding of the subject and to expand their understanding by sharing it with each other.

3.3.4 Ideation Techniques

We proposed three ideation techniques to help teams come up with ideas for interactive artworks. The first technique, called “challenging existing assumptions”, was adapted from Michalko [133, p. 43–52]. In this first technique, the students listed preconceived ideas related to the project and then proceeded to challenge these ideas, promoting unconventional thinking patterns. The second technique was a brainwriting session [167], in which the team selected their favorite existing assumptions from the previous activity and collaboratively wrote a proposal on how to make the reversal of that assumption come true. The third technique, called “translating sensory experiences”, is based on the reported influence of sensory experiences on creativity [177], and consists of listing non-visual sensory elements and trying to give them a visual representation. This third technique could not be conducted in class due to time constraints but was still presented to the students so that they could conduct it outside the classroom if they wanted to.

3.3.5 Requirements Formalization

As a next step towards creating their interactive artwork, students were asked to write formal requirements for their projects. To support this activity, students made use of the Semiotic Framework [127, p. 26–35]. The Semiotic Framework can be described as a “ladder” with six “steps” (which is the reason it is sometimes referred to as Semiotic Ladder): (1) physical world; (2) empiric; (3) syntactic; (4) semantic; (5) pragmatic; and (6) social world. Unlike functional and non-functional, each step of the Semiotic Framework reveals different levels of requirements that are necessary for any system to be made and used, from the very physical components that make up a computational system in the physical world, to aspects of human relations in the social world. To help clarify the more technical levels of requirements, before this activity with the Semiotic Framework we had already conducted a hands-on exploration of the two examples of interactive artworks “Interactive Mondrian” and Emojic Mirror [61]. This exploration led to a discussion about the inner workings of these examples and brought up relevant topics such as emotion recognition APIs, sensors, actuators, microcontrollers, and connectivity, giving the teams an early idea about possible technical requirements that could be raised in the Semiotic Framework.

After using the Semiotic Framework to formalize requirements, the students also created a diagram that we named “communicational map”. Because we encouraged students to go beyond computer screens and mouse & keyboard, in this diagram they were asked to represent both the physical and the virtual components mentioned in the Semiotic Ladder, as well as the involved human actors. Furthermore, the diagram also illustrates how these components may communicate with each other by highlighting what are the paths in which information travels, and what kind of information travels through each path. For instance, a vibration sensor may be triggered by shaking the sensor hidden inside an object; this information reaches a microcontroller through wires; the microcontroller uses Wi-Fi to broadcast the information, a web page is notified of the new value for the vibration variable and updates a visual element accordingly.

3.3.6 Hands-on Workshop with an Electronics Kit

Considering our constructionist stance to learning HCI and the current directions of the HCI field, it is clear to us that only building digital user interfaces (no matter the technology involved) is not sufficient. Therefore, to support a hands-on attitude and encourage novel forms of interaction, we provided each team with a custom-made Arduino-compatible electronics kit (we kept in mind the growing interest, low cost and easy to learn curve of these devices [44]). The kit, properly presented with a set of slides to which we will refer to as "kit slides", was composed of:

- Hardware platform: NodeMCU 1.0 (Arduino-compatible, with built-in Wi-Fi);
- Sensors: temperature & humidity (DHT11), Light-Dependent Resistor (LDR), sound (KY-038), reflexive obstacle (FC-51), vibration (SW-420), and push buttons with colorful covers;
- Actuators: assorted single-color Light Emitting Diodes (LEDs), Red, Green, Blue (RGB) LEDs, and a buzzer; and
- Other components: organizer box, breadboard, jumper wires, and resistors.

The kit was accompanied by custom documentation on every component (made public at a later moment under the name Pincello[1]), to which we will refer to as "Examples of Circuits and Codes", and by an original illustrative tutorial on how to send information from the microcontroller to a remote HTML page and *vice versa*, called "Interactive Mona Lisa". In the example from the tutorial, an LED could be turned on or off from a web page, and a virtual representation of the Mona Lisa from Leonardo da Vinci shook when the vibration sensor was shaken. Students had an entire 2-hour class dedicated to exploring the kit, following the tutorial and asking any questions that might arise in the process. The students were able to keep the kit in their possession until the end of the semester, and they were not even required to use it if they did not want to, as long as they somehow created an experience that went beyond the computer screen. After the hands-on workshop, there were two more 2-hour classes dedicated to using the electronics kit or any other tools the students wanted to, but this time exclusively for prototyping the interactive artwork the teams had been designing up to that moment.

[1] `https://efduarte.github.io/pincello/`

3.3.7 Peer Review Evaluation

After the teams finished a functional prototype, we conducted a session of peer review. The students set up their prototypes inside the classroom simulating an exhibition, and, circularly, each team experimented with and evaluated the prototype of the next team in the alphabetical order. This activity is illustrated in Figure 3.2. To support the evaluation, the students used Costello and Edmond's Pleasure Framework [42]. We opted for this framework instead of more classical HCI evaluation methods because of the nature of the project: in our context, analyzing aspects of playful interaction could yield more meaningful and helpful results than a traditional usability test. We complemented the Pleasure Framework with a part of the SAM [24] in the following manner: for each of the thirteen categories of the Pleasure Framework, we inserted a 5-point Likert scale with the pleasure dimension from the SAM, and after choosing a point in the scale, the evaluators had to justify their answers in writing. Afterward, the teams gathered the results of the peer review and used this feedback to further improve their interactive art prototypes. Besides helping students to finish their projects on time and improving it for the final presentation, this activity was also designed to encourage interaction between groups, allowing the students to experiment with each other's works.

Figure 3.2: Peer review evaluation.

3.3.8 Final Presentation & Feedback Questionnaire

At the end of the semester, each team presented their project in a 10-minute, free format presentation, followed by a live demonstration of their interactive artwork. Later, after the course was over and all the grades were assigned, we sent to the students an online form containing some questions about their experience during the semester. Among other questions, we asked: "Considering the experiences and activities conducted in this course, did your perception of what can be art, technology and HCI change during the semester? Please justify your answer." We also asked students to individually evaluate the tools and methods employed in the project, including the electronics kit. Because the semester was already over, the filling of this questionnaire was entirely optional. Lastly, the students had the option to fill it anonymously if they wanted to.

3.4 Results

Our main results are organized into three categories. First, we present the 9 teams and their interactive artworks; then, we present results obtained from the perception and interactive art concept warm-up activities; finally, we present responses from both the introductory questionnaire and the course feedback questionnaire, highlighting student's reported experience and acceptance of the employed methods and artifacts. Quotes from participants are numbered only for reference within this article and are a free translation from Brazilian Portuguese.

3.4.1 Teams & Interactive Artworks

The InterArt project had 9 teams, and each team co-designed an original interactive artwork from scratch through the proposed design process. The teams are presented in alphabetical order in the following subsections, along with a description of their final artifact and its main features.

500cc

The team name (to be read as *cinquecento*, Italian for the number 500), was chosen after the cultural and artistic events of Italy during the period between 1500 and 1599, which encompasses the period known as the Italian Renaissance. This team's interactive artwork was a sensory dancing platform that captures body movements and translates them to a digital drawing of the dancing. The audience can freely dance to a song on a wooden platform with speakers that vibrate according to the music. The drawing happens as the dancing is captured by a Microsoft Kinect connected to a computer (this is the only team that opted for not using the electronics kit, instead opting for the use of a Microsoft Kinect owned by one of the team members). The computer then projects an abstract painting being dynamically generated by capturing the body movements of anyone dancing over the platform.

Anyone interested in experimenting with the artwork is given the option of wearing a blindfold or noise-canceling headphones while dancing. It was the author's intention to raise awareness and create empathy about physical disabilities, while also highlighting the accessibility of their artifact by showing how people with disabilities are also able to enjoy the interactive artwork (*e.g.*, a deaf person can still feel the music through vibrations on the wooden platform and enjoy the dynamic drawing being generated). Furthermore, the projected dynamic drawing also has noticeable benefits for people that are shy about dancing: it draws the attention away from the person dancing and into the projection, and it does not matter how good or bad a dancer you are, the dynamic abstract drawing tends to always be visually interesting while it takes shape in real-time.

Autorretrato

The team name (Brazilian Portuguese for self-portrait) was chosen after the category of artworks in which an artist portrays him/herself. This team's interactive artwork was a dynamic display of self-portraits based on physiological measurements. There is a curated selection of 16 self-portraits, categorized according to brightness, color temperature, and perception of movement. The interaction occurs as a set of vibration, heart rate and temperature sensors collect data from someone interacting with the artwork, and this collected data is used to either modify a self-portrait currently displayed (*e.g.*, making it warmer and brighter), or to bring up another self-portrait more aligned with the inferred emotional state of the person interacting.

Analogous to the work of Kaipainen *et al.* [112] on Enactive Systems and Enactive Media, this interactive artwork aims at creating a coupling between body and computer through the reading of physiological signals, resulting in a computational system that responds not to deliberate inputs, but to our very physical being in the world. As we do not have fine control over our heart rate (or any control at all in some situations), there is no direct or conscious control over which self-portrait will be displayed, or how will it be modified. Instead, the system chooses the self-portrait and visual modifications more aligned with the inferred emotional state of the person interacting with the artwork, resulting in a coupling between person and machine.

Gabe Newell

The team name was chosen after the BAFTA Fellowship Award-winning game developer Gabe Newell, known for *Half-Life* (1998) and other popular games and achievements in the video game industry. This teams' interactive artwork was a "non-game" exploring the concept of loneliness. Based on the *Loneliness* non-game by Jordan Magnuson, the audience uses gestures in the air (*e.g.*, waving your hand to the right, left, top or bottom of an optical sensor) to control a virtual character that tries to approach new friends, but inevitably repels every other non-playable character. This interaction is supposed to lead us to a feeling of loneliness, and while the feeling of loneliness increases, it is accompanied by the gospel blues song *Dark Was the Night, Cold Was the Ground* (1927–1928) performed by Blind Willie Johnson.

Besides explicitly approaching the subject of loneliness and the difficulties of making friends and fitting in, a relevant problem faced by many people of different ages and in different contexts, the use of a gesture sensor further highlights the loneliness feeling as all the interaction occurs without physical contact. The ultimate intention of the authors, however, is not to make people feel lonely or sad, but to evoke these feelings to raise awareness about how serious of an issue this can be for some people. Furthermore, people that are going through a similar situation of loneliness may perceive that they are not entirely alone, as the artwork acknowledges them.

Guns

The team name was chosen after the hard rock band Guns N' Roses. This team's interactive artwork was a digital musical instrument for composing melodies without the need of knowing how to play any musical instrument. With a curated set of rhythms from various instruments, the audience can shake a physical artifact and press buttons on it to select between instruments and change their rhythms. There is also an algorithm that automatically keeps all the instruments in the composition synchronized to ensure a harmonious melody.

This interactive artwork is designed to allow people without musical skills to develop a different relationship with music. Instead of being only a passive listener, one can take an active instance by composing a pleasurable rhythm, all without the need to learn how to play musical instruments or mastering music theory. Even though the creative process is limited to the permutation of the available arrangements, this is sufficient for people who otherwise would never be able to experience the creation of a song. This low entry barrier is particularly appealing for people without musical practice or education, or even people that are not able to play instruments due to motor disability, highlighting an accessibility aspect in the artwork.

Kubrick

The team name was chosen after the Academy Award-winning film director Stanley Kubrick, known for *2001: A Space Odyssey* (1968) and other popular movies. This team's interactive artwork was a miniature monolith to interact with scenes from Kubrick's *2001: A Space Odyssey*. While a psychedelic part of the movie is projected in a loop sequence, the audience can interact with the monolith by picking it up and moving it in the air. Movement is captured by an accelerometer and gyroscope, and used to control the projection accordingly (*e.g.*, speeding or slowing down the playback rate and adding a red filter proportional to the acceleration captured by the accelerometer). This is one of three artifacts from the InterArt project that were selected to be exhibited in a workshop at the Exploratory Science Museum of Unicamp [62]. Figure 3.3 illustrates the hardware inside the monolith and the artwork exhibited with a 360° projector at the museum.

Because the control of the projection is subtle, it is not trivial to distinguish between an effect caused by moving the monolith and the colorful and abstract transitions of the sequence from the movie. This uncertainty allows the interactive artwork to be mysterious: while it may be clear that something is happening when you interact with the miniature monolith, it is a significant challenge to pinpoint exactly what actions are detected by the system and what kind of response they cause. This cryptic nature and lack of explicit answers and explanations from the artwork is aligned with the approach taken by the director Stanley Kubrick on *2001: A Space Odyssey*, and it allows the interaction to be intriguing, exploratory, and playful.

(a) Monolith hardware. (b) Interactive artwork exhibition.

Figure 3.3: Interactive artwork from the Kubrick team.

Lobisomem Atacando o Galinheiro

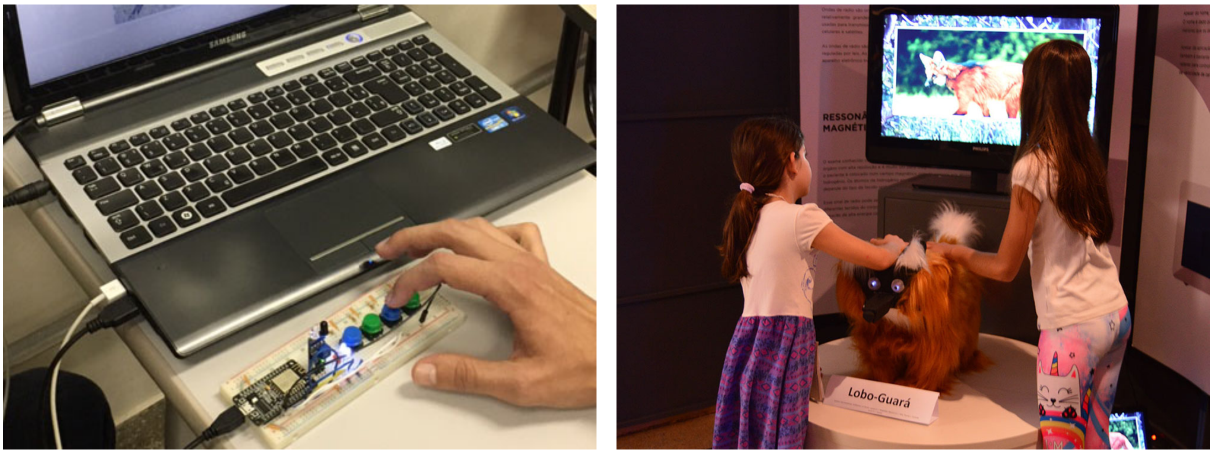
The team name (Brazilian Portuguese for Werewolf Attacking the Chicken Coop) was chosen after the painting with the same name, *Lobisomem Atacando o Galinheiro* (2007), by Brazilian artist Felipe Abranches. This team's interactive artwork was a farm mock-up with sensors to control interactive storytelling involving a chicken coop being attacked by a werewolf. There is a proximity sensor in a chicken, a sound sensor in a tree, and a luminosity sensor. The sensors' activation order determines the sequence of the story being projected, and the story, based on the original painting, addresses the contrast between urban and rural settings and their respective way of life.

By interacting with the mock-up farm in unconventional ways, playing with physical elements based on the original painting, this interactive artwork allows playful non-linear storytelling. To illustrate the details: the proximity sensor in the chickens will make their digital representation flee; the sound sensor in the tree (calibrated to only be activated by blowing on it) will shake the digital trees simulating wind; and turning off the ambient lights (or simply covering the luminosity sensor) will make it nighttime in the story, triggering the appearance of the werewolf. To add significance to the audience choices, the werewolf will behave differently according to previous interactions. For instance, he will be confused if he arrives at the coop but there are no chickens because they had already fled before nighttime.

Lobos-Guará

The team name (Brazilian Portuguese for Maned Wolves) was chosen after the paintings *Lobo-guará I* (2005) and *Lobo-guará II* (2005) also by Brazilian artist Felipe Abranches. This team's interactive artwork was a cardboard maned wolf designed for educational museums. The maned wolf artifact has buttons in important parts (head, body, leg, and tail) that, when pressed, presents relevant information about the wolf both in text and speech. There is also a proximity sensor in its head to detect when someone tries to pet the wolf. When petted, the wolf's eyes become red and he barks, a behavior that is explained by the wolf being a wild and dangerous animal. This is also one of three artifacts from the InterArt project that were selected to be exhibited in a workshop at the Exploratory Science Museum of Unicamp [62]. Figure 3.4 illustrates the hardware prototype and the interactive artwork exhibited at the museum (a layer of synthetic fur was added over the cardboard for this exhibition).

It is common for museums to not allow its public to touch the exhibits. Even though this is an understandable way of protecting and preserving the exhibits, nevertheless it can also be frustrating, especially for children. This interactive artwork goes in the opposite direction by not only allowing but requiring people to touch it. It is through this tactile exploration (that became less obvious and even more interesting after the addition of the synthetic fur for the exhibit) that the interaction occurs, adding a tangible dimension to the educational experience of learning about the maned wolf (which is also an important cultural figure in some regions of Brazil). This tangibility was also intended by the authors to allow the interactive artwork to be accessible, *i.e.*, even though a blind person will not be able to see the visual and textual information projected, it will still be able to hear it while touching the artifact.



(a) Hardware prototype. (b) Interactive artwork exhibition.

Figure 3.4: Interactive artwork from the Lobos-Guará team.

Nychos

The team name was chosen after the urban/graffiti artist and illustrator Nychos, known for his "dissections", "cross-sections", and "x-rays" of animals and other famous pop culture characters. This team's interactive artwork was a reinterpretation of famous Nychos' "dissections" of Darth Vader and Yoda from Star Wars. When the audience reaches out to a proximity sensor, the characters act as if you are trying to use "the force" against them (*e.g.*, Darth Vader shows disdain in your futile attempt), and when a vibration sensor is shaken, an animation of the dissection is played back and forth, giving movement to the previous static works of art.

This interactive artwork gives praise to a specific culture and kind of artwork not initially created for museums, but now often shown in galleries. Considering how the original artist plays with famous pop culture characters by "dissecting" them, this interactive artwork gives a new dimension to this playfulness by giving the audience new ways to interact with these characters, as well as control over the "dissection" that can be played back and forth. It can be argued that, symbolically, the ability to reach your hand towards a proximity sensor to simulate the use of "the force" can also be considered, in a way, a metaphor for technology as a kind of "magical" power.

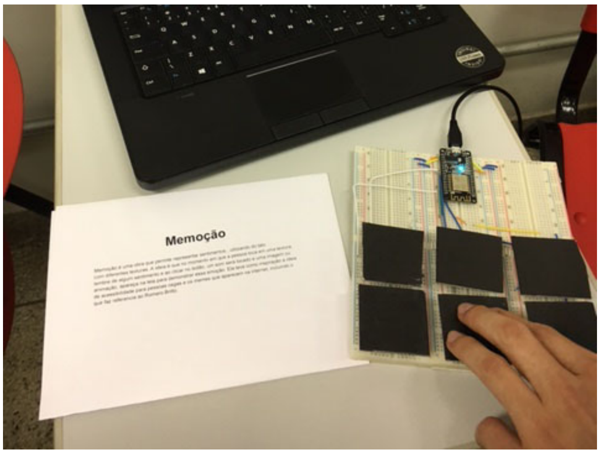
Romero Britto

The team name was chosen after the Brazilian artist Romero Britto, known for his use of vibrant colors and bold patterns. This team's interactive artwork was a sensory black box with textures inside that evoke emotions associated with Internet memes. Inside the box, there are six buttons covered by different textures (*e.g.*, rough, soft, gooey), and when a texture is pressed, a related meme is projected, along with a corresponding sound. For instance, pressing the gooey texture evokes a disgust meme and sound. To keep the experience non-repetitive, the meme and sound are selected randomly from a curated collection of 10 memes and 2 sounds for each of the six emotions. This is also one of three artifacts from the InterArt project that were selected to be exhibited in a workshop at the Exploratory Science Museum of Unicamp [62]. Figure 3.4 illustrates the hardware prototype and the interactive artwork exhibited at the museum.

By making the artifact in the form of a mysterious black box, people are invited to explore the artwork by sticking their hands into the unknown. This "blind" exploration allows what can be considered the main characteristic of the interactive artwork to take the spotlight: multi-sensoriality. As you touch each of the six different textures, you experience a collection of emotions related to those textures reinforced through a combination of touch, image, and sound. The use of Internet memes, in turn, gives a light-hearted (and sometimes even comical) tone to the interaction, even for emotions that are commonly considered negative, such as anger or disgust.

3.4.2 Perception & Interactive Art Concept Warm-ups

For the perception warm-up question that asked what did the students "perceive" in a picture of Lygia Pape's *Divisor* (1968), there were 28 responses from group A (the answer was private) and 24 from group B (the answer was public within the group). We gathered the responses, translated them from Brazilian Portuguese to English, and conducted a brief analysis of the data by looking at the most used words by students in their responses (stop words were not considered, and we grouped words such as "children" and "child" into the singular form). As a result, Figure 3.6 illustrates the top 15 most frequent words in both groups A and B. It is noticeable how the first group's responses had a greater emphasis on literal aspects of the artwork (*e.g.*, child, cloth, head), while second group's responses tended more towards finding conceptual meaning (*e.g.*, individual, people, collective). This different emphasis becomes evident when looking at some of the responses, such as quote Quote 1 from group A and Quote 2 from group B. The results

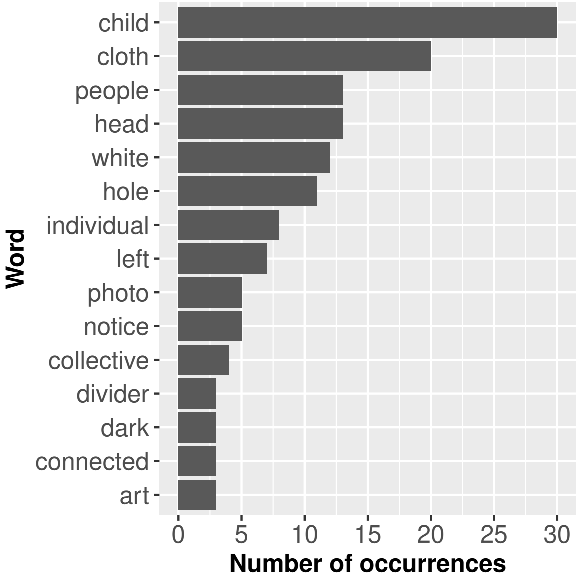


(a) Hardware prototype.

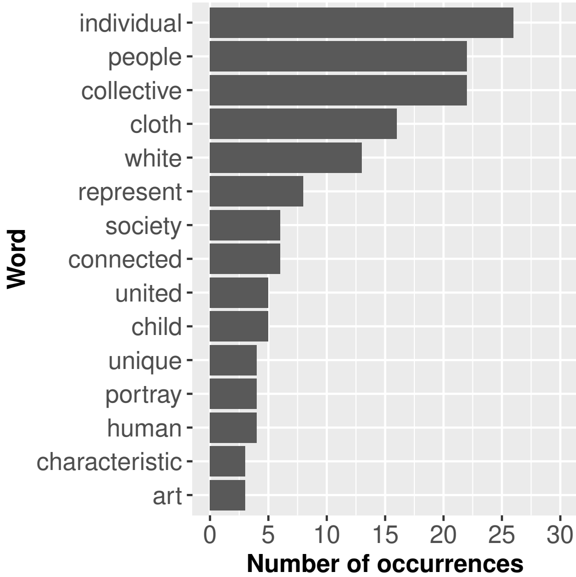
(b) Interactive artwork exhibition.

Figure 3.5: Interactive artwork from the Romero Britto team.

from this warm-up also led to a productive discussion inside the classroom, as it engaged the students on the subject of perception by allowing them to actively participate and construct meaning, instead of simply being lectured about it.



(a) Group A.



(b) Group B.

Figure 3.6: Top 15 most frequent words from the perception warm-up, by group.

Quote 1: "Children in the middle of a large sheet with holes, through which they pass their heads. Most of them are looking forward, but some look at each other." (Group A)

Quote 2: "The work portrays the participation of the individual as part of something greater. In this case, it is a work of art of a neo-creative artist.

However, the analogy can expand to the participation of being in Society." (Group B)

For the task of forming a concept of interactive art of their own, instead of adhering to any arbitrary definition, the teams freely researched the subject and collected a wide range of what they considered to be interactive art examples. The examples brought up by the students varied widely, from unanimous choices such as interactive artworks exhibited in museums, to controversial ones such as a book that invites the readers to systematically destroy parts of it in different ways, or a popular rock band that always invites a random person from the audience to sing the last song of a concert. After the presentations, 46 students answered the follow-up question of "Did watching your colleague's presentations somehow aggregate or modified your initial concept of interactive art? Please justify your answer.". The vast majority (a total of 43 students) agreed that watching their colleague's presentations aggregated to or modified their initial concept of interactive art. When asked to inform what has been aggregated to or modified in their initial concept, most students mentioned the acknowledgment of different perspectives that they had not thought about before, as can be seen in the samples from Quotes 3 to 5.

Quote 3: "Acquiring other perspectives and examples of Interactive Art. For example, taking accessibility into account in art"

Quote 4: "The idea that interactive art is metaphorically a symbiosis between the artwork and the viewer because it exists with his participation."

Quote 5: "I did not consider some types of art as capable of interactivity."

3.4.3 Introductory & Feedback Questionnaires Responses

There were 51 responses to the introductory questionnaire. We will focus our analysis on the last question, that asked the students to "Indicate an artist or artwork that you admire.". The answers were considerably varied among respondents. Some pointed out famous painters, graphic artists or sculptors (*e.g.*, Vincent Van Gogh, Leonardo da Vinci, Claude Monet, Pablo Picasso, M. C. Escher, Michelangelo). Other responses contemplated music (*e.g.*, Ed Sheeran, Raul Seixas, Johann Sebastian Bach, System of a Down), literature (*e.g.*, George R. R. Martin, Carlos Drummond de Andrade) or cinema (*e.g.*, Dennis Villeneuve, Bill Murray). There were also names of people with other trades usually more related to design, such as industrial design (Jonathan Ive) or video game development (Falco Girgis). It is noticeable how the personal tastes of the students ended up being reflected in the themes of the final artifacts, as there were artifacts that explored famous paintings, music composition, storytelling, or video games. This was consistent with the constructionist approach, which demands us to allow the students to pursue something meaningful for them. Three responses, however, stood out and caught our attention, they are presented in Quotes 6 to 8. It is worth noting that the student from Quote 8 had shown interest in digital games in a previous question, a field in which many argue that video games are a form of art.

Quote 6: "none"

Quote 7: "I did not think of any"

Quote 8: "I'm not very attached to art"

For the course feedback questionnaire, in turn, there were only 12 responses. This significant drop in the number of responses can be attributed to the questionnaire being optional and being sent only after the semester was officially over and the final grades were attributed. Although the responses may not be statistically representative of the entire class, they still provide relevant feedback towards the overall experience of the course and the usefulness of methods and artifacts employed during the InterArt project. For instance, for the question "Considering the experiences and activities during the semester, did your perception of what can be Art, Technology and Human-Computer Interaction change?", 9 out of the 12 respondents answered "yes". To further illustrate the answers, Quotes 9 and 10 are two justification examples from students who responded "yes", while Quote 11, in contrast, is from a student who responded "no", even though his response seems out of the topic of the question, instead being more oriented towards his/her design notion expectations for a computer engineer.

Quote 9: "The projects of the other teams showed me the various interpretations of art and made me reflect that there are several kinds of interaction between art, technology and human-computer interaction that I had never stopped to think about."

Quote 10: "I believe that my perception of what can be considered art has improved greatly. At the beginning of the course, the students were asked their favorite artist and I answered none because, at that moment, I did not see that innumerable ways of expressing yourself are great examples of art."

Quote 11: "I think that the way the topics were covered did not help to create the design notion needed for a computer engineer."

Regarding the methods and artifacts used to support the InterArt project along the semester, we provided 14 statements that students had to answer by using a 5-point Likert scale. The scale ranged from "completely" agree to "completely disagree", and students also had to justify their answer. As can be seen in Figure 3.7, 2 questions were referring to ideation, 2 referred to requirements, 5 referred to evaluation and the last 5 referred to the electronics kit. In general, the feedback was mostly positive towards the methods and artifacts used throughout the semester, and the responses are accompanied by qualitative feedback. In the following subsections, we will provide details for the answers for each of these 4 groups of statements.

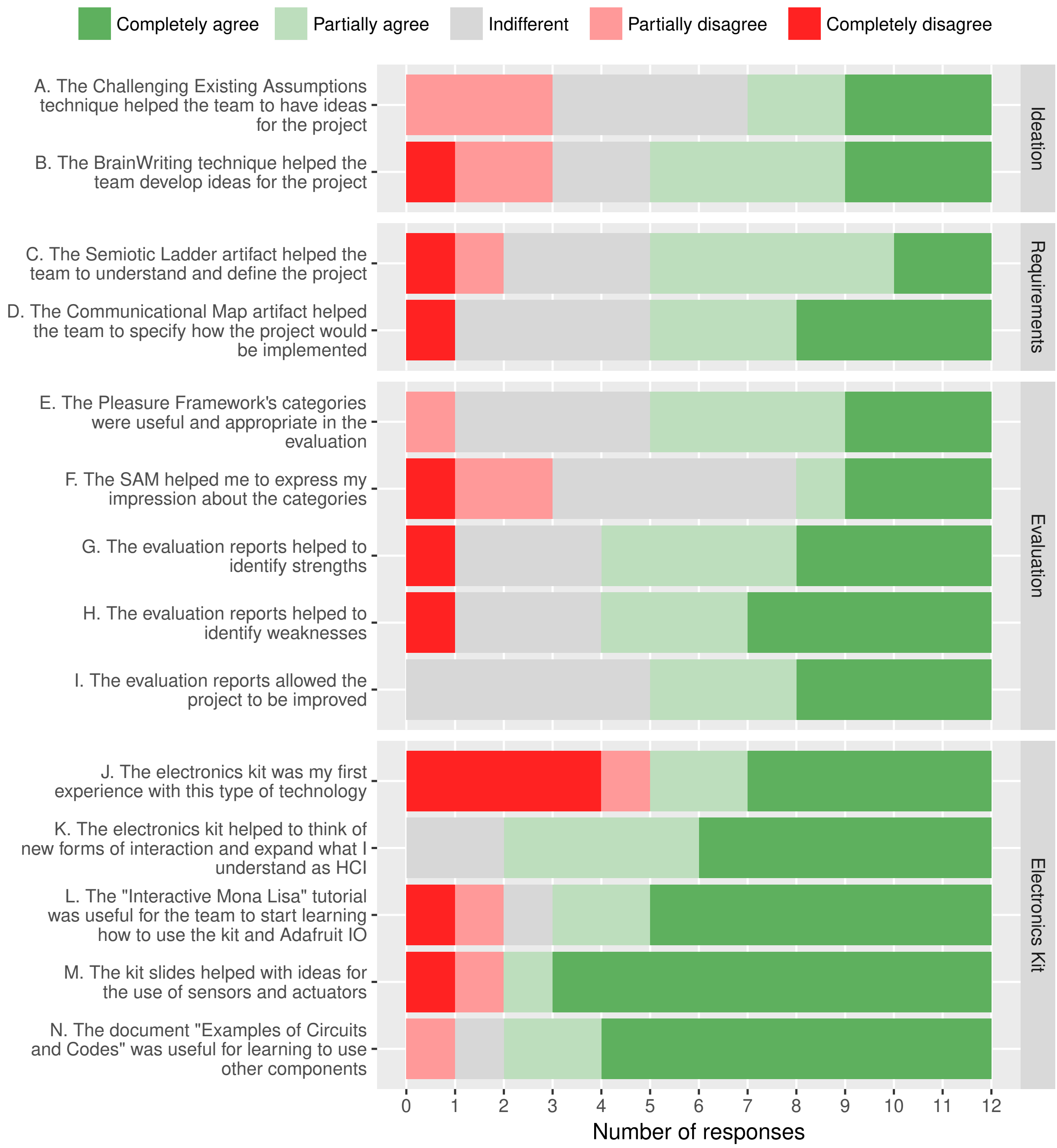


Figure 3.7: Student feedback on the used practices and artifacts.

Feedback for ideation techniques.

For the Challenging Existing Assumptions and BrainWriting techniques, statements A ("The Challenging Existing Assumptions technique helped the team to have ideas for the project") and B ("The BrainWriting technique helped the team develop ideas for the project") in Figure 3.7 respectively, there were mostly positive responses. Quote 12), for instance, highlights how the participatory nature of these activities facilitated engagement within the respondent's team and allowed the emergence of several different options to be pursued in the project. The student from Quote 13, in turn, expresses how the Challenging

Existing Assumptions technique had a major positive role for his team in determining the basic idea of the project. Lastly, to provide a counterpoint, Quote 14 contrasts with the previous two examples with the argument from the student that, in his opinion, the creation of an interface is supposed to be linked primarily with system requirements and client needs, and therefore concludes that the BrainWriting was not a suitable technique because it supposedly led to a polluted design.

> *Quote 12: "In my opinion and personal experience, one of the biggest barriers to team brainstorming is the self-censorship that most participants do. However, in the way the ideation techniques were conducted, for example, a paper for each participant, it was much easier to express the ideas that emerged, allowing the team to generate several different options and choose the best ones to implement/execute."*

> *Quote 13: "The Challenging Existing Assumptions basically guided our work, which had as its frame the creation of accessible and creative zoos (contrary to the idea that a person with visual impairment, for example, would not have much to enjoy in such an environment). The BrainWriting, in turn, only had the function of guiding the challenge of assumptions."*

> *Quote 14: "The BrainWriting has greatly hindered the creation of the application interface. I do not think the technique works for this purpose, the creation of an interface is much more linked to the system requirements and what the client wants, while the technique led to several different styles of good design being superimposed, creating a polluted design. In the end, my team had to redo everything."*

Feedback for requirements artifacts.

Regarding the Semiotic Ladder and Communicational Map artifacts, statements C ("The Semiotic Ladder artifact helped the team to understand and define the project") and D ("The Communicational Map artifact helped the team to specify how the project would be implemented") in Figure 3.7 respectively, most of the responses were positive for both artifacts. In Quote 15, the student argues how the Semiotic Ladder helped him to obtain a more holistic view of the project's components, while in Quote 16, another student reported the Communicational Map's importance in planning the parts of the project. As a counterpoint, the student from Quote 17, argues that, in his opinion, these artifacts may not be of much help if there are already well-defined ideas for the project.

> *Quote 15: "I do not know if my understanding is in accordance with the objectives of the use of the Semiotic Ladder, but the 'climb' from the physical world to the 'meaning' of the presented concepts, organized by the Semiotic Ladder, helped a great deal to understand the role of each component of our project and to communicate the desired message."*

Quote 16: "The map helped plan the parts of the project, improving the way we organized ourselves."

Quote 17: "I believe that, with clear ideas, these artifacts provided little help."

Feedback for evaluation artifacts.

For the Pleasure Framework and SAM artifacts, statements E ("The Pleasure Framework's categories were useful and appropriate in the evaluation") and F ("The SAM helped me to express my impression about the categories") in Figure 3.7 respectively, the former had mostly positive responses, while the latter had a mixed feedback. Furthermore, the majority of the students agreed that the evaluation reports helped in identifying strengths (statement G), weaknesses (statement H) and allowed the project to be improved (statement I). Quote 18 highlights how the Pleasure Framework helped in understanding hedonic qualities, and how the SAM can be useful to identify and categorize feelings. The student from Quote 19 emphasizes how the Pleasure Framework can bring forth aspects overlooked by the team, while also reporting that the SAM was overshadowed by written justifications. The student from Quote 20 argues how evaluation is essential in his understanding of interactive art, and that the peer-review process was not only useful but necessary. As a counterpoint, the student from Quote 21 argues that even though it is a pictorial instrument designed for children, in his opinion, the SAM can be confusing and was not helpful during the evaluation process.

Quote 18: "The Pleasure Framework's categories were useful because they helped categorize hedonic quality in a way that was not very subjective. The SAM also helped to interpret my impression, because it is not always easy to identify and categorize what we are feeling or what the object makes us feel."

Quote 19: "The Pleasure Framework introduced concepts and aspects not previously considered by the team, so it was very useful. The SAM had less attention, considering that the focus of the feedback was on the justifications."

Quote 20: "The concept of Interactive Art is precisely the art in symbiosis with its appreciators, so it does not make sense only the creators to evaluate if it is good. The peer review was necessary to identify the positive and negative aspects of the work."

Quote 21: "The SAM is confusing if you are not used to the framework, and through it, I was not able to explain what could be improved in the work of the team I evaluated, nor did it help to critically evaluate the project."

Feedback for the electronics kit.

Concerning the electronics kit, overall, 7 students reported that this was their first experience with this type of technology, while the remaining 5 students had previous experience (statement J in Figure 3.7). A total of 10 students agreed that the kit helped them to think of new forms of interaction and expanded what they understood as HCI (statement K), and no student disagreed. Lastly, most students agreed that the "Interactive Mona Lisa" tutorial, presentation slides and examples of circuits and codes were useful (statements L, M, and N). The student from Quote 22 considered the kit to be the best experience in the course, and the student from Quote 23 praised the quality of the provided material. The student from Quote 24, in turn, reported how his concept of what can be an IoT system has been expanded during the course. Lastly, as a counterpoint, the student from Quote 25 reported that a lack of previous technical experience with some languages could increase the project difficulty. The feedback on the electronics kit is particularly important in our study because of our commitment to a constructionist approach to learning HCI. Considering how the students had to design, construct and program a physical interactive artwork, the electronics kit and accompanying documentation had the vital role of being the scaffold that supported them in this process, and the feedback from the students towards the kit suggests that it was successful in this regard.

> *Quote 22: "It was definitely the best experience I've had in the course."*

> *Quote 23: "All the material was very well explained and was a great base for the creation of our project."*

> *Quote 24: "It helped a lot to think about new forms of interaction because my concept of IoT was just to automate some actions and to collect data on everyday objects. Even having seen some examples of art using technology, implementing a system whose goal was to get a message across and be interactive has caused a change of perspective."*

> *Quote 25: "Anyone with little or no experience with HTML, CSS, and JS had difficulty implementing the project, and the tutorial did not help in this regard."*

3.5 Discussion

Even though there is no agreed consensus on the topics that compose the field of HCI, Hewett *et al.*'s [103] broadly accepted definition of HCI as "[...] a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" can provide some insights on what, in general, HCI educators should be concerned with. It seems clear that the competence of design (in the sense of doing creative work) is necessary but not enough for HCI practitioners, as the competences of evaluation and implementation are also necessary, completing a cycle. Interactive systems and major phenomena surrounding them, however, are concepts that seem to be constantly challenged by innovation and new contexts of technology use. Therefore, these ever-evolving concepts should often be revisited inside the classroom, preferably with the involvement of the students themselves. In this direction, it is our understanding that the adoption of a constructionist approach to learning HCI can play an important role in allowing and fostering this involvement from the students, because they are able to investigate innovative technologies that they are genuinely interested in, as well as working with contexts of technology use that make sense to them.

It is important to emphasize that we are not advocating against the design, evaluation, and implementation of more "traditional" interactive systems, such desktop or mobile applications designed for well-defined and/or work-related problems. In fact, as presented in Section 3.2, one of the projects of the HCI course addressed in this article (the redesign, in the form of a mobile app, of their university's current web app for managing classes, grades, and other academic matters) involved what we consider a traditional system, and this redesign project involved skills, methods, and competencies that are likely needed in the industry right now. We are, however, advocating that HCI educators could and should explore new ways of expanding the students' perceptions of what can be an interactive system, and by doing so in a constructionist way, it is likely that we, educators, will also expand our own understanding. Overall, our approach yielded the positive results we presented in Section 3.4. Based on our results, we highlight and discuss the following main aspects and benefits of the approach:

- **Creative Freedom**: following on one of the fundamental ideas of constructionism, if we want the students to experience the construction of an artifact that is somehow meaningful to them, this includes giving them the creative freedom to make their own decisions about what to construct and how. Accordingly, we noticed that the high degree of freedom we provided the students within the InterArt project had several positive effects. As can be seen in Section 3.4.1, in which we present the teams and their interactive artworks, by having creative freedom in choosing their team name and the kind of interactive artwork they would construct, the students had the opportunity to express themselves and pursue something that they are highly interested in, as well as represent and pay tribute to artists and artworks that they admire. The creative freedom, in turn, also brought an unexpected cultural value that came from, for instance, appreciating local and relatively unknown artists such as Felipe Abranches. We conclude that this creative freedom, therefore, contributed to the high degree of engagement we witnessed from the students. It was noticeable how many of them cared for the project and felt proud after the final presentation.

- **Participation & Collective Sensemaking**: during the whole semester we aimed towards a collective construction of knowledge. It is already expected by our constructionist approach that instead of providing authoritative definitions that students would listen to passively, we designed the course's activities to encourage active participation. However, going beyond individual participation, we can argue that we extended the constructionist approach to explicitly include social participation, towards what can be considered a socio-constructionist approach [12]. Students could initially research a subject on their own as warm-up activities, but afterward, they would openly discuss it with the class. The perception and interactive art concept warm-ups are two examples of this approach, and both led to meaningful in-class discussions. Quotes 3 to 5 illustrate the benefits the students saw in the discussion originated from the interactive art concept warm-up, while Quote 12 generally highlights the importance that participatory techniques had during the project. These two warm-up activities showed that encouraging a collective construction of knowledge can be fruitful for most students, as their colleagues are likely to bring in different aspects and points of view that can enrich an initial, individual concept.

- **Social Awareness**: during the semester we also encouraged students to think about the concept of socially aware design [11]. As a result, during the InterArt project, we constantly noticed the students questioning themselves: if their interactive artwork was placed in a museum, or other public space, who could affect or be affected by it? Could a blind person also appreciate their work? What about other disabilities or conditions? For instance, during ideation, in the Challenging Existing Assumptions technique, some teams challenged the idea that a blind person could not properly visit a museum. This can be seen in Quotes 3 and 13, that illustrate accessibility and people with visual impairment being taken into account in the design of interactive artworks, respectively. Following our constructionist stance, instead of arbitrarily demanding accessibility in the interactive artworks, we observed that by introducing the subject under the lens of social awareness, the students were able to expand their view of the impact of designing new technology. This expanded view, in turn, contributed towards the students caring about accessibility and willingly incorporate it into their interactive artworks. In the end, most of the teams created interactive artworks that do not depend on vision alone, and three of them, 500cc, Lobos-Guará, and Romero Britto, actually had accessibility as a central aspect of their project.

- **Expanded View of HCI**: the idea of bringing elements from the maker culture to the classroom was intended to provoke and expand what the students previously understood as HCI. The answers to statement K ("The electronics kit helped to think of new forms of interaction and expand what I understand as HCI") in Figure 3.7, illustrated by Quote 24, which mentions a change of perspective about being able to use technology to communicate an idea instead of only doing tasks, indicate that this objective was achieved. The availability of tools, as well as the learner's ability to construct something with them, are paramount in a constructionist approach. In this sense, the electronics kit and documentation provided to the students act as a form of scaffolding, but even this scaffolding needs some kind of balance. On the one hand, if there is not enough scaffolding, the students will most likely bump into technical difficulties and not be able to construct what they want. On the other hand, if the scaffolding provided is too restrictive, like a closed platform, it severely hinders creativity. Quotes 22 and 23, which praise the experience of using the electronics kit and its documentation, indicate that our substantial effort of preparing an electronics kit with hand-picked components and writing meaningful documentation was important for the success of the InterArt project. In the end, the projects tacitly explored varied and important vanguard concepts in HCI, such as pervasive and ubiquitous computing, IoT, and enactive systems and embodied interaction.

- **Appropriation of Methods and Artifacts**: when we expand our view of HCI, inevitably we must also expand our view of HCI evaluation. In this study, our appropriation of the Pleasure Framework also seemed important in expanding students' views of qualities to be considered in interactive interfaces. This is illustrated in Quotes 18 and 19, that highlight how the Pleasure Framework's categories were useful and introduced concepts and aspects not previously considered by the team. We, however, must emphasize that we opted for the Pleasure Framework due to the specific theme of the InterArt project, which involved constructing interactive artworks. Much like a constructionist learner works with tools towards an objective that is significant to him/her, HCI researchers and practitioners should be able to critically assess the usefulness of different evaluation methods in different domains and contexts, and also be able to adapt, combine, or remix those evaluation instruments and methods as needed. Furthermore, considering the wide range of specific domains and contexts that may arise when we start designing for open-ended scenarios that go beyond traditional, work-related problems, this competence of assessing and choosing or creating evaluation methods becomes especially important.

3.5.1 Known Limitations

Besides the overall positive results, we acknowledge that our constructionist approach to learning HCI does not come without some limitations. Working with interactive artworks, for instance, may not resonate well with every student since the beginning, as previously illustrated in Quotes 6 to 8 from students that could not indicate an artist or work of art that they admire. Participatory methods, in turn, may also not be well received by some students, as indicated by Quotes 14 and 17, from students that already had more strict views about interface design or what they wanted to create. No approach, of course, will be universally accepted by all the students. The student from Quote 11, for instance, already had a preconceived view of what a computer engineer should know about design, which we conjecture to be a more objective, market-oriented perspective. However, our approach did work with some students that first seemed prone to dislike it: the student from Quote 10, for instance, did not show interest in art at the beginning of the course but in the end reported a change of mind about the subject and overall positive experience.

Another known limitation is affordability and know-how of state-of-the-art gadgets and technologies. In our study, we relied on relatively low-cost hardware. The electronics kit provided to the students has a cost of approximately US$60.00 per kit, already considering local availability and taxes. Hypothetically, this value can be lowered to around US$20.00 per kit depending on the country and availability of components. Even though this value is relatively affordable, not every institution and HCI program may have a budget available for providing students with this kind of material, especially in economically disadvantaged countries. Furthermore, these components will need maintenance or replacement over time, and there is a constant release of better and/or cheaper alternatives. Besides the actual price, a substantial level of know-how is needed to both initially compose the kits, as well as to keep them documented, supplied, and updated.

Lastly, considering the necessary physical components and the idea of active participation, collective sensemaking, and physical construction of artifacts in teams, it is possible that the constructionist approach described in this article may not be suitable for the expanding modality of virtual classes, such as in Massive Open Online Courses (MOOCs). Our close contact with the students, particularly during practical activities, seemed to be essential to the success of the InterArt project. All things considered, we do not rule out the possibility of a constructionist approach to learning HCI in MOOCs, but it should be noted that a virtual classroom would need to emulate and/or find proper alternatives to our activities and methods. These alternative activities and methods should ensure that the students can somehow work with innovative technologies that go beyond the computer screen, and learn HCI by constructing things they are interested in.

3.6 Conclusion

Considering our specific research question ("Can students learn HCI through a constructionist approach by exploring emergent technologies, such as Arduino and other devices, in the design of open-ended scenarios, such as the creation of interactive artworks?"), the study shows that it is possible to learn HCI through a constructionist approach by employing novel technologies and proposing the design of an open-ended scenario. As an example of an open-ended scenario, or study also shows that the construction of interactive artworks as a project theme is a viable option in an undergraduate HCI course for Computer Science and Computer Engineering students. In a general sense, the technologies and tools that we employed proved to be useful in expanding the students' view on what can be an interactive system. Our open-ended scenario, in turn, fostered creativity and participation among the students. Even though we cannot expect our approach to resonate well with every student (can any approach?), it allowed a significant number of students to rethink their perception of art, technology, and HCI. In summary, our constructionist approach also provided a relatively open learning environment for students to explore and construct with new technologies (*e.g.*, Arduino, electronics and the Internet of Things), express themselves and their tastes creatively, and ultimately play an active role in enacting the course's main project.

Regarding our general research question ("Can HCI students be prepared not only for current design problems but also for those that will be faced in the next 5, 10 or 20 years?"), we can make educated guesses, but we cannot predict the technology that will be available and the design problems that our students will be facing in the next 5, 10 or 20 years from now. Nevertheless, we do believe that by fostering an attitude of being open and capable to explore new tools and technologies to construct novel, unconventional forms of interaction, and by practicing design in a socially aware manner, our students will be somehow prepared for the unforeseen challenges that they may face in the future, be it as researchers or practitioners. Moreover, we believe that by encouraging participation and critical thinking, and being able to work with state of the art technology and interaction techniques, these students may not only be prepared to cope with future technologies and design challenges but may indeed play an active role in constructing the technology and respective design problems of the future.

Chapter 4

InstInt: Enacting a Small-scale Interactive Installation Through Co-design

4.1 Introduction

Advances in technology are changing the way people interact with computer-based systems, going much beyond the keyboard, screen and touch into the physical space. The concept of ubiquitous computing [171] is now technologically materialised in computers with varied sizes and formats for different purposes. Computational technology can be embedded in everyday objects with wireless connection capability, opening numerous IoT possibilities. Novel devices such as Raspberry Pi's and Arduino's are relatively easy to learn and use, even by people without expertise in computer science or engineering [44]. Because of these advances, new design techniques and practices are needed to cope with the changes and to understand how users perceive and interact in such new technologically-enhanced spaces. These advances bring numerous challenges to HCI research, such as how to consider the multitude of implications these new devices can bring to the design and evaluation of interactive systems. Nevertheless, they also bring a unique opportunity: easier, more open technologies can allow a new level of co-design and co-authorship in interactive systems that go all the way from design to actual construction of new artefacts.

Currently, many exciting design ideas for technology-enhanced devices are constantly presented and released, and many relatively affordable DIY fabrication tools and inventor kits are inspiring and facilitating an artefact "makers" culture. Maker culture phenomenon, albeit not free from critique [6], make use of these technological advances and empowers an increasing number of people to constitute communities of practice and maker spaces to share knowledge and independently develop their own, handmade, technological projects [126]. While the *ad hoc* construction of things enhanced with ubiquitous technology might favour the familiarisation of some people to contemporary technology, academic research efforts on methods and processes for the design and prototyping of computationally embedded artefacts might benefit a broader spectrum of people, from new makers to those who will make use of the enhanced space.

As argued in the literature [23, 37, 38, 1], a common strategy to develop technologically-enhanced artefacts has been to pursue clearly articulated and appealing design concepts, motivating them by theory, market considerations, or designer-intuition. Moreover, as discussed by Bowers *et al.* [23], while much research is concerned with investigating individual innovative computerised devices, less concern has been shown regarding how a multiplicity of devices might combine to make emerge a coherent experience. In this direction, literature suggests that public spaces, such as airports and museums, for instance, are both rich and challenging environments for the design of technology embedded into a physical space [37, 38, 1]. In public spaces, people are involved in a broader range of activities that go beyond the traditional work-oriented scope. Moreover, even in contexts usually open to participatory collaboration with academia, such as museum institutions, the design process does not always make participants as an active and able part of the entire design process, beyond the initial stages [38].

In this context, this paper investigates the process of co-designing a small-scale technologically enhanced artefact intended for a public space. Our objectives are twofold:

1. Describe and illustrate a design process in which technical and creative abilities are integrated by exploring novel relationships and possibilities enabled by emergent media and interaction technologies; and

2. Promote a more holistic and socioenactive participation in the co-design of interactive artefacts by identifying different design approaches and strategies in the use of ubiquitous computing technologies.

To achieve our objectives, we present the InstInt case study and reflect on the process of co-designing a small-scale interactive installation for a public space context. The study is illustrated with the participation of a small group of graduate students, coming from different backgrounds, in the context of a project in an HCI course. The paper is structured as follows: in Section 4.2 we present a background and related work. In Section 4.3 we present the case study, describing the context, design process, conducted activities, and outcomes. In Section 4.4 we discuss our main findings by reflecting on the case study and our objectives. Lastly, in Section 4.5 we present our conclusion and final considerations.

4.2 Background and Related Work

In HCI, when the design of interactive systems expanded beyond well-defined work-related problems and delved into our homes, everyday lives, and culture, it was plausible to expect the need for design theories and methods more aligned with this third-wave HCI context [21]. Participatory Design, albeit being available since the early 1970s, regained popularity to face third-wave challenges, presumably due to its inherent inclusion of people in the design process, which allows a more grounded and realistic grasp at the elusive and open-ended design problems that people face daily. It is from participatory approaches that the concept of co-design and co-authorship emerged in HCI. Literature has shown several approaches towards the co-design and participatory design of interactive installations.

In this section, we will briefly discuss some results from the literature that we consider relevant to our study, without exhausting the subject.

The benefits of participatory approaches in the design of interactive installations have been reported in the literature for at least the past 14 years. In 2004, Frecon *et al.* [86] reported on how a museum installation about visualising sound perception in submarines, initially not well received by people with experience on the subject, was redesigned by conducting meetings with stakeholders to collect design suggestions; the focus of their work is on interaction and technical details of the installation. Similarly, Devecseri *et al.* [47] mention the use of a participatory design process that was employed to further develop PhotoRobot, a Kinect-based installation. There are other works that present interactive installations designed with some kind of participatory design or co-design approach (*e.g.*, [45, 23, 138, 157, 9]). Several studies have their contributions oriented towards showing the created product qualities, while details of the design process are often not presented or not thoroughly described.

For studies that do give some focus to the design process, participatory approaches are usually privileging early design phases. Some studies emphasise the benefits of conducting fieldwork at the intended interactive installation site before any practical design activities. Ciolfi *et al.* [37], for instance, report how fieldwork at an airport was important in understanding the various stakeholders involved and their interrelations before any brainstorming or concept design activities. Ciolfi and Petrelli [36], in turn, describe how field walks with a local community of cultural heritage volunteers at a historic cemetery provided valuable insights and prepared stakeholders for brainstorm workshops conducted afterwards. Other studies present varied approaches to early phases of design. The work of Patsoule [144] exemplifies a rapid ethnographic study in a museum with the objective of better understanding stakeholders and their interactions. The works of François [110] and Ciolfi *et al.* [39] each present two similar approaches for early phases of the design of, respectively, augmented environments and tangible interactive installations: integrating stakeholders into the design team to generate design concepts in an open-ended manner, or developing early working prototypes to gather feedback from users and lead the design from there. Last but not least, the work of Sim *et al.* [159] describe how children can participate in the generation of ideas for a virtual reality exhibit by drawing over parts of a given storyboard with museum artefacts, simulating an augmented reality experience mediated by special glasses.

Regarding the more abstract concepts of authorship and co-authorship, Jacucci *et al.* [107] compare the dichotomy between designers and users in HCI to artists and audience. The authors argue that the growing interest in participatory design and participatory art can play the role of blurring these dichotomies. In participatory art, artists usually foster audience participation through two approaches: by creating conceptual frameworks or digital environments and then inviting people to contribute within them; or by organising environments or events that are subsequently appropriated and extended by the joint participation of audience and artist. According to Ciolfi *et al.* [38], museum curators and other cultural heritage professionals are usually not actively involved in the design process of interactive technology in their domains. However, in the cases they are involved, the main responsibility for the design still lies with other people, such as technology experts, design consultants and researchers. In a museum context, Ciolfi *et al.* [38] present a co-design process that iterates divergent (generation of new concepts) and convergent (selection of concepts to pursue) phases. The authors describe practical activities such as sketching in hardware, in-situ scenario building, bodystorming and combining technology and content.

Even though there is an inherent use of multiple senses in interactive installations, we did not find in the literature much emphasis on accessibility or universal access in the co-design of interactive installations. The work of Partarakis *et al.* [143] addresses the need for accessibility in cultural heritage exhibits, raising some challenges on the subject, although without showing practical results.

A brief analysis of related work shows many valuable contributions to the fields of participatory design and HCI for the design of interactive installations. Nevertheless, the literature also shows a tendency to focus on results, products and services [10, 119], while the design processes and practices lack thorough presentation and discussion. While we acknowledge that there are seminal works that give greater emphasis on design processes and practices (*e.g.*, [153, 172]), these are usually only present in conferences and journals in which participatory design or co-design is the main topic, and, to the best of our knowledge, they do not approach the design of interactive art or interactive installations. Furthermore, possibly due to a significant technical expertise gap among stakeholders, the prototype construction is usually conducted by experts after gathering results from early stage participatory design activities. In our view, participatory approaches could get inspiration from maker culture to involve people with varied skills and experiences not only in early, conceptual design phases but also all the way towards the physical prototyping.

4.3 The InstInt Co-Design Case Study

The study illustrated in this paper was conducted with five students attending an HCI special topics course of a graduate program at Unicamp, Brazil, during the second semester of 2017. This is a specialised, non-mandatory, course intended for students with interest in expanding their knowledge on HCI and research methods in the field. The project we describe here was part of the program of the discipline, and the students consented with the use of results in scientific research and publications. We (a professor and two intern teachers) ministered the course with a sociotechnical perspective to the design of interactive systems, and we used inclusive and participatory approaches [11, 127, 154]. The participants had different formal education backgrounds (Computer Science, Computer Engineering and Visual Arts), different levels of programming experience (from basic Web front-end technologies, such as HTML, CSS and JavaScript, to more complex, full-stack system engineering), two of them had experience with graphical design, and one had experience with sound design.

The course's main program included: concepts, theories, scientific schools of thought and research methodologies in HCI; and design and evaluation practices and processes for pervasive and ubiquitous systems, including interactive installations and IoT scenarios.

For the course's main project, named InstInt (short of *instalação interativa*, Portuguese for interactive installation) and our focus in this paper, we asked the participants to idealise, co-design and prototype (in a small scale) an interactive installation for a public space. We wanted the participants to do something more than working together in a pre-given, well-defined design problem. We conceived the InstInt project with the goal of allowing the participants to enact their own design project with creative freedom, and our main task as educators was to mediate a co-design process (from the very conception, all the way to actual construction) of an open-ended design problem.

We defined an interactive installation as an artwork that is three-dimensional and site-specific, and that involves the participation of the audience not only as a passive observer but also as someone capable of acting on it. Interactive installations may involve computers, sensors and actuators to perceive and react to movement, sound and other stimuli, allowing the audience (local or remote) to change aspects of the artwork. We chose to work with this kind of artefact because it allows us to explore novel technologies and design and co-design tools, while also considering social contexts for interaction. We conducted several activities designed to support the participants during the InstInt project, including exploration, ideation, requirements, sketching and co-construction. We will briefly describe the activities and their respective results as follows.

4.3.1 Exploration: Interactive Art Gallery

Before formally introducing the InstInt project, we provided the participants with an experience that pointed towards what they would be working with. Simulating a museum exhibit, we selected and displayed three interactive artefacts[1]

- **Maned Wolf**: an interactive cardboard maned wolf designed for educational museums. It is connected to a computer through Wi-Fi, and as people interact with the wolf, the computer projects images and play sounds related to information about the wolf.
- **Monolith**: a miniature monolith to interact with scenes from Kubrick's *2001: A Space Odyssey*. There are a gyroscope and a Wi-Fi connection in the monolith, and when it is picked up and moved, it controls the speed and colour of psychedelic scenes being projected.
- **Memotion**: a sensory black box with textures inside that evoke emotions associated with memes. When a texture is pressed, a computer displays a meme and sound related to feelings evoked by the texture.

Pictures of the activity and artefacts can be seen in Figure 4.1. The artefacts had very distinct intentions, as well as interaction approaches. We asked the participants to freely explore them in any way they wanted, but to take notes regarding three HCI-related aspects: 1) *What kinds of interaction does the artwork reveal?* Answers for the Maned Wolf highlighted the tactile exploration, but also sound and visual interactions. The Monolith

[1] These artefacts were created by undergraduate students in the previous semester in a project named InterArt [55].

was more enigmatic, it could be moved, shaken, rotated, but the actual results from these actions were not clear. Lastly, Memotion was oriented towards touching different textures, but also with sound and visual feedback; 2) *What technologies/devices are involved?* Besides the obvious computer with a graphical interface, participants noticed buttons on the Maned Wolf and Memotion and guessed about Arduinos, some kind of motion sensor and Bluetooth connection on the Monolith; and 3) *For each interactive artwork, write three words that emerge from the interaction.* The Maned Wolf was recognised for being both cute/pretty and comical, but also for its accessibility and educational values. The Monolith was curious, mysterious, extraterrestrial, but also frustrating. Lastly, Memotion was fun, curious and recognised for its accessibility.

(a) Maned Wolf. (b) Monolith. (c) Memotion.

Figure 4.1: Exploring three interactive artworks during the Interactive Art Gallery activity.

To conclude the activity, we presented the participants with Costello and Edmonds' Pleasure Framework [42], and asked them to evaluate the three artworks with regard to the thirteen categories of the framework. The participants mainly highlighted "exploration", "discovery", "danger", "sensation" and "simulation" for the Maned Wolf, "creation", "exploration", "difficulty", "fantasy" and "camaraderie" for the Monolith, and "exploration", "discovery", "captivation" and "sensation" for Memotion. This evaluation allowed the participants to experience an evaluation method that goes beyond traditional usability testing, and discover hedonic qualities that are relevant for interactive art and installations.

4.3.2 Ideation: Collaborative Sensemaking

The open-ended nature of the InstInt project required that, as a first step, participants formulate a general idea of the interactive installation. To mediate this task, we proposed activities involving three distinct ideation techniques. The first one, Challenging Existing Assumptions, was adapted from Michalko [133]. The participants listed preconceived ideas related to the project, and then challenged these ideas, promoting unconventional thinking patterns. For the second technique, Brain Writing [167], the participants selected their favourite ideas from the previous activity and collaboratively wrote a proposal on how to make the reversal of that idea come true. Translating Sensory Experiences, is based on the reported influence of sensory experiences on creativity [177]: it consists of trying to give a visual representation to non-visual sensory elements. This third technique was not conducted in class due to time constraints but was still presented and used by the participants.

With the context broadly defined as a “public space”, each participant had to choose a specific public space for the Challenging Existing Assumptions technique. The selected public spaces were: 1) train station; 2) bus station; 3) science museum; 4) visual arts museum; and 5) public park. The main preconceived assumptions that emerged are:

“People do not communicate in a train station”

“Only sighted people use a bus station”

“Children do not like or go to science museums”

“Only sighted people go to a visual arts museum”

“People in public parks have a lot of free time”

These assumptions are not necessarily prejudiced ideas from the participants, but thoughts believed to be possible as common sense. Each statement was then used as the starting point for a collaboratively written proposal on how to make the reversal of that statement come true. Examples of the reversals, a summary of the proposed solutions and the main value (the central aspect of it) are presented as follows:

- **People can notice each other in a train station**: interactive installations could instigate people to look around and notice other people; and serve as a playful experience, like a game in which two or more people need to collaborate with each other to achieve a certain goal. The main value here is “human connection”.
- **Blind people can use an accessible bus station**: interactive installations could allow blind people to share their experiences and difficulties about the use of public spaces; and provide information about bus schedules, destinations and other relevant information in an accessible manner. The main value here is “accessibility”.
- **Science museums can engage both children and adults at the same time**: interactive installations could allow children to play games with colleagues, both local and remote; allow both children and parents to interact together, participate and enjoy; and allow visitors to explore interactive representations of traditional exhibition artefacts that they would normally not be allowed to touch. The main value here is “diversity”.
- **Blind people can visit a visual arts museum with multisensory artworks**: multisensory experiences could be provided by interactive installations that expand visual artworks to also include other senses. For instance, allow people to interact with 3D representations of paintings, complemented by audio about the artwork and artist and a smell related to what is represented. The main value here is “multi-sensoriality”.

- **People in a public park have a life story**: installations could display who are the people at the park and what they do; show information about the history of the park and its natural environment; and raise awareness about taking good care of the public space and the people around it. The main value here is "empathy".

Because the purpose of this activity was ideation, and only a single interactive installation would be created, the participants would now face the challenge of combining the many ideas and solutions that emerged in the ideation into a single coherent interactive installation proposal. The ideation activity was successful in highlighting five main desired aspects (one for each participant) that would need to be articulated during the co-design and accommodated in the installation to be proposed: **human connection**, **accessibility**, **diversity**, **multi-sensoriality**, and **empathy**.

4.3.3 Requirements: Problem Clarification

After defining the five main desired aspects of the installation, the participants had to better understand the design problem at hand and define an initial set of requirements to work on. Considering the need for problem clarification, and the social aspects of a public space installation, we mediated this design phase with a socially aware approach to the design of computational systems [11]. This approach understands design as a social process that involves the production and interpretation of meaning by those involved. Various instruments (informal, formal and technical) are used as communication and mediation tools between participants during the co-design of an interactive system. The participants worked with three instruments in particular: Stakeholder Identification Diagram [128], Evaluation Frame [13], and Semiotic Framework [160].

With the Stakeholder Identification Diagram, the participants identified and mapped people and institutions that might affect or be affected by their installation, as can be seen in Figure 4.2. Besides passengers and museum or public park visitors, this artefact supported the identification of less obvious stakeholders that might also play an important role (*e.g.*, institutions, sponsors and governmental organisations), or are often only recognised in later stages, if at all, such as people with disabilities. The Evaluation Frame, in turn, was used to anticipate problems related to stakeholders, and raise possible solutions to these problems. For instance, a question was raised about whether people with visual, hearing or physical disabilities would be able to interact with the installation, therefore, the installation's inputs and outputs might be thought of in an accessible way. Another concern was the lack of resources and infrastructure to build the interactive installation, which could be mitigated by using low-cost technologies and materials. Furthermore, approval from authorities and conformity with applicable laws are necessary to place an installation in a public space.

Lastly, the Semiotic Framework, also known as Semiotic Ladder, was used to organise requirements in different levels, from the social world (*e.g.*, culture, values etc.), all the way down to the physical world (*e.g.*, needed devices and components). With a top-down approach, starting with the social world, the participants specified the following requirements:

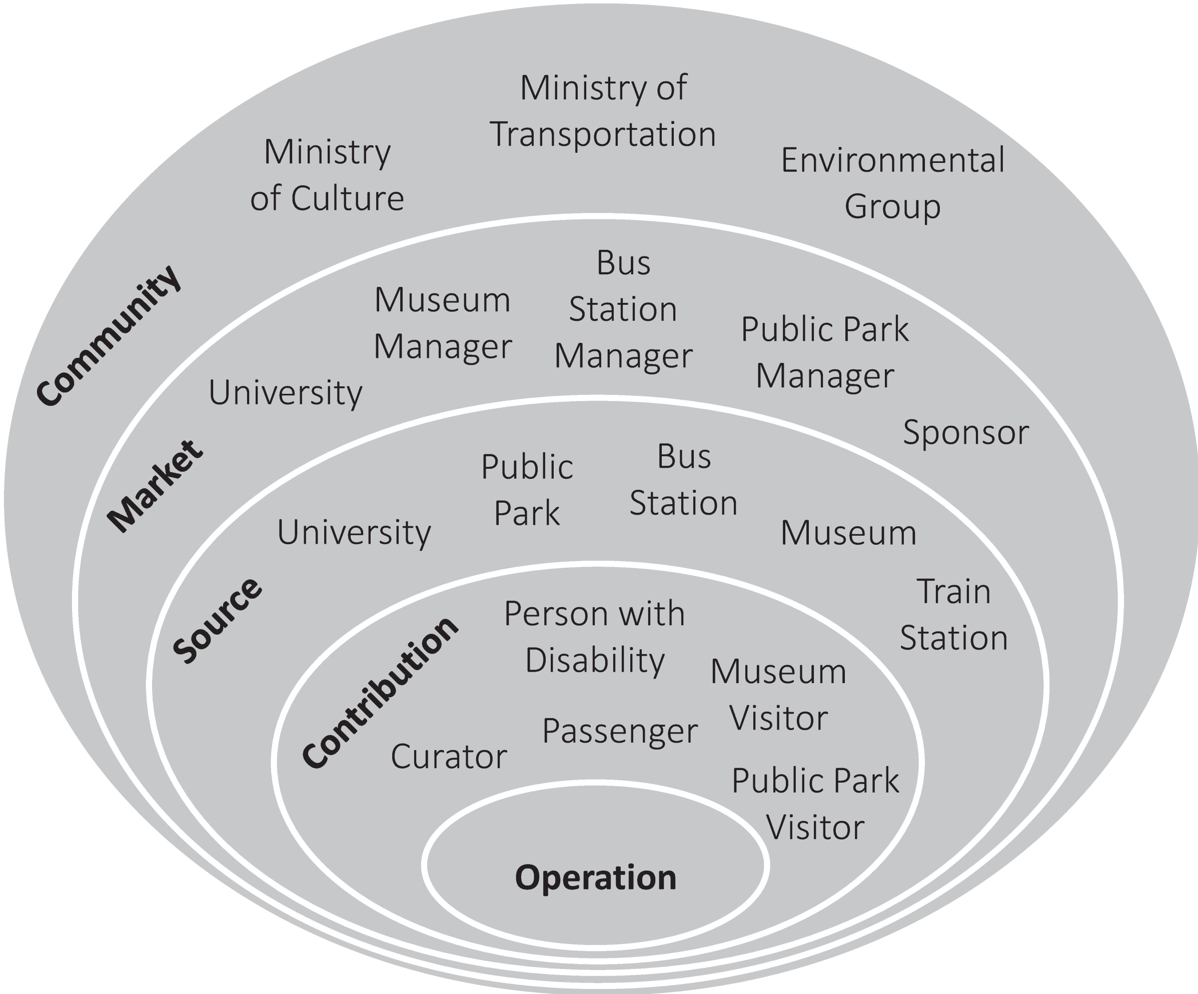


Figure 4.2: Map of stakeholders resulted from the use of the Stakeholder Identification Diagram [128].

- **Social world**: Make strangers notice themselves and the environment in a deeper way than usual.
- **Pragmatic**: Foster interest in the public. Then, foster interaction between people to reach a common goal.
- **Semantic**: A "game" with rules.
- **Syntactic**: An interaction that considers a physical position in space. Inputs and outputs must be thought of in an accessible way. Simple language should be used.
- **Empirical**: Public space noise control.
- **Physical world**: Speakers, lights, projected images, motion engine, touch-sensitive surfaces.

It is important to emphasise that, even though these project stages were conducted and are presented in sequential order, problem clarification was an on-going process. Sketching in paper and co-construction with physical prototyping, which we will address next, and informal discussions with the professor and intern teachers also contributed to a continuous problem clarification and requirements refinement.

4.3.4 Sketching: Paper Prototyping

With an initial clarification of the design problem and requirements, we mediated a participatory sketching activity using the BrainDraw [136] method. Each participant started sketching a solution for the interactive installation, and after 60 seconds intervals, they would exchange their paper sheets in a cyclical order until everyone worked in every drawing. After that, they would highlight and discuss design options they found interesting in the design initiated by them. This activity was intended to allow everyone involved to participate in the design process, even people that are introverted or shy about expressing their ideas, while also smoothing potential authoritarian characteristics of some participants.

We conducted three BrainDraw rounds. A picture of the activity being executed by the participants can be seen in Figure 4.3 and a sample from the three BrainDraw rounds can be seen in Figure 4.4. Solutions from the first round were significantly varied, as each participant did their best to express their understanding of the yet open and elusive design problem at hand. Solutions included an interactive dome with movement sensor and projections; a musical totem with ribbons that could be pulled in a specific order (round 1, sample "B" in Figure 4.4); a giant piano keyboard painted on the ground in which keys are activated by pressure sensors; an interactive climbing wall with sound, projections and sensors along the climb (round 1, sample "A" in Figure 4.4); and an interactive room with surround sound and projections on the walls that responds to the position and movement of people inside. Even though solutions varied considerably, the discussion after the first round was an important step towards a mutual understanding of the physical form of the installation and the kind of interaction the participants wanted it to provide.

In the second BrainDraw round, the participants converged towards the idea of a circular, audiovisual installation with ribbons that can be pulled. Design solutions for the main form of the circular installation included totems (round 2, sample "A" in Figure 4.4), giant umbrellas (round 2, sample "B" in Figure 4.4), and a carousel. For interaction, all the designs included audiovisual responses for presence, touch and movement. For instance, each ribbon could represent a musical instrument to be played; ribbons could be rolled up in the totem in a manner that resembles the local folkloric *dança das fitas*; and ribbons could have different sizes so that people of different heights would participate together. The design solutions in this second round ended up being chosen as the physical aspect of the interactive installation, but the interaction itself still needed to be better specified.

The third BrainDraw round was focused on the actual interaction. We recommended participants to think about three distinctive interaction moments: what happens when 1) no one is interacting with the installation; 2) a person interacts alone, or two or more people interact together with the installation; and 3) people leave the installation. Because this round was more complex and needed more detail, each participant worked on each drawing three times. From the design solutions, the following ideas emerged: 1) The

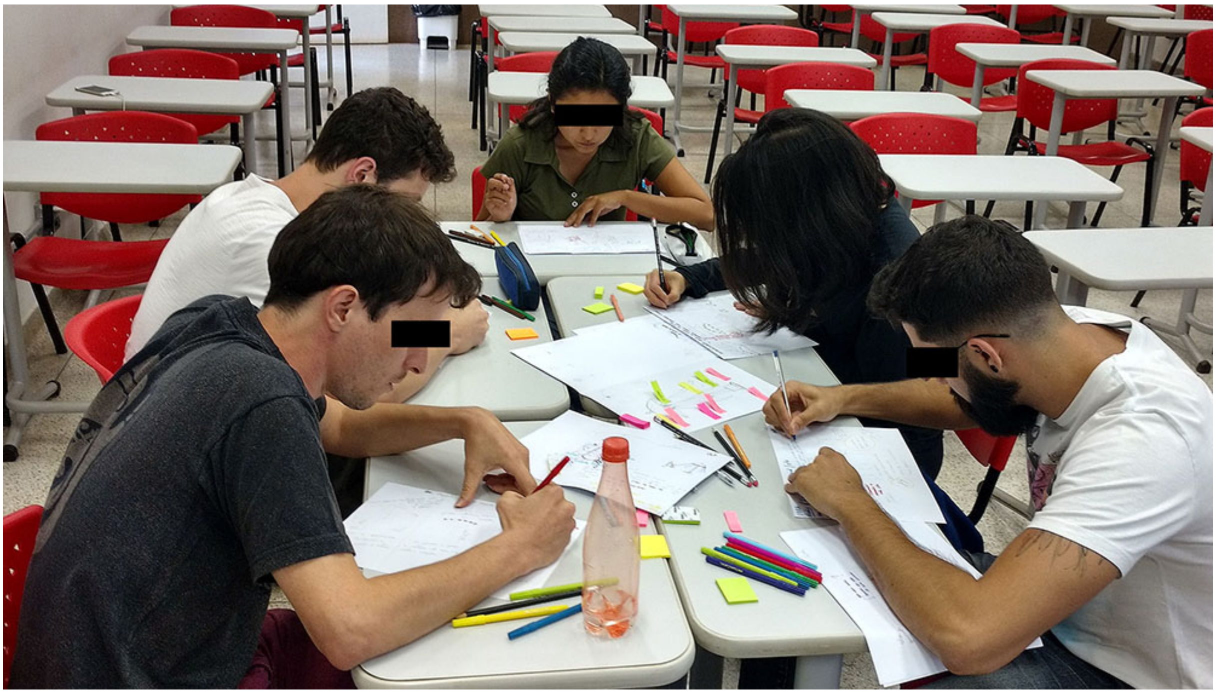


Figure 4.3: The participants during a BrainDraw round.

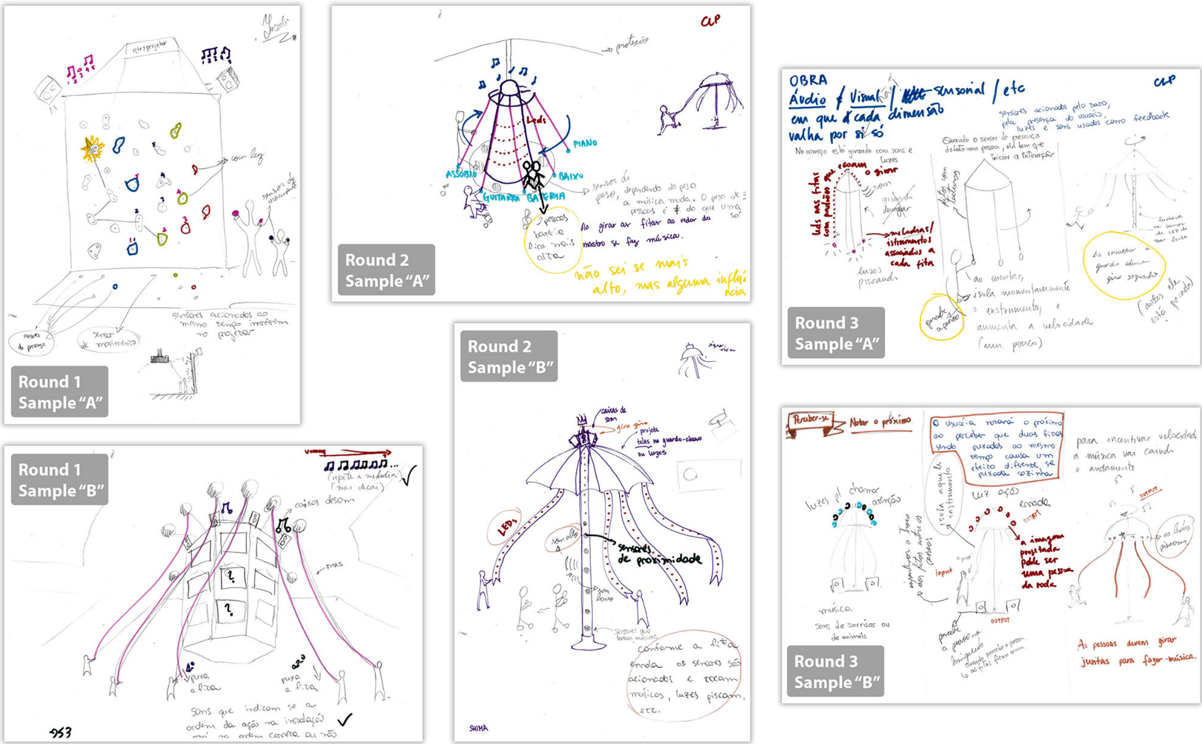


Figure 4.4: Sample of two (out of five) BrainDraw designs from each of the three rounds.

installation should make use of sound, light and movement to invite people to interact with it. 2) Being close and touching the ribbons makes the installation "happier" with joyful sound and blinking lights, but two or more people are needed for a higher level of happiness. 3) When people leave, it becomes less happy with slower movements and light effects, and a melancholic sound.

After three BrainDraw rounds, the participants consolidated the design solutions into an interaction scenario, highlighting how the scenario articulates their individual goals of human connection, accessibility, diversity, multi-sensoriality, and empathy. Expanding on the third BrainDraw round, the scenario is organised in four distinctive moments:

1. **Waiting for interaction**: the installation plays an instrumental sound at a low volume, blinks some colourful lights and spins at a low speed. The colour of the lights is linked to the current predominant musical instrument (multi-sensoriality). A tactile floor guides people with or without visual disabilities towards the installation (accessibility).
2. **One person interacting**: when a person approaches, ribbons are lowered. Some ribbons have a rustic appearance but play a pleasant sound when touched, and some are pretty but play a less pleasant sound (empathy). The ribbons also control blinking lights and a projected image inside the dome (multi-sensoriality and accessibility). Some ribbons are too high and can only be touched by adults, while others are too low and are more easily touched by children (diversity).
3. **Several people interacting**: when several people interact with the installation at the same time, the music becomes progressively more cheerful and energetic as more people collaborate and coordinate new sequences for touching the ribbons (human connection). In accordance with the music, lights, projection and spin movement also react to how people interact with the ribbons, providing different forms of feedback (multi-sensoriality and accessibility).
4. **People leaving the installation**: like a spring-loaded toy, exciting melodies, lights and projections start losing energy when people leave, and the installation becomes a little bit more melancholic instead of happy.

4.3.5 Co-construction: Physical Prototyping

For the construction of a small-scale interactive installation, we provided each participant with a custom-made electronics kit, and they also had access to varied affordable crafting materials. The kit was composed of:

- Controller: NodeMCU (with built-in Wi-Fi);
- Sensors: temperature & humidity, LDR, sound, reflexive obstacle, vibration, tilt, touch and push buttons with colourful covers;
- Actuators: micro servo motor, assorted single-colour LEDs, RGB LEDs and buzzer; and
- Other components: organiser box, breadboard, jumper wires, copper foil tape, and resistors.

The electronics kit was accompanied by customised documentation on every component, and by an original illustrative tutorial on how to send information from the microcontroller to a remote web page and *vice versa*[2]. Halfway throughout the course, the participants had an entire 2-hour class dedicated to exploring the kit, following the tutorial and getting help. Afterwards, they could keep the kit in their possession until the end of the semester.

The participants started physically prototyping their installation by experimenting with separate, small proofs of concept (initially, every participant worked individually on separate exploratory ideas). These proofs of concept included: connecting copper foil tape to a touch sensor, to simulate touch-sensitive ribbons; creating a web page that dynamically composes a music from sounds of varied instruments in response to inputs; creating a web page that remotely controls LEDs, and to make them blink in different patterns and colours; building a rotating base for the installation prototype with a micro servo motor; and building a small, home-made projector using a cardboard box, a smartphone and a magnifying glass. After a few weeks, when these small projects were working well independently, all the participants started bringing them all together in the co-construction of a small-scale mock-up of their interactive installation. This co-construction effort lasted a few more weeks and is illustrated in Figure 4.5.

In the end, although not implementing every desired technical functionality due to time constraints (the InstInt project was only a part of a semester course), the final prototype ended up being a plausible minimum viable product that shows the essence of the interactive installation. The smartphone-powered projector, as initially desired, was set aside for not being bright enough and being difficult to accommodate in the base alongside the micro servo motor. More importantly, the prototype is the materialisation of something that was co-designed (and co-constructed) by five people, articulating five different desired aspects that were all embedded into the final artefact. Figure 6 illustrates the final prototype (we must disclose that, unfortunately, pictures and videos do not convey the captivating and mesmerising feeling of interacting with the artefact first-hand).

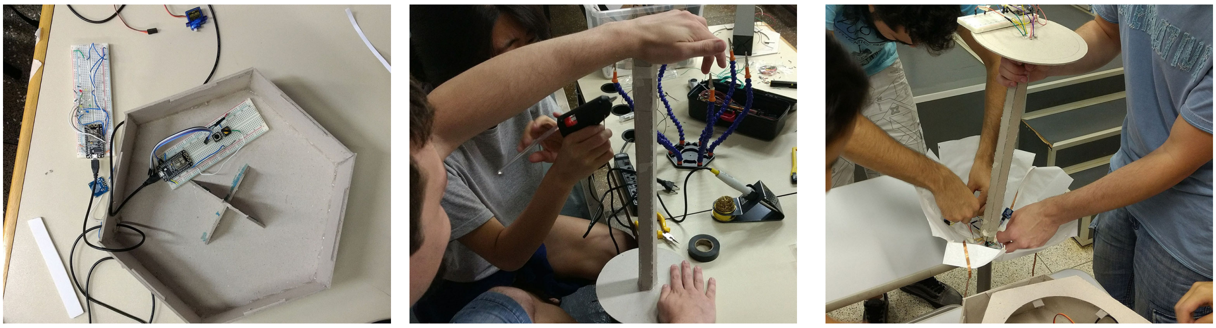


Figure 4.5: Physical co-construction of the small-scale interactive installation.

4.4 Discussion

Exploration and ideation activities are relatively common in participatory approaches shown in the literature. These activities for early design phases provide participants

[2] `https://efduarte.github.io/pincello/`

Figure 4.6: Final prototype of the small-scale interactive installation.

with both a more informed understanding of available technologies and its possibilities, as well as the opportunity to express individual ideas in the form of conceptual designs. Nevertheless, if their participation does not reach the prototype construction stages, they may not be able to continue advocating towards their ideas and desires for the final artefact. In this work, we argue that there is still room for expanding the understanding of co-design beyond including people in conceptual design stages (and sometimes evaluation). Inspired by maker culture, participatory approaches could allow the very practical design and construction of artefacts to be genuinely co-authored by the participants.

Our focus lied in articulating a design process with a group of people with diverse backgrounds, in which every person is actively involved in every design phase, from ideation and conceptual design, all the way to the physical construction of the artefact. Although our case study is relatively limited in scope at this moment, it suggested ways of coping with all design phases.

From this expanded co-design approach, a challenge that arose was the active and continuous articulation of the particular focus of each stakeholder throughout the entire process. The materialisation of concepts can become an increasingly complex task when the construction is also participatory, but it is also an opportunity for stakeholders to not only advocate for their needs and desires but to actually take part in implementing it in the final artefact. In our case study, an interplay between the values that emerged during ideation (human connection, accessibility, diversity, multi-sensoriality, and empathy) was alive during the entire subsequent design process. It was essential that each participant had the means to advocate and act towards his or her initial proposed value whenever necessary. In this direction, the subsequent methods and instruments that we chose to mediate the co-design and co-construction played an important role in fostering the interplay between the five initial values, and in allowing each participant to always have a say and something to do.

During problem clarification, each participant was able to express which stakeholders they found relevant and then anticipate possible problems and solutions. Because the participants derived their main value from different public spaces, the Stakeholder Identification Diagram and Evaluation Frame instruments allowed the emergence of common aspects that permeate all five initial contexts. Moreover, the Semiotic Framework supported the articulation, in the form of requirements, of a newly found common understanding of the problem. Even though the described requirements were not very detailed, they were sufficient to support an evolving common understanding. In paper prototyping, we chose the BrainDraw technique to specify the design in a way that all the participants could express their ideas and contribute to each other design concepts. At the end of a BrainDraw round, each drawing has no discernible author anymore, but it carries the co-authorship of a concept that emerged from all the participants. Finally, it was also important that every participant had its own electronics kit to experiment with, as it empowered them to be able to participate in the physical construction of the small-scale interactive installation. In the end, each participant was able to put time and effort towards the expression of his or her own priorities and values, while also being aware of the goals and contributions of other team members when working together.

Analysing the small-scale interactive installation, it is possible to perceive how each of the initial value from each participant is materialised there. Both the values of accessibility and multi-sensoriality complement each other in the installation through the use of lights, sound and touch, allowing a broader range of people to interact with the artwork, which is also tangential to diversity. The values of human connection, empathy and diversity emerge in how the installation was designed to allow different people to interact with it and with each other. Some interaction states are only achieved when people physically collaborate with each other, and even some of the touch-sensitive ribbons have different heights so that both children and adults can play at the same time. In a genuine manner, the artwork has the potential of promoting human connection, empathy and diversity by leading different people to notice each other in ways that otherwise would probably not happen, no matter age, social class or disabilities, and does so in an accessible and multi-sensorial way. The ways of how some features materialise more than one value at the same time reinforce how there was a close integration of technical and creative abilities. The participants, in their own words, praised the conducted design process and the final artefact they co-designed:

> "*I see the essence of what each author of the project imagined at the beginning, somehow contained in the final artefact. [...] even if each author had a different goal and different formal training, we were able to explore the best of each one.*"

> "[...] *we were able to bring together, in an organic way, five concepts that, if not totally opposed to each other, did not seem to initially converge in a coherent theme. Maybe that is why the work has become rich, as if the artefact, once built, did not excel by individual qualities but by its own peculiarity that has emerged in this union.*"

> "[...] *giving voice to everyone on the project, especially in its design, added me a lot because although I have already worked on some projects, I have always felt a lack of foundation for this aspect in design.*"

Reflecting upon the design process, the participatory physical prototyping conducted by the participants highlight how construction is not simply a scripted materialisation of a pre-given design. In the InstInt case study, the co-construction was a part of the design process, as it had a substantial influence on the design of the final artefact. From our design approach emerged something that we call a **socioenactive design process**. On the concept of enaction, Varela *et al.*'s [168] enactive approach consists of two points: "*(1) perception consists in perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided.*" [168, p. 173]. In other words, the enactive approach does not understand cognition as something that occurs in the brain alone (like the idea of a brain in a vat), the body and its sensorimotor capabilities also play an equally important role in the cognitive process.

Appropriating the concept of enaction to our design and HCI context, the act of physically constructing a digital artefact is an intrinsically perceptually guided action as you mount, fit, and connect things. In turn, it is our understanding that the sensorimotor experimentation with the features, sensibility, and precision of a varied range and combinations of devices, sensors and actuators allow the emergence of cognitive structures that lead to new design ideas and solutions. When the physical construction also happens in a participatory manner, as we advocate and illustrate in this paper, the design is not only enactive, it is socioneactive. In our case study, one particular design solution illustrates this concept: the participants first envisioned an installation that continually rotates in the same direction, like a carousel. However, when experimenting with the available micro servo motor that can only rotate 180 degrees, participants ended up implementing it to rotate back and forth in a semicircle, resembling a waltz dance that further corroborated to the captivating experience provided by the small-scale installation. We acknowledge that this socioenactive design process may also occur in other activities at different levels, such as problem clarification, programming or digital design, but it seems that it stands out and can be better perceived and exemplified when physical, participatory construction is involved.

In the socioenactive design process we described above, every participant brings forth his own identity into what is being co-created. Therefore, it is plausible to expect that, with different participants, the same design process we conducted in this case study would end up with different results altogether. We can not foresee what kind of interactive installation different groups of people (*e.g.*, varied motivations, demographics or design and computational skills) would devise, or the different challenges that would arise in the process. We can, however, expect that the result will always be a materialisation of a genuine collaborative design effort, a social enactment of a digital artefact.

4.5 Conclusion

The pervasiveness of more open and affordable technologies have the potential of redefining the concept of co-authorship by reducing the divide between the roles of user and designer in the context of interactive systems design. At the same time, the increasingly higher number of current ubiquitous technological devices demands research efforts on how to combine a multiplicity of devices embedded in a physical space into a coherent experience. This demand is even more challenging in the context of public spaces, where there is a wide diversity of backgrounds and purposes of the people that inhabit the space.

Although the benefits of participatory approaches in the design of computer-based systems, including interactive installations, has been reported in the literature for some time, there is still room for expanding the concept of co-design. Novel forms of participation and co-authorship can be fostered with a closer relationship with the maker culture phenomenon and through the investigation of the design processes and practices of co-created physical artefacts.

In the InstInt case study, we described and illustrated a co-design process to facilitate participants in collaboratively enacting their technical and creative abilities. This enactment happened in the holistic and participatory co-creation of a small-scale interactive installation for a public space context. Each participant was able to advocate and act towards his or her own ideas and objectives, while also being aware of each other values and efforts. Our results revealed that the participants were able to coherently articulate and materialise five initial values into a single artefact. We found that the participants benefited from having autonomy and creative freedom to devise their own priorities, advocate towards their interests, and the means to physically implement their ideas, first in small proofs of concept, and later in the installation. Moreover, the participants' readiness to interact and help each other throughout the entire project was essential in allowing individual efforts to be combined into a coherent final materialised design, and to constitute a socioenactive design process.

The socioenactive design process we presented in this paper combines a wide range of participatory design tools and techniques from the literature into a unified method: first, participants acquire some first-hand experience with key concepts and involved technologies before any form of ideation and, afterwards, they collectively guide the direction of the project, enacting a digital artefact that is genuinely co-authored. This design process can be useful for HCI educators and practitioners seeking for new activities and approaches for the design of open-ended scenarios, especially those involving problems that are not well defined and computational technologies that go beyond the screen and into the physical environment.

For future work, we intend to follow up and expand upon the socioenactive design process that emerged in the InstInt project, joining a museum institution and the applicable stakeholders into the co-design of a full-scale version of the interactive installation presented in this paper.

Chapter 5

InsTime: a Case Study on the Co-design of Interactive Installations on Deep Time

5.1 Introduction

The field of HCI has a particular relationship with new technologies. When technological developments change how we understand, design and interact with computers, and new practices and methods emerge from these developments, HCI itself is bound to *evolve together*. This phenomenon can be illustrated with the emergence of devices such as Raspberry Pis and Arduinos and their encompassing "maker culture", in which communities of practice and maker spaces allow people to share knowledge and independently develop their technological projects [126]. According to Wakkary and Stolterman [169], the growing interest of HCI in *making* has influenced most educational programs related to interaction design. Currently, students are working with a wide variety of materials to shape and develop physical artifacts. Consequently, pervasive devices and 3D-printing techniques are changing the concept of *sketching* in HCI, expanding the design of computational systems from the constraints of classical GUIs.

We emphasize the words "evolve together" because HCI is not passively influenced by technological and societal developments. Through its related areas of Design, Computer Science, Engineering, Psychology, among many others, the field of HCI can play an active role in envisioning and producing new technology and sociotechnical contexts. This active role can be illustrated with speculative design, in which design proposals challenge assumptions, preconceptions, and established notions about the role that products play in our everyday life, contributing towards more desirable futures [67, p. 6]. As an alternative to "affirmative design", or "design as it is usually understood", Dunne and Raby describe speculative design as "more of an attitude than anything else, a position rather than a methodology". In HCI, this attitude can be perceived in some research through design studies (*e.g.*, [178, 90, 16]). The resulting artifacts are usually not suited for production or consumption (which commonly is not their purpose anyway), but they can materialize knowledge by being "vehicles for embodying what 'ought to be"', potentially influencing both research and practice communities [178].

Considering how novel technologies and practices can substantially change what we understand as an interactive system, there is a growing need to investigate the different ways in which interaction design is changing. Making an analogy with The Structure of Scientific Revolutions by Thomas Kuhn [121], in the same way that it is argued that science does not progress from the simple accumulation of facts, progress in interaction design is not necessarily the result of the accumulation of new technology and features. Kuhn argues that scientific progress comes from the successive and overlapping reframing of ideas, described as paradigm shifts. Correspondingly, we consider the current changes in interaction design (*i.e.*, the successive and overlapping reframing of ideas about how we are supposed to design and evaluate interactive systems for new contexts and with newer technologies, and the new pervasive role of technology in our lives), as a paradigm shift in HCI.

In this paper, we investigate aspects of this paradigm shift through a case study of the InsTime project, in which 45 Computer Science and Computer Engineering undergraduate students designed 9 interactive installations addressing the concept of deep time. The concept of deep time revolves around Earth's age, estimated to be around 4.54 billion years. It is a difficult-to-grasp concept because it involves an order of magnitude we are not used to. To put it into perspective, in a 12-hour analogy of Earth's estimated age, humans have existed approximately only for the last 19 seconds. Deep time is a complex theme for installations, but also one that allows different approaches to communicate or experience the concept, and with provocative philosophical aspects to be explored, such as reflecting about our role within this grandiosity. Our objective is to investigate the attitude towards the design of interactive systems that may emerge when designers are faced with an open (yet non-trivial) theme, pervasive technologies, and a co-design process (in this paper we refer to co-design as in co-authorship of a design, which does not necessarily involves participatory design with different stakeholders). Aligned with alternative views on cognition that favor a physical engagement with the world, we base our analysis on aspects from the philosophy of science, affirmative *vs.* speculative design, and concepts of enaction and embodied cognition. We analyze both the design process in the InsTime project, and the resulting interactive installations motivated by the following research question:

> What kind of artifacts and attitude towards the design of interactive systems emerges in the InsTime project?

This paper is structured as follows: in Section 5.2 we present a background on philosophy of science, speculative design, and embodied cognition; in Section 5.3 we present the InsTime project; in Section 5.4 we analyze the design of the installations by framing it against paradigmatic aspects from philosophy of science and a characterization of affirmative *vs.* speculative design; and our results lead to the proposal of an approach to the design of interactive systems that we named socioenactive design. Lastly, in Section 5.5 we present our main conclusions.

5.2 Background

Our work balances theory and practice. We investigate theoretical concepts from the philosophy of science to investigate paradigmatic aspects of interaction design. Concurrently, we investigate the practical approach of speculative design to investigate alternative attitudes towards design. Finally, the theory of embodied cognition allows us to bridge the gap between theory and practice. In the following three subsections we present a brief background on these three subjects.

5.2.1 Philosophy of Science

Concerning fundamental definitions that are often tacit among researchers, Ponterotto [146] broadly defines science as a "systematic quest for knowledge", and philosophy of science as the "conceptual roots undergirding the quest for knowledge". Philosophy of science incorporates beliefs or assumptions regarding a set of "philosophical anchors", areas of study related to how scientists formulate and conduct their research, as well as how they evaluate each other's work in processes of peer review. The five philosophical anchors pointed out by Ponterotto, contextualized with their role in research, are:

- Ontology: the study of the nature of being and reality that will be considered during research (*e.g.*, whether reality is considered objective, subjective, enactive, *etc.*);
- Axiology: the study of the role and place of values in a research process (*e.g.*, deciding whether researchers' and participants' values should be kept out of the research process, or highlighted as an important part of it);
- Epistemology: the study of knowledge, acquisition of knowledge, and the relationship between the knower and the known (*e.g.*, deciding whether researchers should avoid interacting with participants, or actively provide guidance as an important part of the research objective);
- Methodology: the study of methods and processes chosen to conduct research (*e.g.*, how to find and review relevant literature, or the choice between quantitative or qualitative approaches to data analysis); and
- Rhetoric: the study of the language and presentation format used to report research (*e.g.*, length and format of an article, voice and tone in writing, use of illustrations, *etc.*)

These philosophical anchors are used for describing the paradigmatic schema presented by Lincoln, Lynham and Guba [125, p. 108–150], containing Positivism, Postpositivism, Critical Theory *et al.*, Constructivism and Participatory as different research paradigms. These philosophical anchors and research paradigms have already been reported in HCI literature by Duarte and Baranauskas [54], juxtaposed with the three HCI waves. We acknowledge that philosophy of science is not limited to the five philosophical anchors presented, and the anchors are more complex than the short description we can provide here. However, due to their conciseness and comprehensiveness (from the fundamental notion of ontological worldview, to the concretization of knowledge through rhetoric), these philosophical anchors provide an adequate framework to investigate aspects of interaction design.

5.2.2 Speculative Design

According to Dunne and Raby [67, p. 2], design is traditionally associated with objective problem solving: problems are broken down, quantified and fixed. However, many of the problems we face today as a society cannot be "fixed", they are wicked problems with many complexities and lack a correct solution to be found. In an earlier work, Dunne and Raby [66, p. 58] exposed how design is inherently an ideological practice, mentioning how design processes are informed by values (axiology) based on a specific worldview (ontology), while also highlighting two distinct approaches to the design practice – affirmative and critical design:

> "Most designers [...] view design as somehow neutral, clean and pure. But all design is ideological, [...] is informed by values based on a specific worldview, or way of seeing and understanding reality. Design can be described as falling into two very broad categories: affirmative design and critical design. The former reinforces how things are now, it conforms to cultural, social, technical and economic expectation. Most design falls into this category. The latter rejects how things are now as being the only possibility, it provides a critique of the prevailing situation through designs that embody alternative social, cultural, technical or economic values." [66, p. 58]

Dunne and Raby argue that "critical design, or design that asks carefully crafted questions and makes us think, is just as difficult and just as important as design that solves problems or finds answers" [66, p. 58]. Critical design, however, is criticized for lacking methodological specifics, and there is also debate in the HCI community about what can be considered a critical design [14]. Expanding critical design, Dunne and Raby [67] similarly present speculative design as an alternative to affirmative design, with several example projects. By speculating how things could be, instead of affirming how they are, one can "create spaces for discussion and debate about alternative ways of being, and to inspire and encourage people's imaginations to flow freely." [67, p. 2].

Dunne and Raby summarize speculative design in a manifesto called "A/B", in which "A" is a column of keywords for design as it is usually understood, and "B" is a column of alternative keywords for the authors' attitude towards design [67, p. vii]. The manifesto contains 22 pairs of keywords. For instance, while "A" is concerned with "Problem solving", "B" is concerned with "Problem finding". The authors state that it is not their intention for "B" to replace "A", but instead to add another dimension, something to be compared with and to generate discussion. The authors also leave open the opportunity for the creation of subsequent "C", "D", "E", *etc.* columns, that can represent yet different perspectives on design.

5.2.3 Embodied Cognition

In opposition to the mainstream understanding of cognition as a process contained inside the brain as an information processing machine, Varela, Thompson and Rosch [168] argue about the importance of having a body and being in the world. Their embodied cognition theory, also known as the enactive approach to cognition describe cognition as "laying down a path as you walk it". Under this perspective, cognition is not considered to be contained entirely in the brain; the environment and the whole body are part of it, and action cannot be separated from perception and *vice versa*.

In analogy to the embodied cognition theory, to the field of HCI, by embedding computational technology into everyday physical objects and environments we can bring meaning to our engagement with the world. In this sense, from a phenomenological perspective, meaning is created, manipulated and shared through our interaction with technological artifacts, characterizing what Dourish [52] called embodied interaction. As a more technical and illustrative example, the concept of enactive systems from Kaipainen *et al.* [112] contributes to a view of human and computer as a dynamic coupling. The authors' premise is that an enactive system can detect both deliberate and unconscious actions, such as body movements or physiological readings (*e.g.*, heart rate), and respond in accordance to the readings. This feedback, in turn, may directly affect the person and cause new readings, composing an ongoing enactive cycle.

We argue that the theory of embodied cognition is useful not only to investigate how we may interact with computational technologies, but also to investigate our very approach to the design of pervasive, interactive systems that span beyond the virtual and into the physical world.

5.3 The InsTime Project

The InsTime project was conducted with $N = 45$ Computer Science and Computer Engineering students attending an HCI undergraduate course at Unicamp, Brazil, during the first semester of 2018. In the course's program a project should be developed along with the classes. The students organized themselves in 9 teams of approximately 5 members each, with names inspired by the theme of "time". In the course, we (a professor and two intern teachers) adopted a sociotechnical perspective to the design of interactive systems, making use of inclusive and participatory approaches. We challenged the students to create an interactive installation that explores the concept of deep time. Supported by a design process, students had plenty of creative freedom to decide how to approach the theme and who is their intended audience.

5.3.1 InsTime's Design Process

The InsTime project was structured in a similar way as the InterArt [55] and InstInt [59] projects. This design process was chosen for favoring research, concept creation, and technological exploration in a blended and balanced way. We conducted the following activities: (1) Introductory Questionnaire; (2) Research on Deep Time; (3) Hands-on

Pincello Tutorial; (4) Generation of Ideas; (5) Paper Prototyping; (6) Presentation of Initial Proposals; (7) Physical and Digital Prototyping; (8) Formative Peer Review; And (9) Final Presentation. We briefly describe each in the following:

1. Introductory Questionnaire: we asked the students about their motivations and technical skills. But there was one last cryptic question: "Indicate an author, work or event that represents time for you.". The answers varied, with reference to movies (*e.g.*, Back to the Future), books (*e.g.*, The Posthumous Memoirs of Bras Cubas by Machado de Assis), paintings (*e.g.*, The Persistence of Memory by Salvador Dalí), concepts (*e.g.*, cryptography), and events (*e.g.*, the victory of Deep Blue over Kasparov).

2. Research on Deep Time: the teams were asked to research the concept of deep time and preparing a 10-minute presentation containing: a) their understanding of deep time; b) at least one example of how to represent the concept of deep time; and c) their methodological process. The teams presented different perspectives on the subject and varied representational examples. One noticeable feeling that emerged within students was the duality between how infinitely small we are in the universe and the scale of time, while at the same time we have the power to greatly transform our environment much beyond our lifespan.

3. Hands-on Pincello Tutorial: we wanted to allow students to explore different technologies and expand their view beyond computers and smartphones. Similarly to InterArt and InstInt, we provided each team with a Pincello electronics kit [58]. In this activity, the teams were tasked with following the tutorial on how to send sensor information from the microcontroller to a remote web page and *vice versa*. Besides expanding their perception of computational systems, this activity also provided the teams with technological tools they could use for the rest of the project, as they kept the kit until the end of the semester.

4. Generation of Ideas: to kick-start ideas, we conducted two ideation techniques. In the first, called Challenging Existing Assumptions and adapted from Michalko [133], the students listed general preconceived ideas related to deep time and then challenged these ideas to promote unconventional thinking patterns. In the second, called Brain Writing [167], the students selected their favorite ideas from the previous technique and collaboratively wrote a proposal on how to bring those ideas to reality. This activity allowed each team to formalize a small set of initial concepts.

5. Paper Prototyping: each team selected three ideas from the ideation activity and listed possible ways to implement them. Afterward, the teams conducted a Brain-Draw [136] paper prototyping round for each idea: each student started sketching an interactive installation, and in 60 seconds intervals they would exchange their paper sheets in a circle until everyone worked in every drawing. The BrainDraw method allows the entire team to participate, even students that are introverted or shy about expressing their ideas. The method also has the benefit of smoothing potential authoritarian characteristics of some participants. In the end, each

team consolidated the paper prototypes into a single schematic drawing of their interactive installation proposal.

6. Presentation of Initial Proposals: we asked each team to make a 10-minute presentation of their proposal. To highlight both the social (*e.g.*, culture, values, *etc.*) and technical (*e.g.*, needed devices) aspects involved, the teams had to frame their proposals within Stampers' Semiotic Framework [160]. Each team received feedback and suggestions from the instructors and the other students.

7. Physical and Digital Prototyping: we provided students with two 2-hour classes to materialize their proposals. We also provided them with guidance and technical support. Of the 9 teams, 8 made use of the provided electronics kit. One team, instead, pursued the use of webcams and the OpenCV[1] computer vision library.

8. Formative Peer Review: each team set up its prototype inside the classroom simulating an exhibition, and the teams experimented with and evaluated the installation of the next team in alphabetical order. For the evaluation, the students used Costello and Edmond's Pleasure Framework [42] to analyze aspects of playful interaction, and the AttrakDiff questionnaire [100] to measure hedonic, pragmatic and attractive qualities of the installation. The teams were able to use the obtained results to improve their projects for the upcoming final presentation.

9. Final Presentation: at the end of the semester, each team presented their project. The presentations contained a short video (between 3 and 5 minutes, telling the story behind the design and construction of the team's interactive installation) and a brief live demonstration of the final artifact.

5.3.2 InsTime's Interactive Installations

The 9 teams delivered interactive installations that explored available technologies in varied and creative ways. They were constructed with affordable materials or even scrap readily available, such as tin cans and cardboard. In the following, we briefly describe the final concept and how the interactive installation works in terms of interaction design.

Chronos

Named after the personification of time in pre-Socratic philosophy, this team explored Earth's geological periods, including their duration when compared to each other and main characteristics. The interactive installation, composed of a styrofoam mock-up, a tangible hourglass, and a display, is focused on presenting educational information regarding the periods, including geology, life forms, and atmosphere composition. Furthermore, through the hourglass, the installation plays with the understanding of the duration of each period.

The interactive installation, illustrated in Figure 5.1, has images of five geological periods (Archaeozoic, Proterozoic, Paleozoic, Mesozoic, and Cenozoic), and each period has 4 LEDs with alongside 4 push buttons. First, the display prompts the audience

[1] `https://opencv.org/`

to pick-up and shake the hourglass (it contains a vibration sensor hidden inside), and, proportional to the duration of each period, the amount of time shaking the hourglass will define which period will be selected (selecting some periods may be challenging by design due to their relative low duration when compared to others). When a period is selected, the display plays a video about the selected period and the 4 LEDs in the respective period are turned on. When a button is pressed, further information about that period is displayed according to where the button was positioned (*e.g.*, a button on top a of a volcano will display geological information). A new period can always be selected by shaking the hourglass again.

Figure 5.1: Chronos' interactive installation.

CronoBit

Named after a combination of the concepts of time and digital technology, this team explored the significance of the human impact on natural processes. The interactive installation, composed of a display and two tin can drums with drumsticks, is focused on highlighting, in a playful way, how human beings can dramatically accelerate natural processes that otherwise would take much longer, such as erosion (*e.g.*, accelerated through deforestation) or the evolution of a species (*e.g.*, accelerated through selective breeding).

The interactive installation, illustrated in Figure 5.2, has two drums labeled "humanity" and "nature" (they contain sound sensors inside that are calibrated to detect the drumming). The display invites the audience to pick up the drumsticks and play the drums to start the interaction. You can choose between two natural processes: the erosion of a coastline or the evolution of a species. Each option contains a temporal sequence of images, and the current image is replaced by the next one every time a drum is played, generating an interactive animation. However, the "nature" drum plays the animation in normal speed, while the "humanity" drum drastically increases its speed by skipping several images. For instance, by playing the "nature" drum you can watch a naturally slow process of erosion on a coastline, but it is accelerated when the "humanity" drum is played, symbolizing human impact on erosion through actions such as intensive farming or deforestation.

Figure 5.2: CronoBit's interactive installation.

De Volta Para o Futuro

Named after the movie *Back to the Future (1985)*, this team explored the concept known as *flow state*, *i.e*, the subjective way we perceive the passage of time when engaged in a playful activity. For instance, not perceiving the passage of time when having fun. The interactive installation is composed of a display and 4 pairs of push buttons and LEDs in 4 different colors: green, red, blue and white.

The interactive installation, illustrated in Figure 5.3, is inspired by the classic *Simon* electronic game of memory skill, in which the player has to memorize crescent sequences of colors and reproduce them. In this installation, the game starts and the first sequence is triggered by pressing the green button. After the LEDs blink in a specific sequence, you are tasked with pressing the buttons in the same order, which always leads to a more complex sequence. After a mistake is made the interaction departs from the original game: besides showing the final score, the display asks the player to estimate how much time s/he believes s/he spent playing. The estimated time is then displayed and contrasted with the actual time spent, highlighting how our perception of the passage of time may be subjective. It is expected by the authors that, because the player was engaged and having fun, s/he will usually guess less than the actual time spent playing.

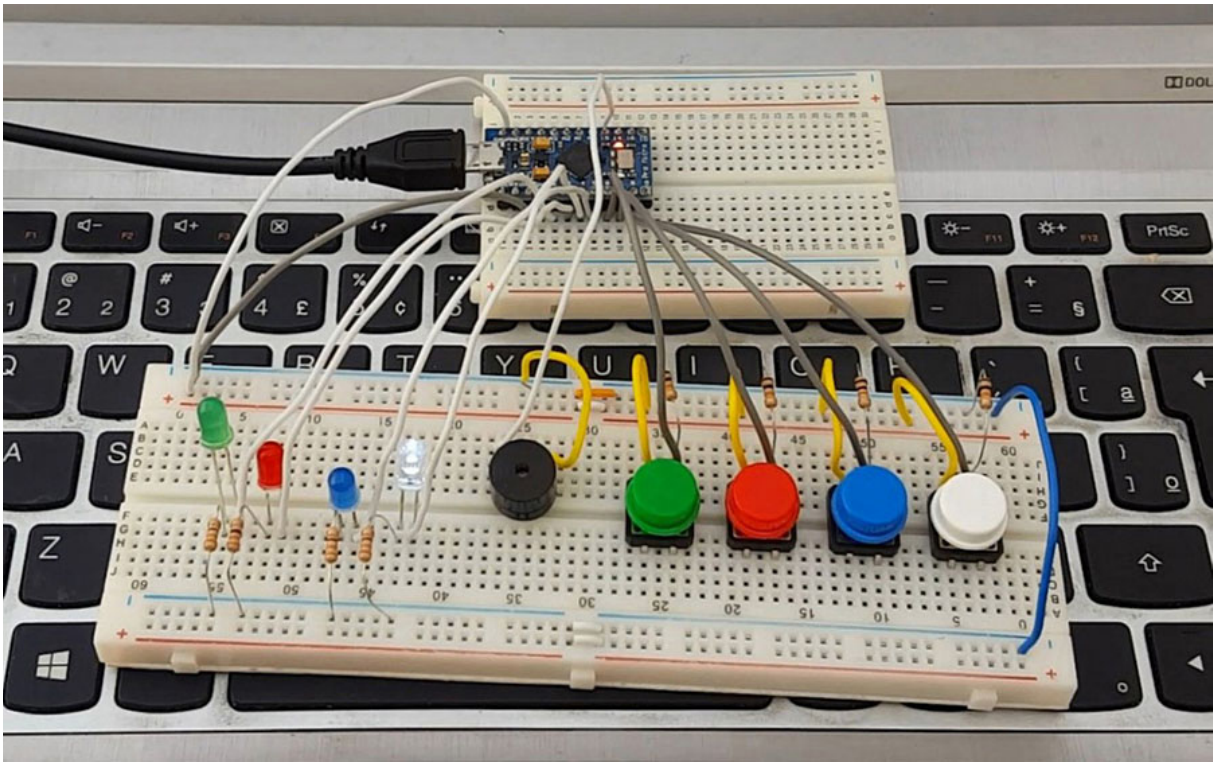


Figure 5.3: De Volta Para o Futuro's interactive installation.

General Purpose Timer

Named after a Computer Architecture component, this team explored how to raise awareness on the environmental consequences of the disposal of trash in different ways. It also has an educational purpose, by presenting the audience with proper destinations for each kind of trash. The interactive installation uses a camera and the OpenCV library to detect the selected kind of trash, and where it was disposed, while a display informs the consequences of the respective choice.

The interactive installation, illustrated in Figure 5.4, invites the audience to pick up a piece of "trash" among a yellow banana, a red battery, a white styrofoam piece, and a green glass bottle. The selected object can be "disposed of" by placing it over one of four symbols that represent: disposal at sea, incineration, landfill, and recycling. The installation detects the kind of trash that was selected by reading its color, and where it was placed by identifying the quadrant. After the detection, the display presents information about the consequences of that choice. For instance, a battery discarded in the ocean will take thousands of years to decompose while also releasing harmful heavy metals in the ecosystem. At any moment you can switch your choice to explore the different consequences and find a better outcome or try another object.

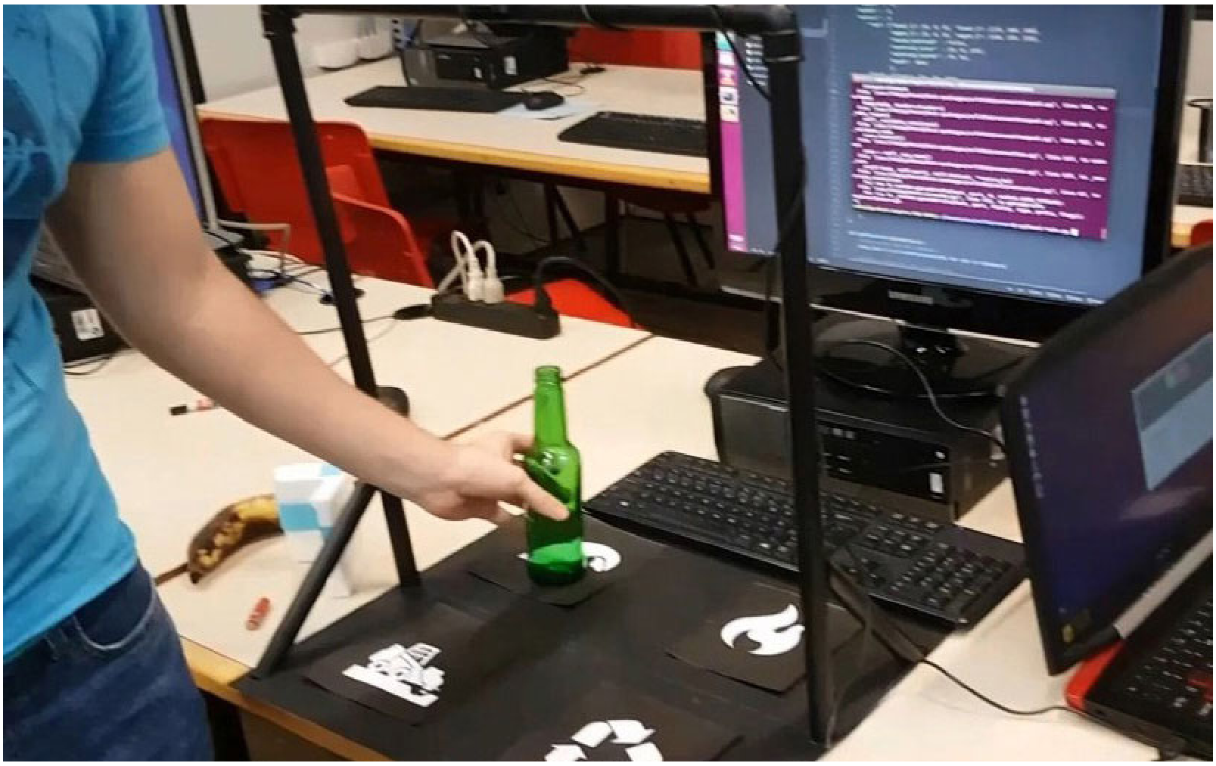


Figure 5.4: General Purpose Timer's interactive installation.

Limbo

Named after the concept from Catholic theology, this team explored the direct manipulation of Earth's and humanity's history, aimed at tangibly highlighting how old Earth is in comparison to any memorable human event. The interactive installation is composed of a display with a 3D representation of Earth and a timeline, and the direct manipulation occurs through a hand crank recycled from a bicycle pedal.

The interactive installation, illustrated in Figure 5.5, invites the audience to turn the hand crank (with attached accelerometer and gyroscope) and then see how it controls Earth's digital representation and the information that is displayed. When the crank is turned clockwise, time moves forward in the digital representation, while turning the crank counterclockwise makes time move backward. Some remarkable events, such as major geological eras or the emergence of new life forms, are displayed when the audience passes by their respective position in the timeline, and the hand crank vibrates to reinforce this feedback. By design, it may be challenging to select some events in human history because of their relative proximity in comparison to Earth's age. For instance, moving between geological events may require several turns of the crank, while history events may be only small nudges between each other.

Looper

Named after the movie *Looper (2012)*, this team explored how relatively short is the history of humanity when compared to the estimated age of the universe, associating this scale with how long we can hold our breath. The interactive installation is composed of

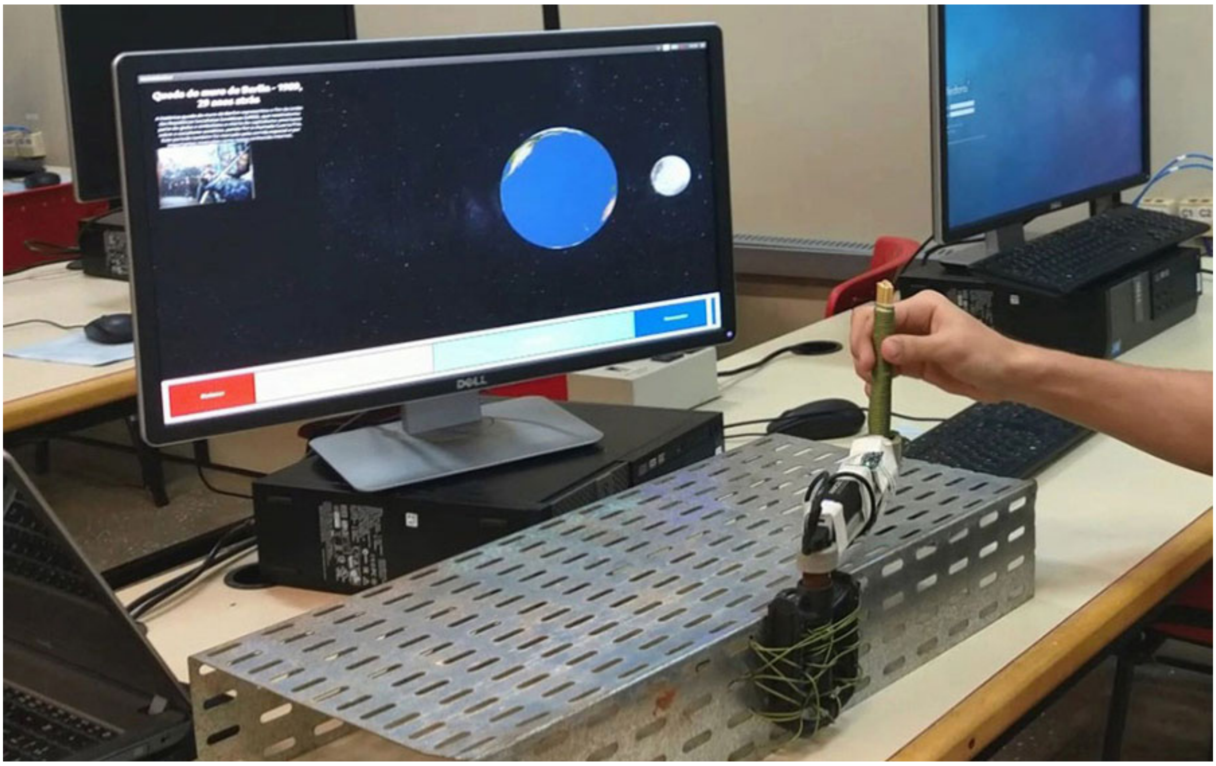


Figure 5.5: Limbo's interactive installation.

a miniature windmill attached to a box, and the box also contains two timelines marked with LEDs along the way. The top one represents human history, and the bottom one represents the estimated age of the universe.

The interactive installation, illustrated in Figure 5.6, invites the audience to blow the miniature windmill for as long as they can (it contains a sound sensor inside calibrated to detect blowing). While the miniature windmill is being blown, the LEDs in the timelines will be turned on in sequence according to how much time was spent blowing. However, because humanity's timeline is so small when compared to the estimated age of the universe, by design, all of humanity timeline's LEDs will be already lit before any LED on the universe timeline is turned on, representing the intended enormous difference in scales. It should be challenging for anyone to highlight the entire universe timeline, requiring the miniature windmill to be blown for a relatively long time.

Rolex

Named after the luxury watch manufacturer, this team explored how technological advances happen at a seemingly accelerating pace and, even though they are often not tangible or graspable (*e.g.*, cloud storage of digital files), the increase in their ecological footprint is alarming. The interactive installation is composed of three light bulbs of different technologies (incandescent, fluorescent and LED) and a display.

The interactive installation, illustrated in Figure 5.7, starts with the incandescent light bulb turned on (the oldest and most energy-inefficient). The audience is then invited to clap their hands, symbolically applauding the technological advances of our time. Each clap of hands (detected by a sound sensor) switches the light bulb that is turned on,

Figure 5.6: Looper's interactive installation.

moving towards the newer and more energy-efficient technologies (fluorescent, and then LED). At the same time, the display switches between information that correlates the ecological footprint of current technologies with the concept of deep time. For instance, approximately 90% of the data in the data centers of the world were created in the last two years. The last piece of information displayed before restarting is an overview of initiatives to neutralize this ecological footprint, presented in an optimistic tone and keeping future generations in mind.

Temporário

Named after the Portuguese word for "temporary", this team explored a social way of watching an educational video about deep time. The number of people watching the video at the same time will impact its playback speed, which can also be related to the passage of time itself. This aspect may encourage viewers to invite friends to watch the video together, engaging more people. The interactive installation is composed of a display, a proximity sensor, and a webcam.

The interactive installation, illustrated in Figure 5.8, uses the proximity sensor to detect if someone is nearby, and the webcam to identify how many people are watching at the same time. Initially, the video is paused before anyone approaches. After someone starts looking at the screen, the video starts playing at normal speed, and as more people watch together, the playback speed is increased up to 160%. When nobody is looking at the video anymore, the picture receives a grayscale filter and the video rewinds until someone approaches again. Besides playing with the passage of time, this concept can be used to make the display of educational videos in museums more engaging and efficient

Figure 5.7: Rolex's interactive installation.

when compared to videos that loop regardless of whether someone is watching or not.

Time

Named after the ambiguous word "time" (which also means team in Portuguese), this team explored the relationship between deep time and nuclear energy, while also providing educational information about its benefits and hazards. The interactive installation is composed of a display and a scale model of a city with a nuclear power plant. It was built with cardboard and other recyclable materials, and it contains sensors and actuators embedded in elements of the scenario.

The interactive installation, illustrated in Figure 5.9, has buildings, light poles with white LEDs, a clock controlled by a micro servo motor, two cooling towers with RGB LEDs inside (initially white), and a proximity sensor in front. The audience is invited to start the interaction by pressing a big green button that starts a video about the benefits of nuclear energy. However, when someone brings their hands close to the cooling towers the RGB LEDs inside and the background of the display turns to red to signify danger, and an educational video about the hazards of nuclear energy is displayed. The main objective was not to advocate against the use of nuclear energy, but to show the positive side without concealing the negative aspects.

Figure 5.8: Temporário's interactive installation.

5.4 Discussion

Our objective in this section is to analyze the kind of design that we observed in the InsTime project and the resulting qualities of its interactive installations. We analyze the design of the interactive installations by considering our background presented in Section 5.2, which includes paradigmatic aspects from the philosophy of science, Dunne and Raby's characterization of affirmative *vs.* speculative design, and the embodied cognition theory. This is done by framing the A/B list from Dunne and Raby with the five philosophical anchors from the philosophy of science, and by looking at this framing with an enactive perspective. From that juxtaposition, we organized the 22 pairs of keywords from A/B using five categories: (1) paradigm, (2) methodology, (3) ontology, (4) axiology & rhetoric, and (5) epistemology, as can be seen in Table 5.1. In the following subsections, we elaborate on how this categorization was done, and discuss how the kind of design observed in InsTime can be seen in our categorization (both the original and new keywords are presented in italic).

5.4.1 Paradigm

Dunne and Raby [67] argue that affirmative design is *affirmative* in relation to the status quo, while speculative design is *critical* towards it. We understand this pair of keywords as a summary of the kind of design that they represent, and therefore this category is not a philosophical anchor in itself; instead, it is derived from the more encompassing notion of a scientific paradigm. Following on the work of Duarte and Baranauskas [54], affirmative design seems aligned with the objective understanding of reality in which researchers deal

Figure 5.9: Time's interactive installation.

with "the one true reality" with rigorous experimental methods and supposed neutrality, while speculative design seems aligned with the more subjective nature of the critical-ideological research agenda in which researchers deal with a reality that is shaped by social, political, cultural, economic, ethnic, and gender values, and make use of more naturalistic methods of inquiry while denying the possibility of true neutrality.

By looking at the interactive installations of InsTime, we do not consider them to be affirmative as they all engage people to see things differently, for instance, by showing in different ways how small is our existence to the age of the universe. Even though we can see some critical aspects emerging from the teams CronoBit (*e.g.*, playing drums to see accelerated erosion) and Rolex (*e.g.*, applauding technological advances), we feel that the encompassing paradigm tends more towards socio-constructivism in which researchers have a personal involvement to deal with multiple, constructed realities that are subjective and influenced by context. Considering the way the students were involved and interested in sharing different viewpoints, and how the interactive installations invite people to create their understanding of the concept of deep time in different ways (*e.g.*, tangibly by Limbo, through the significance of human impact by CronoBit, or through our perception of the passage of time by De Volta Para o Futuro), we find it more fitting to describe the design in InsTime with the alternative keyword *socio-constructivist*.

5.4.2 Methodology

For Dunne and Raby [67], affirmative design is about *problem solving*, and therefore it *provides answers*. Furthermore, *design for production* implies its relationship with mass markets, and *design as solution* implies its use to solve well-defined problems. In a general sense, affirmative design works *in the service of industry*. Speculative design, on the other hand, is about *problem finding*, and therefore it *asks questions*. Furthermore, it is focused on *design for debate* of ideas, and *design as medium* implies that the artifacts created are not the goal, but instead, they act as a means for fomenting reflection and debate. In a general sense, the authors argue that speculative design works *in the service of society*. We understand these aspects as relative to how design is methodologically aligned.

The installations from InsTime were not about problem-solving or providing answers, nor were they oriented towards production, design as a solution or in service of industry. On the other hand, they were also not about problem finding but instead aimed at exploring the hard-to-grasp concept of deep time. They do not simply ask questions, but instead raise questions and help the audience in constructing answers (*e.g.*, General Purpose Time does not ask about the right ways of discarding trash, but instead highlights what happens when you do it in different ways, supporting you in constructing knowledge). Furthermore, considering the socially aware perspective of the project, we see that design was not for debate, but participation and engagement; not as a medium, but as a means of allowing everyone to equally participate and co-design something; and not in the service of society as a whole, but more specifically in the service of interested parties that affect or are affected by it. Therefore, considering these methodological differences, we describe the design in InsTime with the alternative keywords of *problem clarification*, *raise questions and construct answers*, *design for participation*, *design as co-design*, and *in the service of interested parties*.

5.4.3 Ontology

According to Dunne and Raby [67], affirmative design is concerned with *fictional functions*, creating things *for how the world is*, meaning that the world should be the object of change and intending to *change the world to suit us*. Furthermore, technological advances inspire *science fiction* and the prediction of *futures* grounded in *the "real" real*. Speculative design, in turn, departs from works of fiction to design *functional fictions*, creating things *for how the world could be*, meaning that people should be the object of change and intending to *change us to suit the world*. The social impacts and changes introduced by technology inspire *social fiction* and the conception of fictional *parallel worlds*, in which credible technology and plausible outcomes create *the "unreal" real*. We understand these aspects as regarded to ontology as they deal with different worldviews and the adopted notion of reality in design.

The interactive installations from InsTime are not aimed at creating fiction from functions (*i.e.*, science fiction), nor creating functions from fiction (*i.e.*, social fiction). Instead, they deal with fiction that emerges from their use, or, drawing from the enactive approach from Varela, Thompson and Rosch [168], fiction that is enacted by the audience. For instance, the work of Looper does not present any kind of story, but the narrative about how big the history of the universe is in comparison to our existence is enacted through the action of blowing the miniature windmill. The interactive installations are not about how the world is or could be, but about how we can enact the world; thus, change is not done exclusively in the person or the world as separated entities but happens as a result of person-world coupling. Instead of projecting futures, parallel worlds, and realities, the installations seem more focused on the phenomenological here and now and in what reality their audience brings forth through their enaction. Taking these ontological differences into account, we describe the kind of design we saw in InsTime with the alternative keywords of *emerging fictions*, *for how we can enact the world*, *change as a result of person-world coupling*, *enactive fiction*, *here and now*, and *the "interpreted" real.*

5.4.4 Axiology & Rhetoric

Dunne and Raby [67] claim that affirmative design is concerned with *narratives of production*, giving high value for *applications*, *fun*, *innovation*, and *concept design.* Furthermore, it looks at a person as a *consumer*, and it *makes us buy* products that emphasize *ergonomics* and *user-friendliness.* Speculative design, conversely, is concerned with *narratives of consumption*, valuing *implications*, *humor* (preferably in the more intellectual form of satire), *provocation* and *conceptual design.* It looks at a person as a *citizen*, and it *makes us think* through designs that emphasize *rhetoric* and *ethics.* We understand these aspects as equally related to values that surround design and its materialization, and therefore a subject of both axiology and rhetoric.

Examining the installations from InsTime, their narratives are neither of production or consumption – even though General Purpose Time and Rolex do explore aspects such as trash and ecological footprint. By comparing how small is our lifespan and the history of mankind in comparison to the age of Earth or the universe, the installations narrate about our very existence, our being in the world. They are not concerned about applications, and although the implications of our actions on the planet make an appearance, the installations mainly foster involvement from the audience. Fun (*e.g.*, the game from De Volta para o Futuro) and humor (*e.g.*, Rolex approach to applaud worrying technological advances) are present, as well as innovative ways of interacting with computer systems, and provocations to think about deep time, but in a general sense we see more emphasis on affect (*i.e.*, how people affect and are affected by the installations) and exploration. Furthermore, we see the design not exactly as concept or conceptual, but as situational, the person not only as a consumer or a citizen, but as a societal being. The design is not intended to make people buy; in terms of embodied cognition [168], making people think is a byproduct of making them act (*e.g.*, pick up things, blow, turn a crank, clap their hands, *etc.*). Lastly, although ergonomics, rhetoric, user-friendliness, and ethics are important values, the installations seem to give higher value to the more encompassing concepts of lived experience and social awareness. In view of these axiological and rhetorical differences, we describe the design we saw in InsTime with the alternative keywords of *narratives of being in the world*, *involvement*, *affect*, *exploration*, *situational design*, *societal being*, *make us act*, *experience*, *social awareness.*

5.4.5 Epistemology

For Dunne and Raby [67], in affirmative design results originate from a strict *process*, while in speculative design *authorship* is the corresponding keyword. While they do not elaborate on the meaning of process or authorship, we infer a contrasting approach between the more structured classic design cycle (*i.e.*, analyze, propose, and evaluate solutions), and a more free and authorial approach to design. We understand that this pair of keywords is related to the philosophical anchor of epistemology, as it concerns knowledge, acquisition of knowledge, and the relationship between the knower (designer) and the known (design).

Turning our gaze to the interactive installations from InsTime, we acknowledge that our design process played an important role in the outcome, as well as the authorial contributions from individual team members. Neither of these aspects, however, seem to define InsTime in epistemological terms. Because our process was designed to allow everyone in the team to participate through co-design, the final artifact is not a simple aggregation of the authorial contributions of individual team members, but instead a unified materialization that emerged from the entire team. Therefore, considering how co-design is in the spotlight in the design of InsTime's installations, we see the alternative keyword of *co-authorship* as more applicable.

5.4.6 Towards a Socioenactive Design Attitude

The paradigmatic stance taken by designers (with corresponding choices regarding ontology, axiology, epistemology, methodology, and rhetoric) forms a useful framework to interpret Dunne and Raby's contrast of affirmative *vs.* speculative design. Alongside aspects from the theory of embodied cognition, this framework was also useful to compare Dunne and Raby's original comparison against the kind of design that we saw emerge in the InsTime project, in which the students were faced with an open theme, had access to pervasive technologies, and adopted a co-design process. As presented above within the five categories, the design in InsTime featured the social construction of knowledge through the integration of individual experiences. Alongside an enactive worldview, participation and co-authorship were major aspects throughout the design process, leading, among other values, to an emphasis in social awareness, situational design, and affect.

Even though there is some consonance between aspects of speculative design and the kind of design that we observed in InsTime (*e.g.*, some critical aspects emerging from the work of the teams CronoBit and Rolex), we do not think that the kind of design observed in InsTime can be fairly described in terms of affirmative or speculative design. We perceived substantial differences in every dimension of our analysis. For instance, the epistemological emphasis on authorship that we see in speculative design as it is presented by the authors seems irreconcilable with the focus on co-design and co-authorship through participatory design techniques that we observed in InsTime. Following Dunne and Raby's [67] opening for the creation of subsequent "C", "D", "E" *etc.* columns in their A/B list, with subsequent different design attitudes, this non-conformity of the design in the InsTime project with neither affirmative nor speculative design leads to our suggestion of a third column. Much like speculative design, this third column that we propose is not intended

Table 5.1: A characterization of socioenactive design. Extended from Dunne and Raby [67].

	"A"	**"B"**	**Socioenactive Design**
Paradigm	Affirmative	Critical	Socio-Constructivist
Methodology	Problem solving	Problem finding	Problem clarification
	Provides answers	Asks questions	Raise questions and construct answers
	Design for production	Design for debate	Design for participation
	Design as solution	Design as medium	Design as co-design
	In the service of industry	In the service of society	In the service of interested parties
Ontology	Fictional functions	Functional fictions	Emerging fictions
	For how the world is	For how the world could be	For how we can enact the world
	Change the world to suit us	Change us to suit the world	Change as a result person-world coupling
	Science fiction	Social fiction	Enactive fiction
	Futures	Parallel worlds	Here and now
	The "real" real	The "unreal" real	The "interpreted" real
Axiology & Rhetoric	Narratives of production	Narratives of consumption	Narratives of being in the world
	Applications	Implications	Involvement
	Fun	Humor	Affect
	Innovation	Provocation	Exploration
	Concept design	Conceptual design	Situational design
	Consumer	Citizen	Societal being
	Makes us buy	Makes us think	Makes us act
	Ergonomics	Rhetoric	Experience
	User-friendliness	Ethics	Social Awareness
Epistemology	Process	Authorship	Co-authorship

as a replacement for the other two, but rather as an alternative, a different perspective to the design of interactive systems.

Taking into account that we observed a strong presence of aspects related to Baranauskas' [11] notion of social awareness in the categories of paradigm (*e.g.*, a socio-constructivist approach), methodology (*e.g.*, focus on problem clarification, and participation), and epistemology (*e.g.*, emphasis on co-authorship), we can argue that the social aspect seems to play a defining role in our third column to be proposed. In addition, the concepts of enaction and embodied cognition from Varela, Thompson and Rosch [168] are strongly present in the defining category of ontology (*e.g.*, the stance of not dealing with an objective reality that is given, nor a subjective reality that is completely constructed inside one's mind, but instead with a reality that is enacted as a result of person-world coupling). Much like both the social and enactive aspects seem inseparable in the axiology & rhetoric category, we expand on the previously reported socioenactive design process from Duarte, Gonçalves and Baranauskas [59] to name the attitude towards design that emerged in the InsTime project as **socioenactive design**. To formally summarize this characterization, Table 5.1 expands the A/B manifesto from Dunne and Raby, now framed against our working categories, and with the addition of the third column for socioenactive design.

Although not labeled as such, concepts related to socioenactive design can be seen in HCI literature in recent years. Grounded on the embodied cognition theory, Jaasma *et al.* [106] present a system for participatory sensemaking with the use of tangible tokens and IoT technology. Furthermore, the concept of embodiment is discussed in varied contexts: Chu [34] argues that tangible and embodied interaction with cultural heritage artifacts can provide a more complete sense of the cultural context in museum spaces; D'Arcey, Haines, and Churchill [68] investigate speculative pervasive artifacts to better understand what they propose as "embodied states", a mapping of combinations for physical activeness and cognitive directness; and Giaccardi *et al.* [91] propose what they call "embodied narratives", a performative technique for early stages of a co-design process. Co-design and co-creation are also featured by Avram and Maye [9], who describe a collection of co-design case studies and methods for the co-design of cultural heritage tangible interactive exhibitions. Knowles *et al.* [116] also address co-design by discussing challenges and unexpected outcomes from a co-design case study with older adults. Notwithstanding, with the installations from the InsTime project and our characterization of socioenactive design we bring forth these individual aspects into a formal, paradigmatic framing.

5.5 Conclusion

HCI's relationship with the emergence of new technologies and techniques can be both exciting and challenging. There are always new promising possibilities of interaction being opened by new devices and practices. Meanwhile, interaction designers need not only to cope with constant changes in the sociotechnical landscape, but also to find ways to take part in understanding, envisioning and developing these new technologies and practices. In this paper, we analyzed the kind of design that emerged in the InsTime project, a project characterized by its open theme of deep time, unconventional approaches to interaction brought by contemporary, pervasive technology, and co-authorship.

It is our understanding that theory and practice shape any effort in understanding the design of interactive systems. As a practical example of the kind of design that is currently emerging from the availability of new practices and devices, we investigated the design process and the 9 resulting interactive installations from the InsTime project. We presented the concept behind each installation and how they work. In a juxtaposition of theory and practice, we framed the following four items against each other: (1) a theoretical background in philosophy of science and its philosophical anchors; (2) a blended theoretical and technical background on embodied cognition and its applications in interactive systems; (3) a contrast of affirmative *vs.* speculative design, from the influential work of Dunne and Raby [67]; and (4) the empirical evidence from InsTime and its installations. This framing, summarized in Table 5.1, allowed us to perceive the emergence of a different attitude towards design, with equal emphasis on social and enactive aspects, which we named socioenactive design. We highlight the following takeaways from our study:

- The open theme of deep time gave students the freedom to create experiences instead of solving problems, while also serving as a compass for not losing sight of the main goal: to explore the concept of deep time;
- Access to pervasive technologies (*e.g.*, sensors, actuators, computer vision *etc.*) allowed the students to envision more embodied ways of interacting with computational systems;
- A co-design process allowed every student to express his or her ideas on equal footing, and to pay attention to how their creations may impact or be impacted by society; and
- We characterize what emerged in InsTime as socioenactive design, which has an equal emphasis on situated creative freedom, embodied interaction, and social awareness.

Chapter 6

"Maned Wolf in the Museum:" a Case Study on Learning Through Action

6.1 Introduction

In the context of HCI and inspired by the concept of ubiquitous computing [171], over two decades ago Ishii and Ullmer [105] envisioned what the authors named a Tangible User Interface (TUI). TUI contrasts with a classic GUI manipulated with keyboard and mouse (and, more recently, touchscreen), in the sense that technology is embedded in everyday physical objects and environment, allowing interaction to come into the real world, and going beyond the virtual. This kind of user interface, when applied in educational contexts, presents an opportunity to study how tangible *digital* artifacts work on the learning process [161, 158, 140]. In particular, it is an invitation to revisit the concept of *learning through action*.

This is an idea that has been widely investigated and experimented in varied learning contexts. In this paper, we draw on the concept of enaction from cognitive science to better understand and characterize the role action has during the learning process, while someone is interacting with a digital artifact. The context we chose to work on is that of an interactive artwork that could be displayed in a museum, and therefore simultaneously touches the worlds of art, education, and technology. We wish to challenge the concept that museum exhibitions are not to be touched and that they are meant to have an unquestioned admiration [49]. In fact, John Dewey's [49] concept of aesthetics informs our perspective on the relationship people have with art and with the kinds of artifacts we find in museums. According to the author:

> When an art product once attains classic status, it somehow becomes isolated from the human conditions under which it was brought into being and from the human consequences it engenders in actual life-experience. When artistic objects are separated from both conditions of origin and operation in experience, a wall is built around them that renders almost opaque their general significance, with which esthetic theory deals. [49, p. 3]

> So extensive and subtly pervasive are the ideas that set Art upon a remote pedestal, that many a person would be repelled rather than pleased if told that he enjoyed

> his casual recreations, in part at least, because of their esthetic quality. The arts which today have most vitality for the average person are things he does not take to be arts: for instance, the movie, jazzed music, the comic strip, and, too frequently, newspaper accounts of love-nests, murders, and exploits of bandits. For, when what he knows as art is relegated to the museum and gallery, the unconquerable impulse towards experiences enjoyable in themselves finds such outlet as the daily environment provides. [49, p. 5-6]

Therefore, in this paper, we present a case study where we tried to break down the walls built around artistic objects. To do so, we proposed an experimental scenario, simulating a museum visit with an interactive art exhibit that *needs* to be touched. Following the TUI philosophy, this exhibit is a tangible digital artifact, meant for educational contexts, and built with low-cost materials and hardware. It bridges the virtual and physical worlds by providing multimedia information when sensors in the artifact are triggered.

This paper is structured as follows: in Section 6.2 we discuss the background of our research with a focus on the premise of learning through action. In Section 6.3 we present our case study, entitled "Maned Wolf in the Museum", in which we present the interactive artifact we used, the activity we conducted and the results we collected. In Section 6.4 we discuss our main findings and their implications with regard to their relationship with the concepts of enaction and learning through action. Lastly, in Section 6.5 we present our conclusions and directions for future work.

6.2 Background: Learning Through Action

In what can be considered a first characterization of what would later be known as the "enactive approach", Dewey [48] argues about how we do not experience the world in ordinary sequences of stimulus and responses. For example, imagine a child reaching for a candle and learning how the flame is hot and can burn. One could interpret the light as a stimulus and the movement of reaching for the fire as a response, or the heat from the fire as a stimulus with the response of a sudden movement of taking the hand off the flame after feeling pain. Dewey, however, describes how there is a more complex sensorimotor coordination taking place: "*[...] it is the movement which is primary, and the sensation which is secondary, the movement of body, head and eye muscles determining the quality of what is experienced.*" [48, p. 358].

In a similar fashion, Bruner [26] proposed a sequence for the learning process, composed of three moments: the action-based (enactive), the image-based (iconic) and the language-based (symbolic). Bruner says that these moments appear for a child in this particular order. However, based on their own observations, Francis et al. [84] argue that the three stages do not develop sequentially in time, nor are distinct from one another. Instead, the authors claim they are co-occurring and co-dependent, which is coherent with the sensorimotor coordination described by Dewey. In a way, this vision is also similar to what Varela et al. [168] described as "laying down a path in walking", *i.e.*, we construct our understanding as we go, through bodily processes, such as walking, gesturing or interacting with others. In this sense, there is also the idea of "enactive metaphors" [87], metaphors we act out instead of simply ingesting them from a text. For instance, when an infant picks up a banana and pretends it is a phone, the action of picking up the banana and placing it by her ear is a way of treating the banana metaphorically. Furthermore, the infant enacts a metaphor built on her previous experiences with phones, and on her perception of the banana's shape.

All of these perspectives are somehow consistent with how Varela et al. [168] describe cognition, as something that cannot be entirely contained inside the brain; the body and the environment are an essential part of this equation. In a definition that is purposely circular to highlight the concept of co-origination of organism and world, the so-called "enactive approach" consists of two points:

> (1) perception consists in perceptually guided action and (2) cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided. [168, p. 173].

Considering that the context of our work touches the complex and elusive world of art through the concept of interactive art, the work of Dewey [49] on aesthetics might offer an insight into how we can apply the concept of enaction in our work. The author highlights the importance of a coordination between perception and action to describe art not as something static and pre-given, but as an experience that is enacted:

> In order to understand the esthetic in its ultimate and approved forms, one must begin with it in the raw; in the events and scenes that hold the attentive eye and ear of man, arousing his interest and affording him enjoyment as he looks and listens [...] The sources of art in human experience will be learned by him who sees [...] the zest of the spectator in poking the wood burning on the hearth and in watching the darting flames and crumbling coals. [...] he is none the less fascinated by the colorful drama of change enacted before his eyes and imaginatively partakes in it. He does not remain a cold spectator. [49, p. 4-5]

6.3 Case Study: "Maned Wolf in the Museum"

Our case study took place at the Programa de Desenvolvimento e Integração da Criança e do Adolescente (PRODECAD). Located on the campus of Unicamp, it is a space that offers complementary education to children from 4 to 14 years old after regular school hours. Furthermore, our study is part of a project approved by the university's research ethics committee under the number 32213314.8.0000.5404. In August 2017, we conducted an activity named "Maned Wolf in the Museum", which was conducted with two separate groups. The first group was composed of 7 teachers, all women between ages 40 to 53 years old. The second group had 15 children, 5 girls, and 10 boys, with ages from 8 to 11 years old. The entire activity was documented by video and photos. This separation is a convention already adopted in our research project, in other activities that were conducted in this location.

We introduced the activity by informally asking the participants if they were already familiar with the maned wolf (a wild canid from South America, also common in the city of Campinas), and most of them answered yes. Then, we talked about the experience of visiting a museum, which can be fun, but with the downside that visitors are usually not allowed to touch things. Finally, we explained that we would simulate a visit to a museum, but with an exhibit that people are allowed to freely explore and touch.

Such exhibit is the *interactive maned wolf*, an adaptation of one of the results of a project named InterArt, where undergraduate students were asked to create interactive artworks [55]. The interactive maned wolf was designed for educational museums, and the students made it out of thin cardboard and other relatively inexpensive craft materials. However, particularly for this activity, researchers covered the original cardboard with a fabric that resembles fur, as can be seen in Figures 6.1 and 6.2. In terms of hardware, the artifact is controlled by an Arduino-compatible NodeMCU 1.0 ESP8266 development board with built-in Wi-Fi. The maned wolf's eyes are semitransparent spheres, with a white LED in each one that glows constantly. Some parts of the wolf (head, body, leg, and tail) have push-buttons that, when pressed, send a signal to the microcontroller, which forwards this signal through Wi-Fi to a computer located in the same room. This exchange of messages is managed through a protocol named Message Queuing Telemetry Transport (MQTT), appropriate for quick communications between everyday objects. In turn, the computer is responsible for presenting the information that corresponds to the button that was pressed. Such information includes image, sound, and text. In a similar fashion, there is a proximity sensor on the top of the wolf's head, meant to detect attempts to pet the wolf. When petted, for a few seconds the white LED behind the eyes turn off, and red ones turn on. In addition, the computer emits barking sounds, and then the informational text and voice explain that such behavior is because the wolf is a wild and dangerous animal. We relied on relatively low-cost hardware and craft materials. Besides an ordinary computer with a web browser, the electronic components used cost approximately US$20.00 already considering local availability and taxes. Hypothetically, this value could be lowered to around US$5.00 if it was possible to directly import components from China without additional taxes.

We asked the participants to freely explore the interactive maned wolf for about 15 minutes. They were provided with a paper containing an illustration of a maned wolf, and some empty boxes to fill in information that they learned while interacting with the artifact. In particular, the children were organized into two groups of 7 and 8 children respectively, so that while one group interacted with the artifact, the other waited outside the room, making drawings of the maned wolf. A sample of these drawings is illustrated in Figure 6.3. After the free exploration of the artifact ended, we conducted a conversation about what technologies the participants imagined were present in the interactive maned wolf. After we gathered their guesses, we gave them a brief explanation of the actual hardware, and allowed them to look "under the hood". This was possible because the wolf's body has a lid, so we can open it like a shoe box and look at the hardware and wires inside. We finished the activity by applying an evaluation instrument. We used the SAM [24], which the participants were already familiar with from previous activities. The SAM is a non-verbal pictorial instrument based on the PAD emotional state model, and it is intended to allow people to express their feelings on these three dimensions, towards something like an artifact or even an experience (in this case, their answer was regarding

Figure 6.1: Teachers exploring the interactive maned wolf.

the entire activity). The evaluation instrument was also complemented with the following two open questions answered in writing: “What did you like the **MOST**?” and “What do you like **LEAST**?”.

6.3.1 Results

Our main results are: 1) the behaviors of the participants while interacting with the artifact; 2) the responses of the participants when imagining what kind of technologies are behind the artifact and making sense of how it works; and 3) the feedback from the SAM instrument and the participants’ answers for what they liked most and least.

Interaction Behavior

Regarding the behavior while interacting with the artifact, both teachers and children were initially hesitant to take the first step. This was expected as we intentionally did not explain what the interactive maned wolf could do, and the digital features and means of interaction of the artifact were not clear because the “fur” conceals the wolf’s buttons. However, when someone starts touching and investigating the wolf and discovers, for instance, that there are buttons on it, the others around her are more inclined to investigate it together, leading to a social activity. Every group inevitably discovers that pressing a button triggers a multimedia response on the computer. After this discovery, some participants were interested in carefully pressing each button at a time and strictly

Figure 6.2: Children exploring the interactive maned wolf.

Figure 6.3: Sample of maned wolf drawings from the children.

writing down the information to fill in the empty boxes on provided paper – the one with an illustration of the maned wolf. Other participants, however, were first concerned with pressing all the buttons before writing anything. In fact, some children barely wrote anything because they were very entertained with interacting with the artifact. One aspect that took longer to be discovered was the proximity sensor in the head. As people, particularly children, interacted with the wolf, they would trigger the sensor without realizing it, and they would be surprised by the wolf becoming angry. After the first time this event was triggered, some children became especially interested in finding out how to make the wolf angry. After discovering how it worked, they would playfully do it repeatedly.

Making Sense of Technology

With respect to imagining what kind of technologies are behind the interactive maned wolf, it was already obvious for everyone that there were buttons. However, the working of the proximity sensor in the head was still elusive even for the kids who playfully activated it repeatedly. The participants also noticed that there was some kind of communication between the artifact and the computer displaying images and sounds. It was clear that this communication was wireless, as the maned wolf is self-contained, i.e., there are no cables coming out of it, and participants could freely pick it up and move it without interfering with its operation. When trying to figure out how the communication works, most participants did not guess anything beyond some kind of wireless signal, but one teacher, in particular, conjectured that there was a smartphone inside the "belly" of the wolf. When we opened the lid and revealed the inside of the wolf, we showed how the proximity sensor could be triggered without touching it, and how everything was connected to a microcontroller with Wi-Fi connection and powered by a battery. One child, when looking inside the wolf and seeing wires and electronic components, said surprised: "Wow! He is all robotic!".

Evaluation Instruments

With regard to SAM, Tables 6.1 and 6.2 show the responses for each participant. Blank fields indicate that the participant did not give a score for that dimension. The results for "pleasure" indicate that the activity was considered pleasurable and enjoyable by all the participants, and the results for "arousal" indicate that they were all also fairly excited about it. The results for "dominance", in turn, were lower when compared to the other two dimensions, although still relatively high. These lower values indicate that for teachers and children alike, not every participant felt entirely in control during the activity. Proportionally, however, more children felt in control when compared to teachers.

For the open questions about what they liked and disliked, the teachers highlighted that they liked the engineering and dynamic creativity of the activity, the interactivity, and the sensory experience. They also praised how the wolf can be used by people with disabilities, since a blind person, for instance, can still interact with it using touch to find the buttons – just like sighted people – and hear the audio feedback. For things they did not like, only one teacher noted that she would like the wolf to walk and wag the tail. The children, in turn, highlighted the maned wolf artifact itself, and how they were able to see, learn, touch and draw it. For things they did not like, most children wrote "nothing". However, two of them wrote that they did not like that they had to work as a group, and one child reported that he did not like to have to draw the maned wolf. These are literal quotes from the participants (translated from Portuguese):

> **Participant #4, teacher, liked**: "*The structure of the wolf was very interactive, providing much information through the sensory experience (touch) in the plush animal*"
>
> **Participant #5, teacher, liked**: "*A very interesting activity with a lot of interactivity and creativity*"
>
> **Participant #14, child, liked**: "*I liked to touch the maned wolf*"
>
> **Participant #21, child, liked**: "*Of everything. To draw the maned wolf and to write about the maned wolf*"
>
> **Participant #13, child, disliked**: "*Working with the group*"

Table 6.1: SAM results from the teachers.

Participant	Pleasure (from 1 to 9)	Arousal (from 1 to 9)	Dominance (from 1 to 9)
#1	9	9	7
#2	9	9	7
#3	9	7	5
#4	9	7	
#5	9	9	5
#6	9	9	9
#7	9	9	9
Mode	**9**	**9**	**9, 7 and 5**

6.4 Discussion

With regard to the kind of interaction that the artifact evokes, we do not consider problems neither the concealment of the wolf's buttons nor the ensuing uncertainty towards how to interact with it. We find that the exploratory nature of the artifact plays an important role in its educational intention. In this sense, the interactive maned wolf is not simply an exotic keyboard in which people press keys to see what happens; it is a mystery waiting to be solved. Being able to freely touch and investigate the artifact transforms the very act of discovering that there are buttons on it as important as finding out what the button does when pressed. Such freedom is consistent with the enactive approach presented in Section 6.2. While children and teachers explore the maned wolf, they make sense of how the artifact works. The sensorimotor coordination, in this case, involves the hands and eyes to touch the wolf, the head to turn and look at the computer screen, and the ears to listen to the audio information. All of this happens simultaneously, and goes on as one

Table 6.2: SAM results from the children.

Participant	Pleasure (from 1 to 9)	Arousal (from 1 to 9)	Dominance (from 1 to 9)
#8	9	9	9
#9	9	9	9
#10	9	9	7
#11	9	9	7
#12	9	7	5
#13	7	7	7
#14	9		
#15	9	8	4
#16	9	9	9
#17	9	8	8
#18	9	6	8
#19	8	8	8
#20	8	9	8
#21	9	9	4
#22	8	7	9
Mode	**9**	**9**	**9 and 8**

act feeds the other; the multimedia feedback makes them want to explore more of the wolf, so they keep touching it to find other buttons and then triggering other audio and visual information. This loop resembles the one described by Varela et al. [168], where the perceptually guided action is enabled by recurrent sensorimotor patterns, which make cognitive structures emerge and, hence, allow action to be perceptually guided. In this sense, the social component was crucial in this activity, despite some of the children not enjoying it. Taking a first step to interact with the maned wolf was usually slow, but once one person started exploring the artifact, others got excited and wanted to join in. In this case, one person has their action perceptually guided by the cognitive structures that emerge from seeing another person act; such exchange can go back and forth as long as they are all present and involved in the interaction.

In a similar manner, asking participants to guess what are the technologies involved in the artifact, is part of a learning process that goes beyond understanding what the artifact does; it entails making sense of *how* it works. We can see Bruner's three moments happening at the same time: there is action in exploring the wolf and in looking under the hood to see the hardware; the spatial distribution of the wolf and its sensors, along with the images displayed on the computer screen constitute the iconic stage; finally, understanding that pressing a button or petting the wolf has a consequence, and imagining there is a wireless communication between the wolf and the computer are all part of the symbolic phase. For both teachers and children, this experience was interesting to show them that technological devices are not "magical black boxes". By allowing them to explore the artifact, and then showing its inner workings, and illustratively associating it with already known devices or concepts, we gave them a chance to start a more active and informed relationship with technology.

In turn, the results from SAM indicate that both teachers and children, in different ways, found the activity to be pleasurable, and showed some kind of excitement towards it. During the activity, this was observed by how the teachers calmly explored the wolf, discussed its educational qualities and shared their experiences in museums (and the recurrent "do not touch" policy). The children, however, were extremely excited about the prospect of freely exploring the artifact, and besides the physical exploration, some of them explicitly showed interest in learning new information about the animal and writing it down. As for SAM's dominance dimension, most results are high. The lower numbers in comparison with the other two dimensions also highlight what we consider to be an important aspect of our activity: when we work with an artifact such as the interactive maned wolf, inviting towards exploration and somehow elusive, we do not expect (nor want) people to feel completely "in control" of it. The artifact is a mystery that requires some amount of uncertainty (and sometimes discomfort) to be deciphered, and we conjecture that this very uncertainty and elusiveness corroborates to the high levels of pleasure and arousal in the other two dimensions.

Overall, interacting with the maned wolf was not only a technological and educational experience but also a social activity, as the participants explored it together. One challenge perceived in our study was devising means to allow everyone to participate equally in the exploration of the interactive artifact. This is important, as some kids are more prone to take control of the activity, which may refrain shyer children from joining in. This is probably why two children reported that they did not like having to work as a team. However, to simulate a museum scenario, the activity had to include the social component of collective exploration. As discussed earlier in this section, the social component emerged as an important part of the enactive learning process. In this sense, it would be beneficial to investigate how the artifact could promote more participation, and perhaps empathy, among children.

6.5 Conclusion

In this paper, we gathered a brief theoretical background on enactivism situated in an educational context and used it no analyze our case study. We simulated a museum exhibit that, unlike the conventional approach, not only *can* be, but *must* be touched. The exhibit consisted of a tangible digital version of the maned wolf. This interactive artifact had sensors hidden under its artificial fur, and part of the interaction involved discovering where the sensors were, and what each of them did. Then, in our case study, we observed children and teachers using touch, vision, and hearing to explore and learn with the artifact, using a sensorimotor coordination similar to what the enactive approach describes. We also noted the importance of the social component of a collective exploration. Although some children complained about not fully enjoying the experience because of their colleagues, our evaluation indicated that participants were excited and satisfied with the activity, even though some of them did not feel completely in control. This is expected because the artifact requires some discovery, which can evoke unpredictability. We do not see this as a negative aspect because the unpredictable exploration highlights the enactive approach in the way children and teachers interacted with the wolf.

For future work, we want to further mediate an even more active and informed relationship with technology for both teachers and children. Considering that the technologies used in this study allow plenty of customization and rapid prototyping, we find it plausible to consider that both teachers and students could further elevate themselves to the role of technology co-designers. This could be achieved, for instance, by mediating their participation in the creation of a new version of the maned wolf interactive artifact, or even envisioning and building from scratch a novel artifact altogether. We also intend to further explore the social component afforded by the artifact, which was prominent in our analysis, leading towards investigation of the concept of a socioenactive system.

Chapter 7

“The Magic of Science:” Beyond Action, a Case Study on Learning Through Socioenaction

7.1 Introduction

Drawing on the seminal concepts of ubiquitous computing [171] and tangible user interfaces [105], recent advances in HCI have the potential to drastically change our relationship with digital technology. Embedding computational technology into everyday physical objects and environments brings meaning to our engagement with the world. In this sense, from a phenomenological perspective, meaning is created, manipulated and shared through the interaction with technological artifacts, characterizing what is called *embodied interaction* [52]. This concept is to be taken as a *stance* on the design of interactive systems, and not as a specific way of technological design. Hence, it allows us to have insights into how we act *through* technology, and not *on* technology.

With this stance, we turn our gaze to technology-enhanced educational contexts, where researchers are exploring new ways of learning with commercial off-the-shelf technological products [140], and revisiting long-lasting concepts such as the idea of learning through action [60]. We subscribe to the idea that, when investigating technology-enhanced educational contexts, the approach used to understand and explain cognition is as important, if not more, as the novelty of the technology that is employed. In alternative paradigms of interaction with computational systems, human and computer are not viewed as separated agents, their interaction is considered to be coupled in a way that one cannot be separated from the other. Such view on interaction is part of the enactive approach to cognition [168], which, in essence, describes “laying down a path as you walk it”. In other words, under this perspective, cognition is not contained entirely in the brain; the environment and the whole body are part of it, and action cannot be separated from perception and *vice versa*. Considering this tendency of the divide between humans and computers to become increasingly blurred, we are interested in theoretically and empirically investigating how our social relations with each other may be affected by computational technologies, and how these social relations, in turn, can affect how we interact with such technologies.

Drawing from these phenomenological views on cognition and on interaction, in this paper, we intend to extend the idea of learning through action by focusing on the social aspect. Therefore, this paper is structured as follows: in Section 7.2 we present our background on learning through action and enactivism, in Section 7.3 we report on our case study “The Magic of Science” and its results, in Section 7.4 we discuss how our case study allows us to expand on the concept of learning through action, towards learning through socioenaction, and lastly, in Section 7.5 we present our conclusions.

7.2 Background: Learning Through Action and Enactivism

We can say that the concept of learning through action shares the same phenomenological perspective as embodied interaction, and *coupling* is the common ground that unites these visions. To better illustrate the concept of coupling, Heidegger [102] presents the idea of having a hammer “ready-at-hand”, instead of “present-at-hand”; while the latter implies the hammer as the focus of attention in the act of hammering, the former means executing the action with the hammer as an invisible extension of one’s arm. This is similar to what Dewey [48] describes as a child learning how the flame of a candle is hot and can burn; the sensorimotor coordination is complex in that visual stimulus from the flame, perception in the eyes and skin, as well as body movements, are practically simultaneous, since they all influence each other.

In the domain of computational technology, inspired by the enactive approach [168], the concept of *enactive systems* [112] contributes to a view of human and computer as a dynamic coupling. The premise is that an enactive system can detect both deliberate and unconscious information, such as body movements or physiological readings (*e.g.*, heart rate or galvanic skin response), and respond accordingly. This response from the system, in turn, may directly affect the person and cause new readings, composing an ongoing enactive cycle. Therefore, because person and computer are tightly “coupled” in this model, they are not considered as separated systems. To highlight coupling as a common ground, it is worth noting that Kaipainen *et al.* were also inspired by the concept of “learning through action” from Bruner [26], where the learning process has three phases: the action-based (enactive), the image-based (iconic) and the language-based (symbolic). Bruner’s original idea was that these stages occurred in this specific order, and he placed major importance on the enactive stage to allow the others to happen. To illustrate, a floor could not be described before walking on it; then, one could select and organize the perceptions of images, spatial and temporal qualities of the experience. Finally, one could use a word that stands for “floor”.

This specific order proposed by Bruner, however, may not be mandatory. There is reason to believe that the enactive, iconic and symbolic stages from learning through action are, actually, “*complexly emergent, co-occurring and co-dependent*” [84, p. 6]. Indeed, such idea is consistent with the enactive approach from Varela et al. [168], with the description of sensorimotor coordination with the candle flame from Dewey [48], and with the concept of embodied interaction from Dourish [52]. Each of these authors explored their subject with different backgrounds (*e.g.*, Biology, Philosophy, Education, and the more recent and specialized case of Computer Science from Dourish), and it seems that they unknowingly contributed with each other towards an alternative paradigm for cognition, one in which cognition is not contained only in the brain, and action and perception cannot be separated.

We have already revisited the idea of learning through action in an early case study conducted on an educational context and with pervasive technologies [60]. In this earlier study, participants explored an interactive artistic artifact that relied heavily on touch, since it contained hidden electronic buttons. This way, the artifact itself was an invitation to exploration using the body and the senses. With the case study presented in this paper, we intend to expand on this earlier study, to go beyond the concept of an enactive system, moving towards the novel concept of *socioenactive* systems. In essence, the idea is to have embodied actions from multiple humans as part of the system. This way, the enactive cycle consists of more than a single person-computer coupling; instead, we aim at having couplings between people, between computers, and between the collective (*i.e.*, groups of people) and the computational artifacts. Therefore, all these groups affect and are affected by each other. Such a concept of socioenactive systems is the compass of the investigation we conducted and now report on this paper.

7.3 Case Study: "The Magic of Science"

Our case study took place on April 21, 2018, at the Exploratory Science Museum of Unicamp, located inside the campus. The museum has a captive audience that participates in activities and workshops carried out on weekends and during school vacations. Our workshop, named "A Magia da Ciência" ("The Magic of Science", in English), was aimed at children and adolescents between 10 and 15 years old, but parents were also invited to participate alongside their children. We had a total of $N = 15$ participants (not counting parents). The workshop had an approximate duration of three hours and was composed of five phases: (1) reception, (2) exploration, (3) reflection, (4) construction, and (5) evaluation. We describe each phase in the following:

1. **Reception**: We welcomed the participants and their parents as they arrived. We explained the activities that would be carried out, and, as the workshop is part of a project approved by the university's research ethics committee (CAAE 72413817.3.0000.5404), we explained and handed to the participants and their parents the appropriate assent and consent terms.

2. **Exploration**: We used the space provided by the museum to create an exhibition with three interactive digital artifacts, created in the InterArt [55] project. For approximately 30 minutes, the participants were invited to freely explore the three artifacts in any order and manner they wanted. We video-recorded these interactions for further analysis. The three artifacts exhibited are illustrated in Figure 7.1 and described as follows:

Figure 7.1: The three artifacts exhibited: Lobo-Guará, Memoção, and Monolito.

- **Lobo-Guará** (Maned Wolf, in English): an interactive cardboard maned wolf covered with synthetic fur. It has hidden buttons in the head, body, leg, and tail. When the buttons are found and pressed, they provide auditory and visual information in a display behind the wolf. For instance, pressing the button on the leg provides information about the average size of the footprints left by the wolf. Furthermore, a proximity sensor in the head detects attempts to pet the wolf, triggering red eyes and a bark sound to communicate that the wolf is a wild and dangerous animal.
- **Memoção**: (Memotion, in English): a black box with textures inside, intended to evoke emotions associated with Internet memes. Each texture (*e.g.*, rough, soft, gooey) can be pressed, as there is a button under it. When a texture is pressed, a pair of meme and sound related to that texture is shown and played in a display behind the box. For instance, touching the gooey texture evokes a disgust meme and sound. To keep the experience non-repetitive, the memes and sound are randomly selected from a curated collection of 10 memes and 2 sounds for each texture inside the box.
- **Monolito**: (Monolith, in English): a miniature monolith inspired by the *2001: A Space Odyssey* film, used to interact with a psychedelic scene from the movie. The scene is projected with a 360° projector in a dark room. The audience can pick up the monolith and freely move it around, while an accelerometer and a gyroscope capture the movement to wirelessly control the projection. As an example, shaking the monolith can temporarily increase the playback rate and add a red filter to the image.

3. **Reflection**: For approximately 30 minutes, we mediated an open discussion about what kinds of technologies the participants inferred to exist behind the three artifacts exhibited. The participants perceived that Lobo-Guará and Monolito had some form of wireless communication and that the three artifacts somehow communicated with a computer and the displays to show information. The buttons on Lobo-Guará and Memoção were perceived by all the participants, while the inner workings of Monolito (accelerometer and gyroscope) remained a mystery for most, probably due to the more abstract and subtle nature of the artwork.

4. **Construction**: After reflection, we invited the participants to construct an interac-

Figure 7.2: The construction of “magic potions” and “magic wands”.

tive artifact with similar technology in approximately 1 hour. Inspired by the Harry Potter universe, we proposed a “magic potion” (a color-changing LED attached to a battery and a magnetic sensor, enclosed in a transparent container) that could be activated by a “magic wand” (a paper wand with a magnet on the tip). The components are simple and affordable, costing approximately USD$ 1 for each pair of potion and wand. We guided the construction step by step, talking about the concepts involved (*e.g.*, electricity and polarity of direct current found in batteries, as opposed to alternating current commonly found in power outlets). For the activity to be more playful and meaningful, we invited the participants to ornament their potions and wands with a variety of provided stationery materials. The construction phase is illustrated in Figure 7.2.

5. **Evaluation**: At the end, we used two evaluation instruments to gather feedback on the experience during the workshop. The first is an adaptation of the AttrakDiff [100], to measure hedonic, pragmatic and attractive qualities of the experience. Our adapted questionnaire was translated to Brazilian Portuguese with terms more suited for children, and presented in printed form. It is composed of 20 pairs of opposing adjectives (*e.g.*, “boring” or “captivating”), with a 7-point Likert scale for each pair. The second instrument is based on the Emoti-SAM [101], an adaptation of the SAM [24], aimed at surfacing self-assessed emotions. We adapted it as follows: we printed several colored copies of the 15 symbols in Emoti-SAM, and asked each participant to choose the symbol that best represented his or her emotional state towards the workshop and deposit it in an urn.

7.3.1 Results

Our main results from the workshop are discussed in this paper based on: (1) the observed interactions of the participants with the three interactive artworks during the exploration phase; (2) the data collected with the two instruments we used during the evaluation phase. We briefly present these two groups of results in the following subsections.

Observed Interactions

We conducted a qualitative analysis of the video recordings from the exploration phase. Our main objective was to better understand what kind of interactions are evoked by or emerge during the exploration of the three artifacts exhibited: Lobo-Guará, Memoção, and Monolito. Our analysis methodology was inspired by the Grounded Theory method [93], with the use of a coding schema. The coding schema that emerged from our data gives emphasis to the coupling between the participants actions (expressing emotions such as smiling, making individual actions such as touching something, or making social actions such as making comments) and the responses from the interactive artifacts (or the lack of when there is no input, such as touching an artifact without triggering a sensor), highlighting how action and perception may evoke each other. The transcript and a more detailed coding can be found in [63].

For Lobo-Guará, the coding highlights the predominance of touch when interacting with the artwork. People tend to keep their hands on the physical artifact, feeling the fur while searching for hidden features. As previously reported on [60], Lobo-Guará can evoke social interactions, such as group exploration and coordinated actions (*e.g.*, two or more children exploring the artifact at the same time while formulating hypotheses about how it works, and coordinating specific actions to observe respective outcomes). Similarly, Memoção also relies heavily on touch, requiring someone to stick their hand inside a black box and to feel textures inside it. Even though only one person at a time can put their hand inside the black box, a social aspect surrounding Memoção emerged during the workshop: other people around the artifact were also engaged with the artwork, which was evidenced in three ways: (1) by how they gave suggestions to the person who was interacting with the artifact (*e.g.*, "stick your hand in there"); (2) by how they acted surprised with the images and sounds being evoked; and (3) by how they tried to guess what was happening inside the box based on the expressions of the person interacting and on the system's response (*e.g.*, "he's disgusted").

While Monolito also relies on touch in terms that you have to pick up the artifact and move it around, its more abstract and enigmatic nature stood out during the interaction. People who are interacting with the artwork tend to keep moving the miniature monolith in different ways (*e.g.*, shaking, moving horizontally, and making circles). However, they do not seem to be completely sure about how their actions are impacting the projection, highlighting the cryptic nature of the artwork. Furthermore, even though only one person at a time can manipulate the miniature monolith, much like Memoção, we also observed an emerging underlying social aspect in the artwork. For Monolito, people tended to collectively make hypotheses about how the artifact works (*e.g.*, by executing new actions or making suggestions), and tried to test their hypothesis by observing the outcomes in the projection, regardless of who was holding the artifact.

Workshop Evaluation

With regard to our adapted version of the AttrakDiff questionnaire, for adjectives related to pragmatic quality, the participants considered the workshop experience to be mostly *technical*, *simple*, *practical*, *predictable*, and *clearly structured* (as opposed to human, complicated, impractical, unpredictable, and confusing). For hedonic qualities related to identity, they considered the workshop to be mostly *professional*, *stylish*, *integrating*, *bring me closer*, and *presentable* (as opposed to unprofessional, tacky, alienating, separates me, and unpresentable). Concerning hedonic qualities related to stimulation, they described the experience mostly as *creative*, *innovative*, *captivating*, *challenging*, and *novel* (as opposed to unimaginative, conservative, boring, undemanding, and ordinary). Last but not least, with regard to attractiveness, the experience was reported as mostly *pleasant*, *attractive*, *inviting*, *good*, and *motivating* (as opposed to unpleasant, ugly, rejecting, bad, and discouraging). The results from the adapted AttrakDiff questionnaire also suggest that the workshop had both positive hedonic and pragmatic qualities, but with more emphasis on hedonic qualities.

Furthermore, regarding Emoti-SAM, we counted the emoticons that were selected by participants to represent their emotional states towards the workshop, keeping in mind that each participant selected only one emoticon. As a result, all the emoticons selected by the participants represent the highest value in their respective dimensions of pleasure (thumbs up emoticon, selected 2 times), arousal (smiling emoticon full of ideas, selected 10 times), and dominance (emoticon with graduation cap, selected 3 times). These results suggest that the children had a positive experience, with an emphasis on feeling excited and intellectually stimulated by the workshop, as 10 out of 15 participants selected the smiling emoticon full of ideas, related to arousal. The other two emoticons selected, even though to a lesser extent, suggest that the workshop was felt not only as exciting, but also pleasurable, and as somehow educative and/or empowering.

7.4 Discussion

Going back to Heidegger's example of a hammer, that we presented in Section 7.2, on a physical perspective, Monolito is the interactive artifact that got closer to being "ready-at-hand" (*i.e.*, being an invisible extension of one's arm), instead of "present-at-hand" (*i.e.*, being the focus of attention in the act of hammering). We can say that by analyzing the way people hold and make gestures with the miniature monolith, they tend to not pay attention to the physical artifact. Instead, their focus is at the dynamic projection. However, we do not see these two possibilities as discrete and mutually exclusive. It can be argued that, even though there is no focus on the artifact, there is indeed some attention to "the act of hammering" (*i.e.*, the kinds of movement made with the miniature monolith). This is aligned with the cryptic nature of the artifact, which requires people to constantly try to understand it and figure out how to get different results from the system, especially when several people explore Monolito together.

The artifact Memoção, in turn, brought the "ready-at-hand" sensation into the collective aspect. Those who could not touch it understood and spoke out the sensations that were provoked by the imagery and sounds of the memes. While for the person touching the hidden textured buttons the attention is on the "present-at-hand", because of the anticipation of what they might touch (intentional on the design of the artifact). It is possible to say that, on one hand, for the person interacting directly with Memoção, the enactive stage is the one that leads Bruner's "learning through action" process. On the other hand, for the people watching the interaction unfold, the leading of the process interchanges between iconic and symbolic, since the people infer the actions of the person directly interacting based on: (1) images and sounds from the system, and (2) gestures and facial expressions from the person that is acting. Considering how spectators become eager for their turn to come and to enact their learning by placing their hand inside the artifact, we can say that this social aspect of the interaction allowed them to, in a way, "create their own ideas of a floor" before actually "walking on it".

Extending this metaphor to Monolito, its enigmatic nature does not allow people to eventually walk on the floor they symbolized in their thoughts; instead, they are left each with their own unreliable concepts of a floor. Similar to the parable of the blind men who are asked to describe an elephant only by touching distinct parts of it, the descriptions (or hypotheses of how the system work) are different from each other and likely lack a more complete picture because they are based on each participant's own experiences. Differently from the parable, however, Monolito does allow everyone to have the same experience (*i.e.*, touch the entire elephant), but still, there is no confirmation from the system as to what hypothesis is the most accurate. Hence, the collective discussion over the inner workings of the system is what stimulates the interchange between symbolic, iconic and enactive stages of the "learning through action", in a cycle that can be endless without knowing for certain how Monolito works.

Continuing on the floor metaphor, we consider that Lobo-Guará provides a middle ground between a more certain concept of a floor, and some mystery to unveil. This balance takes the emphasis away from either learning stage of enactive, iconic and symbolic; instead, it varies from person to person: while some prefer to figure out the artifact by touching and exploring it, others choose to observe how it reacts to the actions from someone else. Furthermore, differently from Memoção and Monolito, Lobo-Guará can support simultaneous interactions as multiple people gather around the artifact and touch different parts of it, so the collective and the individual aspects can co-exist. Also, unlike Monolito, Lobo-Guará does provide a rather straightforward feedback, although its head sensor can cause some debate at first, drastically reducing the possibility of an endless cycle of attempts to understand the artifact.

These findings are coherent with the idea that Bruner's enactive, iconic and symbolic stages can be co-occurring and co-dependent. Furthermore, they reveal how the social aspects that underlie the "learning through action" process can be vital for constructing socioenactive systems. First, it is important for the system to have an aura of mystery and novelty around it, that invites people to interact with it. Then, there needs to be a balance; on one hand, the mystery needs to be maintained, to promote the discussion between the people involved in the interaction; on the other hand, it cannot remain too mysterious to the point of alienating people, or else the interactions might cease due to frustration or lack of interest. In this sense, the mystery is what invites each person to construct their own ideas about its features; then, the interactions with the systems are what allow these people to interfere with each other's concepts, helping to either construct or deconstruct them. Therefore, a well-balanced mystery that promotes social investigations will nourish the "complexly emergent" nature of Bruner's stages.

In addition, even though the workshop was well received by the participants, this case study has also revealed important gaps that we need to fill in towards socioenactive systems. For instance, Monolito could have a wider variety of feedback, maintaining its cryptic nature. Then, if such feedback would somehow be a response to the participants' hypotheses, we would have a complete enactive cycle, that involves humans (both on an individual and collective sphere), and computer (both in its core programming and reactive behavior from the performed interactions). In a concrete scenario, suppose that when someone shakes the Monolito, the projection changes color, and when they move it sideways, the speed of the movie changes. As people begin to notice and discuss these patterns, the system responds to these hypotheses and decides to make changes: now shaking Monolito will actually shake the projection, and a new action now alters its colors (*e.g.,* waving it like a wand). This change will further the discussions, promoting new hypotheses and enactions of them. Figure 7.3 illustrates this scenario with Monolito, and the labels for each moment highlight the most prominent event that is taking place at each time. However, it does not imply that when the socioenactive system is running these events will all unfold in this particular order. Furthermore, if the adaptation phase repeats itself continuously, each time creating a new change, then this enactive cycle might go on indefinitely, with the social component acting as a fuel as it continuously promotes new interpretations and enactions.

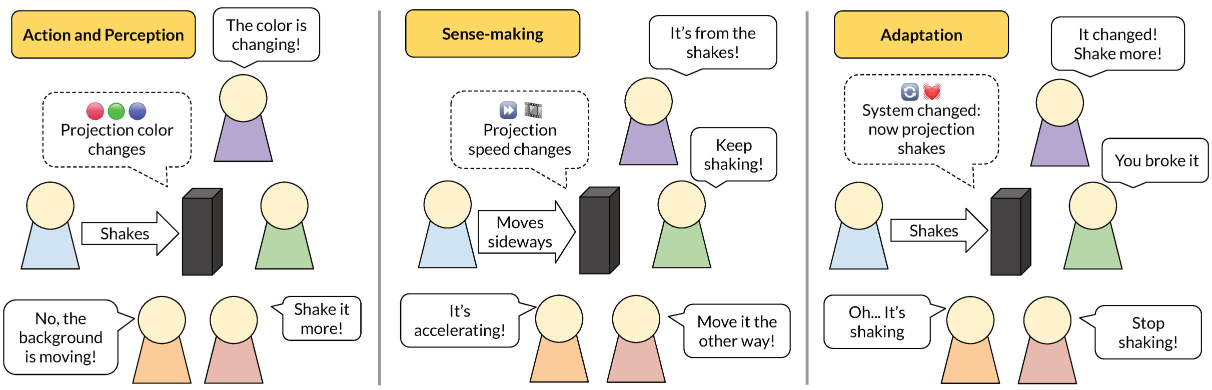


Figure 7.3: Monolito as a socioenactive system.

7.5 Conclusion

Our relationship with digital technology is rapidly changing. Even though newer technologies are often in the spotlight, these fundamental changes, however, are not the result of technological advances alone. Alternative ways of understanding cognition allow us to explore and consolidate new directions in the design of interactive systems, that, in turn, can be applied in educational contexts. In the case study presented in this paper, we investigated how computational interactive artifacts situated in an educational museum exhibit can manifest theoretical concepts related to the enactive approach to cognition. The hands-on nature of the workshop, including the phase of constructing an interactive artifact during the workshop, were aligned with our stance on acting through technology, and the positive feedback from participants showed that they enjoyed this approach. Lastly, with an analysis rooted equally in both theory and practice, we expanded on the long-standing notion of “learning through action”, shedding light on the new concept of socioenactive systems and the notion of “learning through socioenaction”.

Chapter 8

Conclusion

The emergence of a new myriad of computational devices and new interaction contexts brings not only a technological change but also a fundamental shift in how the interaction with computers is viewed and understood. As computational technology is aimed at becoming more transparent and integrated into everyday life, and HCI becomes more concerned with designing interactions that go beyond tasks and well-defined goals, approaches to cognition that describe it in terms of the human brain as an information-processing machine, analogous to a computer with discrete input and output channels, do not properly accommodate the new embodied and pervasive stance to the design of interactive systems. In this regard, Varela, Thompson and Rosch's [168] enactive cognition theory seems more appropriate to support this new design paradigm because it takes into account how cognition is related to the inseparable sensorimotor capacities that come from having a physical body, and that living beings are part of a more encompassing cultural context.

Even though the enactive cognition theory has already inspired the design of so-called "enactive systems", literature on the subject targets the coupling between person and computer while it neglects social and cultural contexts – as exemplified in Chapter 1 with Kaipainen *et al.*'s [112] enactive movie theater – leading to experiences that can be alienating. Consequently, the creation of interactive systems with not only a more coupled interaction but also that take the social dimension into account, is the research opportunity addressed by the "Socio-Enactive Systems" FAPESP Thematic Project (#2015/16528-0). Situated within the aforementioned project, this doctoral thesis presents the *Arte Factus* framework, which contributes towards the design and study of socioenactive digital artifacts. The framework was used to conceptualize socioenaction by designing socioenactive digital artifacts and experimenting with these artifacts in situated practices. Per the enactive cognition theory, conceptualization, design, and practice were not necessarily sequential or incremental activities. The relationship between these activities can be better described by terms of being mutually informed by each other, leading to a continuous transformation of the concept of socioenaction.

Contextualized in the form of interactive art and installations, a socioenactive conceptualization is first seen in Chapter 2, which presents an overview of the relationship and synergies between the fields of HCI and interactive art. The chapter emphasizes different forms of interaction, presented as dialogue genres, featured in interactive art examples found in the literature and other non-academic sources (*e.g.*, digital games and social media). The innovative forms of interaction featured in those examples represent how interactive art can conceptually and technologically inspire the design of computational systems (with or without a previous artistic intent) not only through visual attractiveness, but also by promoting interactions that are more embodied, tangible, and social. These different approaches to interaction bring forth technological and conceptual qualities that are relevant to the concept of socioenaction. Additionally, the chapter also explores design and evaluation approaches that inhabit both the fields of HCI and interactive art. For instance, participatory approaches in the design of interactive installations can challenge traditional understandings of the concept of authorship, creating an opening for the alternative concepts of co-design and co-authorship. It is also evident how the evaluation of interactive art is not primarily concerned with usability, instead of giving more emphasis to experience and considering aspects such as hedonic qualities. While not every socioenactive digital artifact may be intended as art, the study of interactive art examples do provide a substantial conceptual and methodological support, and the examples featured in this chapter provided inspiration for both the design studies and situated practices of this doctoral thesis.

As part of undergraduate and graduate HCI courses, the design studies presented in Chapters 3 to 5 feature three different iterations of a co-design process that is socially aware and closely integrated with pervasive DIY technology. In the form of interactive installations, a collection of 19 interactive artifacts was created, which could later be experimented with in situated practices. Reflecting on how this co-design process contributes to the construction of socioenactive digital artifacts, three emerging aspects can be highlighted: (i) the use of sensors and actuators privileges the design of an interaction that goes beyond the computer screen and traditional input methods, favoring the creation of more transparent computational systems; (ii) a design process that evidences social aspects by considering a wide range of stakeholders that may affect or be affected by the design, and emphasizes co-authorship instead of authorship, is less likely to yield alienating digital artifacts; and (iii) a philosophical stance that people have complex bodies with different sensorimotor capabilities and convoluted emotions, and that computational systems should not be limited to problem-solving and other "purposeful" interaction, can lead to more meaningful and engaging experiences. Consequently, the interactive installations created in these design studies feature a more coupled, embodied interaction, and are co-constructed in a socially aware manner. Alone, none of these aspects is unprecedented in HCI, but articulated together they materialize socioenactive digital artifacts that can be empirically experimented with in subsequent situated practices.

In the form of workshops in educational contexts, the situated practices seen in Chapter 6 present two different empirical studies in which socioenactive digital artifacts were experimented with in non-controlled environments. In the situated practice presented in Chapter 6, which took place in a school, the Lobo-Guará interactive artifact from the InterArt design study was explored with teachers and children. Because the artifact is inherently mysterious (*i.e.*, it is not clear what it does, and no further explanation was provided on purpose), it required tactile exploration that often led to a continuous formulation and testing of hypotheses of how it works. Additionally, the physical form of Lobo-Guará affords several people to interact with it at the same time, transforming the exploration and formulation and testing of hypothesis into a social activity that was reported to be pleasurable and engaging by the participants. In the situated practice presented in Chapter 7, which took place in an exploratory science museum, the interactive artifacts Lobo-Guará, Memoção, and Monolito from the InterArt design study were exhibited and explored with children and adolescents. A more detailed analysis of the interaction was conducted, systematically mapping: the expression of emotions (*e.g.*, smiling or showing surprise); individual actions (*e.g.*, touching or picking something up); and social actions (*e.g.*, interacting with others or making comments). This analysis provided more detail about how these artifacts draw the curiosity of those who approach them, and how they are explored, highlighting how the physical exploration substantially affects and is also affected by the social context. The analysis also evidenced the opportunity of creating artifacts deliberately designed to be interacted with by more than one person at a time. Lastly, the narrative from these two workshops also involved reflecting on what kind of technology was embedded into the artifacts, which favored a more informed relationship with computational technology that is often viewed as a black box.

Revisiting the hypothesis of this doctoral thesis, which stated that "the enactive cognition theory can support the socially aware co-design and study of computational technology to create digital artifacts that evoke an experience that is both enactive and social", the results from the use of the *Arte Factus* framework show that the enactive cognition theory is a good match to the socially aware co-design and study of computational technology. The resulting artifacts, in turn, evoked experiences that were both enactive and social, validating the hypothesis. Moreover, the results from the use of the *Arte Factus* framework also allow a formal understanding and characterization of the concept of a socioenactive digital artifact. This characterization, which was gradually constructed throughout the course of this doctoral thesis as the subject of inquiry and underlying goal, is presented in the following section.

8.1 A Situated, Living Characterization of Socioenactive Digital Artifacts

In light of how the enactive cognition theory emphasizes inseparability (*e.g.*, of action and perception, of being and environment *etc.*), it would be naïve to think of the concept of socioenaction as something that is intrinsically a quality of digital artifacts without regard to how they were designed and how they are experimented with. Instead, a definition of socioenactive digital artifact should encompass not only the hardware and software used to create a digital artifact and its resulting features, but also incorporate how it was designed in terms of social-awareness and co-participation, and take into account the experiences that emerge in practical contexts. This characterization is situated because it comes from the studies and practices that were conducted by specific people, in specific contexts, and with specific participants. Had the people and contexts been different, the outcome would most likely differ accordingly. Another important aspect of this characterization is that it is a living one. What is presented in this doctoral thesis is the current understanding of socioenactive digital artifacts at the time of its writing, but this understanding is expected to be revisited, modified, and transformed by the continued use and appropriation of the *Arte Factus* framework and other studies. Conceptually, it can be summarized that socioenactive digital artifacts are expected to:

- **Be freely explored and provide an open-ended experience, instead of being task or problem-solving oriented.**

  For instance, the small-scale interactive installation from the InstInt design study featured in Chapter 4 is not considered problem-oriented because there is no defined goal in terms of the interaction, and therefore there is no pre-defined set of tasks to that should be carried out. Different combinations of actions will yield different results, but these results are not correct or wrong in any manner, they are just different outcomes that populate the space of possibilities that can be explored.

- **Promote the inseparability of action and perception, with actions creating new perceptions, and new perceptions leading to new actions.**

  The interactive artifact Monolito from the InterArt design study featured in Chapters 3 and 7 can be used as an illustrative example of this inseparability. The projection of psychedelic scenes is played continuously, but it is slightly modified by even minor actions such as picking up the miniature monolith. These elusive modifications to the projection are shown to lead to new perceptions that, in turn, will provoke new actions to further explore and investigate the installation.

Revisiting the research questions stated in the introduction, the first question inquired "how can we construct interactive digital artifacts in a way that they make emerge a socioenactive experience?". In this regard, the co-design process featured in the InterArt, InstInt, and InsTime design studies proved to be successful in supporting the creation of socioenactive artifacts, providing relevant insights regarding how these artifacts could be designed. Concerning design and construction, it can be summarized that socioenactive digital artifacts are expected to be:

- **Socially aware designed, taking into account a comprehensive selection of stakeholders that affect or may be affected by the design.**

  The InterArt, InstInt, and InsTime design studies presented in this doctoral thesis, featured in Chapters 3 to 5 respectively, followed a socially aware design process. To illustrate how this can take place and its results, in the Lobo-Guará interactive artifact from InterArt, for instance, taking into account people with disabilities allowed the installation to be designed with accessibility in mind. A blind person, for example, can still physically explore the wolf and hear the audio feedback.

- **Designed and constructed with pervasive technology, making use of sensor and actuator technologies to go beyond the computer screen.**

  The design process in the InterArt, InstInt, and InsTime design studies also promoted the use of pervasive technology, with sensors and actuators. By freely exploring these technologies, the teams from the design studies were able to creatively design and construct varied interactive experiences that promoted a more coupled use of the body (*e.g.*, the Temporário interactive installation from InsTime, which detects the physical presence, or the Limbo interactive installation also from InsTime, which requires the manipulation of a tangible crank), as well as an interaction that go beyond the computer screen into the physical space (*e.g.*, the interactive installation from InstInt, which does not even have a screen).

- **Co-designed and co-constructed by multiple members of a design team, being more of a co-authorship instead of authorship.**

  The InterArt, InstInt, and InsTime design studies also followed a design process with a strong emphasis on co-design and co-construction. In every design team, all the members participated and had an active voice on the project through the use of participatory design techniques, such as Brain Writing and Brain Draw. As especially emphasized in the InstInt design study, in the end, even though individual designers may have particular interests and unique approaches, the co-design and co-construction processes allow these individualities to be articulated together, leading to a shared co-authorship of the resulting interactive installation.

The second research question, in turn, inquired "how can we formally understand and characterize a socioenactive experience evoked by an interactive digital artifact?". On this subject, the situated practices and ongoing conceptualization of socioenactive digital artifacts provided both empirical and conceptual perspectives about how the socioenaction can take place. Concerning evoked qualities of the interaction, it can be summarized that socioenactive digital artifacts are expected to be:

- **Inviting for exploration and discovery without instructions or knowledge acquired from previous interaction with similar interactive artifacts.**

  The interactive artifact Monolito from the InterArt design study featured in Chapters 3 and 7 can be used as an illustrative example of this invitation for exploration and discovery. Because the dark room with a 360° projection is mysteriously inviting, and the miniature monolith at the center of the room affords the action of being picked up, this installation requires no instructions or previous knowledge about similar interactive artifacts to be explored (it can be argued that watching the movie *2001: A Space Odyssey*, which inspired the installation, can elicit more specific meanings to the installation, but it is still not required at all).

- **Capable of being explored simultaneously by more than one person, responding to the actions of the group and keeping the people engaged.**

  The interactive installation from the InstInt design study, featured in Chapter 4, can be used as an illustrative example of this simultaneity in exploration: the installation was designed to allow several people to interact at the same time by approaching it and touching one of the suspended ribbons, and it is the combined actions of the group interacting with the artifact that determines how it will respond (*e.g.*, the music and the lights may become "happier" as more people participate). Another example is the Temporário installation featured in Chapter 5: it detects how many people are in front of the artifact, watching the displayed video, and it controls the video accordingly to promote engagement with the content being shown.

Looking at all these conceptual, design, and practical characteristics of socioenactive digital artifacts, it would also be naïve to think of the concept of socioenaction as something discrete pertaining to an objective reality. For instance, not all of the socioenactive digital artifacts presented in this thesis contemplate all of these characteristics, yet they all have complementary socioenactive aspects. Instead of labeling a digital artifact discretely as socioenactive or not, it seems to be a more appropriate approach to think of it in terms of *socioenactiveness* as a result of how many of these characteristics are contemplated and how. It is important to emphasize that the *how* is as important as the *how many*, seeing that ideally a balance between concept, design, and practical characteristics, is likely to be more desirable than the absolute number of contemplated characteristics. Furthermore, characteristics that are not contemplated by a digital artifact, while not mandatory, may provide insights for improved new iterations.

Aside from the academic publications, the *Arte Factus* framework, and a situated and living definition of socioenactive digital artifacts, this doctoral thesis also has the following research contributions for Computer Science and HCI:

- A review of the state of the art of the intersection between HCI and interactive art, with a resulting research agenda that can be followed by researchers (Chapter 2);
- A socially aware design process for the creation of interactive artifacts with pervasive DIY technology, well-documented and easy to instantiate (Chapters 3 to 5);
- An affordable, flexible, and relatively easy to use electronics kit, named *Pincello*, to support the design of interactive installations (Appendix A);
- A collection of interactive artifacts featuring various themes, formats, and approaches to interaction, designed and constructed within the scope of this thesis (Chapters 3 to 5); and
- Situated use and evaluation of the experience of socioenactive digital artifacts exhibited in workshops in educational contexts (Chapters 6 and 7).

8.2 Future Work

In the context of the "Socio-Enactive Systems" project, the socioenactive digital artifacts and the experiences presented in this doctoral thesis can be considered as a step towards socioenactive systems. A definition of what is a socioenactive system is still an ongoing effort, but it can be broadly viewed as a complex system in which social (*e.g.*, several people and their direct and indirect interactions with each other and with artifacts), physical (*e.g.*, the physical environment and multiple physical interactive artifacts embedded into it) and digital (*e.g.*, the media and, with some level of intelligence/autonomy, software being executed in interactive artifacts) components are coupled together and mutually affect each other. While this coupled social, physical, and digital triad appears in the artifacts and experiences presented in this thesis, the constitution of a socioenactive system would require not only several people interacting with a physical artifact but instead an actual environment with people separately exploring multiple artifacts that are computationally connected. Every actor, including interactive artifacts, should simultaneously affect and be affected by the environment and what is virtually or physically taking place in it. Moreover, the software should feature some form of intelligence go beyond pre-defined static routines, being capable of detecting complex configurations of the environment and presenting corresponding dynamic responses.

Considering how the thematic project involves an entire team of researchers and has a much bigger scope and timeframe when compared to this thesis, it is reasonable for the socioenactive digital artifacts and experiences presented here to not have the status of socioenactive systems. These artifacts and experiences, however, can be considered building blocks to the construction of socioenactive systems. Through further socioenactive conceptualization, design studies, and situated practices, it should be possible to create more complex systems deserving the socioenactive qualification. For instance, the setting of the "The Magic of Science" situated practice presented in Chapter 7, which features three interactive artifacts being explored by several people in the same environment, could be expanded in future studies. The interactive artifacts could be re-designed to affect and be affected by each other (*e.g.*, the projections of the Monolito could be not only the result of the data captured by the accelerometer & gyro but also take into account what is currently taking place in the other two artifacts). Furthermore, the small-scale installation from the InstInt design study, presented in Chapter 4, could be built in full-scale and inserted into the environment of the situated practice, making it more sensitive to the presence and actions of people involved and providing a more surrounding audio and visual feedback. This feedback, in turn, is dynamically generated as the consequence of the complex social and computational interactions occurring in the environment.

The hypothetical scenario described above, although currently only an exercise of though, exemplifies how the *Arte Factus* framework can contribute towards the construction of the more encompassing and ongoing concept of socioenactive systems. Moreover, further use of the *Arte Factus* framework, in turn, should also contribute back to further its living characterization of socioenactive digital artifacts.

Bibliography

[1] Damien Ablart, Carlos Velasco, Chi Thanh Vi, Elia Gatti, and Marianna Obrist. The how and why behind a multisensory art display. *interactions*, 24(6):38–43, October 2017. ISSN 1072-5520. URL https://doi.org/10.1145/3137091.

[2] Thomas Adajian. The definition of art. In Edward N. Zalta, editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, Stanford, CA, USA, summer 2016 edition, 2016. URL https://plato.stanford.edu/archives/sum2016/entries/art-definition/.

[3] Piotr D. Adamczyk, Kevin Hamilton, Michael B. Twidale, and Brian P. Bailey. HCI and new media arts: Methodology and evaluation. In *CHI '07 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '07, pages 2813–2816, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-642-4. URL https://doi.org/10.1145/1240866.1241084.

[4] Ximena Alarcón-Díaz, Kira Askaroff, Linda Candy, Ernest Edmonds, Jane Faram, and Gillian Hobson. Evaluation in public art: The light logic exhibition. In Linda Candy and Sam Ferguson, editors, *Interactive Experience in the Digital Age: Evaluating New Art Practice*, pages 187–208. Springer International Publishing, Cham, 2014. ISBN 978-3-319-04510-8. URL https://doi.org/10.1007/978-3-319-04510-8_13.

[5] Pietro Albini. Archive of reddit's r/place, April 2017. URL https://github.com/pietroalbini/reddit-place-2017.

[6] Morgan G. Ames, Jeffrey Bardzell, Shaowen Bardzell, Silvia Lindtner, David A. Mellis, and Daniela K. Rosner. Making cultures: Empowerment, participation, and democracy - or not? In *Proceedings of the Extended Abstracts of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, CHI EA '14, pages 1087–1092, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2474-8. URL https://doi.org/10.1145/2559206.2579405.

[7] Mikko Apiola, Matti Lattu, and Tomi A. Pasanen. Creativity and intrinsic motivation in computer science education: Experimenting with robots. In *Proceedings of the Fifteenth Annual Conference on Innovation and Technology in Computer Science Education*, ITiCSE '10, pages 199–203, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-820-9. URL https://doi.org/10.1145/1822090.1822147.

[8] Kevin Ashton. That 'internet of things' thing. *RFiD Journal*, 22(7):97–114, 2009.

[9] Gabriela Avram and Laura Maye. Co-designing encounters with digital cultural heritage. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems*, DIS '16 Companion, pages 17–20, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4315-2. URL https://doi.org/10.1145/2908805.2908810.

[10] Liam J. Bannon and Pelle Ehn. Design: Design matters in participatory design. In Jesper Simonsen and Toni Robertson, editors, *Routledge International Handbook of Participatory Design*, Routledge International Handbooks. Routledge, London, United Kingdom, 2013.

[11] M. Cecília C. Baranauskas. Social awareness in hci. *interactions*, 21(4):66–69, July 2014. ISSN 1072-5520. URL https://doi.org/10.1145/2621933.

[12] M. Cecília C. Baranauskas and Julian E. Gutiérrez Posada. Tangible and shared storytelling: Searching for the social dimension of constructionism. In *Proceedings of the 2017 Conference on Interaction Design and Children*, IDC '17, pages 193–203, New York, NY, USA, 2017. ACM. ISBN 978-1-4503-4921-5. URL https://doi.org/10.1145/3078072.3079743.

[13] M. Cecília C. Baranauskas, Juliano Schimiguel, Carlos A. C. Simoni, and Cláudia Bauzer Medeiros. Guiding the process of requirements elicitation with a semiotic-based approach – a case study. In *Proceedings of the 11th International Conference on Human-Computer Interaction*, pages 100–111, New Jersey, USA, 2005. Lawrence Erlbaum.

[14] Jeffrey Bardzell and Shaowen Bardzell. What is "critical" about critical design? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, pages 3297–3306, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-1899-0. URL https://doi.org/10.1145/2470654.2466451.

[15] Jeffrey Bardzell and Shaowen Bardzell. Humanistic hci. *Synthesis Lectures on Human-Centered Informatics*, 8(4):1–185, 2015. URL https://doi.org/10.2200/S00664ED1V01Y201508HCI031.

[16] Jeffrey Bardzell, Shaowen Bardzell, and Lone Koefoed Hansen. Immodest proposals: Research through design and knowledge. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15, pages 2093–2102, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3145-6. URL https://doi.org/10.1145/2702123.2702400.

[17] Stephen Barrass and Ana Luisa Sanchez Laws. Experience and evaluation in the collective creation of a public digital exhibition. In Linda Candy and Sam Ferguson, editors, *Interactive Experience in the Digital Age: Evaluating New Art Practice*, pages 209–219. Springer International Publishing, Cham, 2014. ISBN 978-3-319-04510-8. URL https://doi.org/10.1007/978-3-319-04510-8_14.

[18] Steve Benford, Chris Greenhalgh, Gabriella Giannachi, Brendan Walker, Joe Marshall, and Tom Rodden. Uncomfortable user experience. *Commun. ACM*, 56(9):66–73, September 2013. ISSN 0001-0782. URL `https://doi.org/10.1145/2500468.2500889`.

[19] Ben Bengler and Nick Bryan-Kinns. In the wild: Evaluating collaborative interactive musical experiences in public settings. In Linda Candy and Sam Ferguson, editors, *Interactive Experience in the Digital Age: Evaluating New Art Practice*, pages 169–186. Springer International Publishing, Cham, 2014. ISBN 978-3-319-04510-8. URL `https://doi.org/10.1007/978-3-319-04510-8_12`.

[20] Susanne Bødker. A human activity approach to user interfaces. *Hum.-Comput. Interact.*, 4(3):171–195, September 1989. ISSN 0737-0024. URL `https://doi.org/10.1207/s15327051hci0403_1`.

[21] Susanne Bødker. When second wave HCI meets third wave challenges. In *Proceedings of the 4th Nordic Conference on Human-computer Interaction: Changing Roles*, NordiCHI '06, pages 1–8, New York, NY, USA, 2006. ACM. ISBN 1-59593-325-5. URL `https://doi.org/10.1145/1182475.1182476`.

[22] Susanne Bødker. Third-wave hci, 10 years later—participation and sharing. *interactions*, 22(5):24–31, August 2015. ISSN 1072-5520. URL `https://doi.org/10.1145/2804405`.

[23] John Bowers, Liam Bannon, Mike Fraser, Jon Hindmarsh, Steve Benford, Christian Heath, Gustav Taxén, and Luigina Ciolfi. From the disappearing computer to living exhibitions: Shaping interactivity in museum settings. In Norbert Streitz, Achilles Kameas, and Irene Mavrommati, editors, *The Disappearing Computer: Interaction Design, System Infrastructures and Applications for Smart Environments*, pages 30–49. Springer Berlin Heidelberg, Berlin, Heidelberg, 2007. ISBN 978-3-540-72727-9. URL `https://doi.org/10.1007/978-3-540-72727-9_2`.

[24] Margaret M. Bradley and Peter J. Lang. Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, 25(1):49 – 59, 1994. ISSN 0005-7916. URL `https://doi.org/10.1016/0005-7916(94)90063-9`.

[25] Richard Brown. Imorphia: An embodied performance system. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3820–3823, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL `https://doi.org/10.1145/2851581.2891087`.

[26] Jerome S. Bruner. The course of cognitive growth. *American psychologist*, 19(1):1, 1964.

[27] Anil Camci. Distractions: Interactive visualizations on a kinetic sculpture using infrasound vibrations. In *Proceedings of the 2016 CHI Conference Extended*

Abstracts on Human Factors in Computing Systems, CHI EA '16, pages 3827–3830, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891104.

[28] Linda Candy. Evaluating Creativity. In John M. Carroll, editor, *Creativity and Rationale: Enhancing Human Experience by Design*, Human–Computer Interaction Series, pages 57–84. Springer London, London, 2013. ISBN 978-1-4471-4111-2. URL https://doi.org/10.1007/978-1-4471-4111-2_4.

[29] Linda Candy. Evaluation and experience in art. In Linda Candy and Sam Ferguson, editors, *Interactive Experience in the Digital Age: Evaluating New Art Practice*, pages 25–48. Springer International Publishing, Cham, 2014. ISBN 978-3-319-04510-8. URL https://doi.org/10.1007/978-3-319-04510-8_3.

[30] Linda Candy and Ernest Edmonds. Introducing creativity to cognition. In *Proceedings of the 3rd Conference on Creativity & Cognition*, C&C '99, pages 3–6, New York, NY, USA, 1999. ACM. ISBN 1-58113-078-3. URL https://doi.org/10.1145/317561.317562.

[31] Linda Candy and Ernest Edmonds. *Explorations in Art and Technology*. Human–Computer Interaction Series. Springer-Verlag London Ltd., London, 2002. ISBN 978-1-4471-1103-0. URL https://doi.org/10.1007/978-1-4471-0197-0.

[32] Linda Candy and Sam Ferguson, editors. *Interactive Experience in the Digital Age: Evaluating New Art Practice*. Springer Series on Cultural Computing. Springer International Publishing, 2014. ISBN 978-3-319-04509-2. URL //www.springer.com/gp/book/9783319045092.

[33] Stuart K. Card, Allen Newell, and Thomas P. Moran. *The Psychology of Human-Computer Interaction*. L. Erlbaum Associates Inc., Hillsdale, NJ, USA, 1983. ISBN 0898592437.

[34] Jean Ho Chu. Design space for tangible and embodied interaction with cultural heritage. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems*, DIS '16 Companion, page 27–28, New York, NY, USA, 2016. Association for Computing Machinery. ISBN 9781450343152. URL https://doi.org/10.1145/2908805.2909420.

[35] Elizabeth F. Churchill, Anne Bowser, and Jennifer Preece. Teaching and learning human-computer interaction: Past, present, and future. *interactions*, 20(2):44–53, March 2013. ISSN 1072-5520. URL https://doi.org/10.1145/2427076.2427086.

[36] Luigina Ciolfi and Daniela Petrelli. Studying a community of volunteers at a historic cemetery to inspire interaction concepts. In *Proceedings of the 7th International Conference on Communities and Technologies*, C&T '15, pages 139–148, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3460-0. URL https://doi.org/10.1145/2768545.2768547.

[37] Luigina Ciolfi, Mikael Fernstrom, Liam J. Bannon, Parag Deshpande, Paul Gallagher, Colm McGettrick, Nicola Quinn, and Stephen Shirley. The shannon portal installation: Interaction design for public places. *Computer*, 40(7):64–71, July 2007. ISSN 0018-9162. URL `https://doi.org/10.1109/MC.2007.255`.

[38] Luigina Ciolfi, Daniela Petrelli, Fiona McDermott, Gabriela Avram, and Dick van Dijk. Co-design to empower cultural heritage professionals as technology designers. In David Bihanic, editor, *Empowering Users through Design: Interdisciplinary Studies and Combined Approaches for Technological Products and Services*, pages 213–224. Springer International Publishing, Cham, 2015. ISBN 978-3-319-13018-7. URL `https://doi.org/10.1007/978-3-319-13018-7_12`.

[39] Luigina Ciolfi, Gabriela Avram, Laura Maye, Nick Dulake, Mark T. Marshall, Dick van Dijk, and Fiona McDermott. Articulating co-design in museums: Reflections on two participatory processes. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, CSCW '16, pages 13–25, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-3592-8. URL `https://doi.org/10.1145/2818048.2819967`.

[40] Rachel Elizabeth Clarke, Jo Briggs, Ann Light, Sara Heitlinger, and Clara Crivellaro. Socially engaged arts practice in hci. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '14, pages 69–74, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2474-8. URL `https://doi.org/10.1145/2559206.2559227`.

[41] Brigid Costello. A pleasure framework. *Leonardo*, 40(4):370–371, July 2007. ISSN 0024-094X. URL `https://doi.org/10.1162/leon.2007.40.4.370`.

[42] Brigid Costello and Ernest Edmonds. A study in play, pleasure and interaction design. In *Proceedings of the 2007 Conference on Designing Pleasurable Products and Interfaces*, DPPI '07, pages 76–91, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-942-5. URL `https://doi.org/10.1145/1314161.1314168`.

[43] Brigid Costello and Ernest Edmonds. A tool for characterizing the experience of play. In *Proceedings of the Sixth Australasian Conference on Interactive Entertainment*, IE '09, pages 2:1–2:10, New York, NY, USA, 2009. ACM. ISBN 978-1-4503-0010-0. URL `https://doi.org/10.1145/1746050.1746052`.

[44] Daniel Cressey. Age of the arduino. *Nature*, 544(7648):125–126, April 2017.

[45] Peter Dalsgård and Kim Halskov. Real life experiences with experience design. In *Proceedings of the 4th Nordic Conference on Human-computer Interaction: Changing Roles*, NordiCHI '06, pages 331–340, New York, NY, USA, 2006. ACM. ISBN 1-59593-325-5. URL `https://doi.org/10.1145/1182475.1182510`.

[46] Antonio Daniele. This is not private. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages

3831–3834, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891086.

[47] V. Devecseri, Z. Farkas, A. Bartók, N. Haláchy, and D. Samu. The technology behind photorobot, an interactive kinect-based installation. In *2012 IEEE 13th International Symposium on Computational Intelligence and Informatics (CINTI)*, pages 401–404, Budapest, Hungary, Nov 2012. IEEE. URL https://doi.org/10.1109/CINTI.2012.6496799.

[48] John Dewey. The reflex arc concept in psychology. *Psychol. Rev*, 3(4):357–370, 1896. URL https://doi.org/10.1037/h0070405.

[49] John Dewey. *Art as Experience.* Minton, Balch & Company, New York, NY, USA, 1934.

[50] Anastasios Dimitropoulos, Konstantinos Dimitropoulos, Angeliki Kyriakou, Maximos Malevitis, Stelios Syrris, Stella Vaka, Panayiotis Koutsabasis, Spyros Vosinakis, and Modestos Stavrakis. The loom: Interactive weaving through a tangible installation with digital feedback. In Marinos Ioannides, editor, *Digital Cultural Heritage: Final Conference of the Marie Skłodowska-Curie Initial Training Network for Digital Cultural Heritage, ITN-DCH 2017, Olimje, Slovenia, May 23–25, 2017, Revised Selected Papers*, pages 199–210. Springer International Publishing, Cham, 2018. ISBN 978-3-319-75826-8. URL https://doi.org/10.1007/978-3-319-75826-8_17.

[51] Diana Domingues, Cristiano Jacques Miosso, Suélia F. Rodrigues, Carla Silva Rocha Aguiar, Tiago F. Lucena, Mateus Miranda, Adson F. Rocha, and Ramesh Raskar. Embodiments, visualizations, and immersion with enactive affective systems. In *Proc. SPIE*, volume 9012, pages 90120J–90120J–13, 2014. URL https://doi.org/10.1117/12.2042590.

[52] Paul Dourish. *Where the Action is: The Foundations of Embodied Interaction.* MIT Press, Cambridge, MA, USA, 2001. ISBN 0-262-04196-0.

[53] Judith Doyle and Naoto Hieda. Avian attractor. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3835–3838, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891093.

[54] Emanuel Felipe Duarte and M. Cecília C. Baranauskas. Revisiting the three hci waves: A preliminary discussion on philosophy of science and research paradigms. In *Proceedings of the 15th Brazilian Symposium on Human Factors in Computing Systems*, IHC '16, pages 38:1–38:4, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-5235-2. URL https://doi.org/10.1145/3033701.3033740.

[55] Emanuel Felipe Duarte and M. Cecília C. Baranauskas. Interart: Learning human-computer interaction through the making of interactive art. In Masaaki Kurosu, editor, *Human-Computer Interaction. Theories, Methods, and Human Issues*, pages

35–54, Cham, 2018. Springer International Publishing. ISBN 978-3-319-91238-7. URL https://doi.org/10.1007/978-3-319-91238-7_4.

[56] Emanuel Felipe Duarte and M. Cecília C. Baranauskas. Revisiting interactive art from an interaction design perspective: Opening a research agenda. In *Proceedings of the 17th Brazilian Symposium on Human Factors in Computing Systems*, IHC 2018, pages 35:1–35:10, New York, NY, USA, 2018. ACM. ISBN 978-1-4503-6601-4. URL https://doi.org/10.1145/3274192.3274227.

[57] Emanuel Felipe Duarte and M. Cecília C. Baranauskas. Interart: A constructionist approach to learning human-computer interaction. Submitted for peer review, 2020.

[58] Emanuel Felipe Duarte and M. Cecília C. Baranauskas. Pincello: An affordable electronics kit for prototyping interactive installations. In *Proceedings of the 22nd International Conference on Human-Computer Interaction (HCI International 2020)*, Cham, 2020. Springer International Publishing. Accepted for publication.

[59] Emanuel Felipe Duarte, Fabrício Matheus Gonçalves, and M. Cecília C. Baranauskas. Instint: Enacting a small-scale interactive installation through co-design. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction*, OzCHI '18, pages 338–348, New York, NY, USA, 2018. ACM. ISBN 978-1-4503-6188-0. URL https://doi.org/10.1145/3292147.3292158.

[60] Emanuel Felipe Duarte, Vanessa R. M. L. Maike, and M. Cecília C. Baranauskas. "Maned wolf in the museum": a case study on learning through action. In *Anais do XXIV Workshop de Informática na Escola (WIE 2018)*, Porto Alegre, RS, Brasil, oct 2018. Sociedade Brasileira de Computação (SBC). URL https://doi.org/10.5753/cbie.wie.2018.245.

[61] Emanuel Felipe Duarte, Vanessa R. M. L. Maike, Elaine C. S. Hayashi, and M. Cecília C. Baranauskas. First steps towards socioenactive interactive art. Technical Report IC-18-02, Institute of Computing, University of Campinas, March 2018. URL http://www.ic.unicamp.br/~reltech/2018/18-02.pdf.

[62] Emanuel Felipe Duarte, Vanessa R. M. L. Maike, Yusseli Lizeth Méndez Mendoza, Camilla Valéria de Lima Tenório Brennand, and M. Cecília C. Baranauskas. "the magic of science:" beyond action, a case study on learning through socioenaction. In *Anais do XXV Workshop de Informática na Escola (WIE 2019)*, pages 501–510, Porto Alegre, RS, Brasil, nov 2019. Sociedade Brasileira de Computação (SBC). URL https://doi.org/10.5753/cbie.wie.2019.501.

[63] Emanuel Felipe Duarte, Vanessa R. M. L. Maike, Yusseli Lizeth Méndez Mendoza, Camilla Valéria de Lima Tenório, and M. Cecília C. Baranauskas. A hands-on experience with interactive art within a museum scenario. Technical Report IC-19-03, Institute of Computing, University of Campinas, March 2019. URL https://www.ic.unicamp.br/~reltech/2019/19-03.pdf.

[64] Emanuel Felipe Duarte, Luiz Ernesto Merkle, and M. Cecília C. Baranauskas. The interface between interactive art and human-computer interaction: Exploring dialogue genres and evaluative practices. *Journal of Interactive Systems*, 10(2):20–34, 2019. ISSN 2236-3297. URL https://doi.org/10.5753/jis.2019.551.

[65] Emanuel Felipe Duarte, Yusseli Lizeth Méndez Mendoza, and M. Cecília C. Baranauskas. Instime: a case study on the co-design of interactive installations on deep time. In *Proceedings of the 2020 Designing Interactive Systems Conference*, DIS '20, New York, NY, USA, 2020. Association for Computing Machinery. ISBN 9781450369749. URL https://doi.org/10.1145/3357236.3395554.

[66] Anthony Dunne and Fiona Raby. *Design Noir: The Secret Life of Electronic Objects*. August / Birkhäuser, Basel, Switzerland, 2001. ISBN 9783764365660.

[67] Anthony Dunne and Fiona Raby. *Speculative Everything: Design, Fiction, and Social Dreaming*. The MIT Press. MIT Press, Cambridge, MA, USA, 2013. ISBN 9780262019842.

[68] J. Trevor D'Arcey, Julia Katherine Haines, and Elizabeth Churchill. Understanding embodied state using speculative artifacts. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, DIS '19, page 671–682, New York, NY, USA, 2019. Association for Computing Machinery. ISBN 9781450358507. URL https://doi.org/10.1145/3322276.3322295.

[69] Umberto Eco. *The open work*. Harvard Univerisity Press, 1989.

[70] Ernest Edmonds. Human computer interaction, art and experience. In Linda Candy and Sam Ferguson, editors, *Interactive Experience in the Digital Age: Evaluating New Art Practice*, pages 11–23. Springer International Publishing, Cham, 2014. ISBN 978-3-319-04510-8. URL https://doi.org/10.1007/978-3-319-04510-8_2.

[71] Ernest Edmonds. The art of interaction: What hci can learn from interactive art. *Synthesis Lectures on Human-Centered Informatics*, 11(1):i–73, 2018. URL https://doi.org/10.2200/S00825ED1V01Y201802HCI039.

[72] Ernest Edmonds and Sean Clark. Tango apart: Moving together. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3663–3666, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2890235.

[73] Ernest Edmonds, Steve Benford, Zafer Bilda, Jill Fantauzzacoffin, Roger Malina, and Hughes Vinet. Digital arts: Did you feel that? In *CHI '13 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '13, pages 2439–2446, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-1952-2. URL https://doi.org/10.1145/2468356.2468797.

[74] Douglas C. Engelbart. Augmenting human intellect: A conceptual framework. Technical report, Stanford Research Institute, 1962. URL https://www.dougengelbart.org/pubs/augment-3906.html.

[75] David England. Art.chi: Curating the digital. In David England, Thecla Schiphorst, and Nick Bryan-Kinns, editors, *Curating the Digital: Space for Art and Interaction*, pages 1–7. Springer International Publishing, Cham, 2016. ISBN 978-3-319-28722-5. URL https://doi.org/10.1007/978-3-319-28722-5_1.

[76] David England, Ernest Edmonds, Jennifer G. Sheridan, Scott Pobiner, Nick Bryan-Kinns, Peter Wright, Michael Twidale, and Carla Diana. Digital arts and interaction (invited). In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '11, pages 609–612, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0268-5. URL https://doi.org/10.1145/1979742.1979538.

[77] David England, Jocelyn C. Spence, Celine E. Latulipe, Ernest Edmonds, Linda Candy, Thecla Schiphorst, Nick Bryan-Kinns, and Kirk Woolford. Art and interaction sig: Cataloging the digital arts. In *Proceedings of the Extended Abstracts of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, CHI EA '14, pages 1115–1118, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2474-8. URL https://doi.org/10.1145/2559206.2559210.

[78] David England, Linda Candy, Celine Latulipe, Thecla Schiphorst, Ernest Edmonds, Younghui Kim, Sean Clark, and Andruid Kerne. Art.chi. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '15, pages 2329–2332, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3146-3. URL https://doi.org/10.1145/2702613.2702637.

[79] David England, Celine Latulipe, Nick Bryan-Kinns, Ernest Edmonds, and Sean Clark. Art.chi ii: Digital art in a post-digital world. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3477–3483, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2856474.

[80] Jill Fantauzzacoffin, Joanna Berzowska, Ernest Edmonds, Ken Goldberg, D. Fox Harrell, and Brian Smith. The arts, HCI, and innovation policy discourse: Invited panel. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '12, pages 1111–1114, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1016-1. URL https://doi.org/10.1145/2212776.2212399.

[81] Jill Fantauzzacoffin, Linda Candy, Ayoka Chenzira, Ernest Edmonds, David England, Thecla Schiphorst, and Atau Tanaka. Articulating lines of research in digital arts, HCI, and interaction (invited sig). In *CHI '12 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '12, pages 1177–1180, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1016-1. URL https://doi.org/10.1145/2212776.2212417.

[82] Wenhan Feng and Yueyue Wang. Urban memory accessor: Mechanical design of interactive installation based on arduino. In Philip F. Yuan, Yi Min (Mike) Xie, Jiawei Yao, and Chao Yan, editors, *Proceedings of the 2019 DigitalFUTURES*, pages 346–354, Singapore, 2020. Springer Singapore. ISBN 978-981-13-8153-9.

[83] Paul M. Fitts. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47(6):381–391, 1954. URL `https://doi.org/10.1037/h0055392`.

[84] Krista Francis, Steven Khan, and Brent Davis. Enactivism, spatial reasoning and coding. *Digital Experiences in Mathematics Education*, 2(1):1–20, Apr 2016. ISSN 2199-3254. URL `https://doi.org/10.1007/s40751-015-0010-4`.

[85] Christopher Frayling. Research in art and design. *Royal College of Art Research Papers*, 1(1):1–5, 1993. URL `https://researchonline.rca.ac.uk/384/`.

[86] Emmanuel Frécon, Olov Ståhl, Jonas Söderberg, and Anders Wallberg. Visualising sound perception in a submarine: A museum installation. In *Eighth IEEE International Symposium on Distributed Simulation and Real-Time Applications*, pages 38–45, Budapest, Hungary, Oct 2004. IEEE. URL `https://doi.org/10.1109/DS-RT.2004.43`.

[87] Shaun Gallagher and Robb Lindgren. Enactive metaphors: Learning through full-body engagement. *Educational Psychology Review*, 27(3):391–404, Sep 2015. ISSN 1573-336X. URL `https://doi.org/10.1007/s10648-015-9327-1`.

[88] Game Freak. Pokémon red. Game [Game Boy], September 1998. Nintendo Co., Ltd., Kyoto, Japan.

[89] Anna Gardeli, Spyros Vosinakis, Konstantinos Englezos, Dimitra Mavroudi, Manolis Stratis, and Modestos Stavrakis. Design and development of games and interactive installations for environmental awareness. *EAI Endorsed Transactions on Serious Games*, 4(12), 12 2017. URL `https://doi.org/10.4108/eai.8-12-2017.153402`.

[90] William Gaver. What should we expect from research through design? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, pages 937–946, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1015-4. URL `https://doi.org/10.1145/2207676.2208538`.

[91] Elisa Giaccardi, Pedro Paredes, Paloma Díaz, and Diego Alvarado. Embodied narratives: A performative co-design technique. In *Proceedings of the Designing Interactive Systems Conference*, DIS '12, page 1–10, New York, NY, USA, 2012. Association for Computing Machinery. ISBN 9781450312103. URL `https://doi.org/10.1145/2317956.2317958`.

[92] Alicia M. Gibb. New media art, design, and the arduino microcontroller: A malleable tool. Master's thesis, Pratt Institute, School of Art and Design, 2010.

[93] Barney G. Glaser, Anselm L. Strauss, and Elizabeth Strutzel. The discovery of grounded theory; strategies for qualitative research. *Nursing Research*, 17(4), 1968. ISSN 0029-6562. URL https://journals.lww.com/nursingresearchonline/Fulltext/1968/07000/The_Discovery_of_Grounded_Theory__Strategies_for.14.aspx.

[94] Jennifer Golbeck. 'back off, man. i'm a scientist.': Using fiction to teach beginners hci. *Interactions*, 24(2):70–73, February 2017. ISSN 1072-5520. URL https://doi.org/10.1145/3029599.

[95] Sukeshini Grandhi. Educating ourselves on hci education. *interactions*, 22(6):69–71, October 2015. ISSN 1072-5520. URL https://doi.org/10.1145/2834811.

[96] Jonathan Grudin. The computer reaches out: The historical continuity of interface design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '90, pages 261–268, New York, NY, USA, 1990. ACM. ISBN 0-201-50932-6. URL https://doi.org/10.1145/97243.97284.

[97] Jonathan Grudin. A moving target: The evolution of human-computer interaction. In Julie A. Jacko, editor, *Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications*, Human Factors and Ergonomics, pages xxvii–lxi. CRC Press, Boca Raton, FL, USA, third edition, 2012.

[98] Byeongwon Ha. Endless ripples: A growing interactive donation device. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3843–3846, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891103.

[99] Steve R. Harrison, Deborah Gail Tatar, and Phoebe Sengers. The three paradigms of HCI. In *Alt. Chi. Session at the SIGCHI Conference on Human Factors in Computing Systems*, pages 1–18, San Jose, CA, USA, 2007. ACM.

[100] Marc Hassenzahl, Michael Burmester, and Franz Koller. Attrakdiff: Ein fragebogen zur messung wahrgenommener hedonischer und pragmatischer qualität. In Gerd Szwillus and Jürgen Ziegler, editors, *Mensch & Computer 2003: Interaktion in Bewegung*, pages 187–196, Wiesbaden, Germany, 2003. Vieweg+Teubner Verlag. ISBN 978-3-322-80058-9. URL https://doi.org/10.1007/978-3-322-80058-9_19.

[101] Elaine C. S. Hayashi, Julián E. Gutiérrez Posada, Vanessa R. M. L. Maike, and M. Cecília C. Baranauskas. Exploring new formats of the self-assessment manikin in the design with children. In *Proceedings of the 15th Brazilian Symposium on Human Factors in Computing Systems*, IHC '16, pages 27:1–27:10, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-5235-2. URL https://doi.org/10.1145/3033701.3033728.

[102] Martin Heidegger. *Being and time*. SCM Press, London, UK, 1962.

[103] Thomas T. Hewett, Ronald Baecker, Stuart Card, Tom Carey, Jean Gasen, Marilyn Mantei, Gary Perlman, Gary Strong, and William Verplank. Acm sigchi curricula for human-computer interaction. Technical report, Association for Computing Machinery (ACM), New York, NY, USA, 1992.

[104] Kasper Hornbæk and Antti Oulasvirta. What is interaction? In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, pages 5040–5052, New York, NY, USA, 2017. ACM. ISBN 978-1-4503-4655-9. URL `https://doi.org/10.1145/3025453.3025765`.

[105] Hiroshi Ishii and Brygg Ullmer. Tangible bits: Towards seamless interfaces between people, bits and atoms. In *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, CHI '97, pages 234–241, New York, NY, USA, 1997. ACM. ISBN 0-89791-802-9. URL `https://doi.org/10.1145/258549.258715`.

[106] Philémonne Jaasma, Evert Wolters, Joep Frens, Caroline Hummels, and Ambra Trotto. [x]changing perspectives: An interactive system for participatory sensemaking. In *Proceedings of the 2017 Conference on Designing Interactive Systems*, DIS '17, page 259–269, New York, NY, USA, 2017. Association for Computing Machinery. ISBN 9781450349222. URL `https://doi.org/10.1145/3064663.3064796`.

[107] Giulio Jacucci, Mira Wagner, Ina Wagner, Elisa Giaccardi, Mauro Annunziato, Nell Breyer, Jonas Hansen, Kazuhiro Jo, Stijn Ossevoort, Alessandro Perini, Natacha Roussel, and Susanne Schuricht. Participart: Exploring participation in interactive art installations. In *2010 IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities*, pages 3–10, Seoul, South Korea, Oct 2010. IEEE. URL `https://doi.org/10.1109/ISMAR-AMH.2010.5643313`.

[108] Javier Jaimovich. Ground me! an interactive sound art installation. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 391–394, Sydney, Australia, 2010. URL `https://www.nime.org/proceedings/2010/nime2010_391.pdf`.

[109] Maša Jazbec and Floris Erich. Investigating human identity using the idmirror interactive installation. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3851–3854, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL `https://doi.org/10.1145/2851581.2891091`.

[110] François Jégou. Co-design approaches for early phases of augmented environments. In Saadi Lahlou, editor, *Designing User Friendly Augmented Work Environments: From Meeting Rooms to Digital Collaborative Spaces*, pages 159–189. Springer London, London, 2009. ISBN 978-1-84800-098-8. URL `https://doi.org/10.1007/978-1-84800-098-8_6`.

[111] Yvonne Rogers Jenny Preece, Helen Sharp. *Interaction Design: Beyond Human-Computer Interaction*. Wiley, Hoboken, NJ, USA, fourth edition, 2015.

[112] Mauri Kaipainen, Niklas Ravaja, Pia Tikka, Rasmus Vuori, Roberto Pugliese, Marco Rapino, and Tapio Takala. Enactive systems and enactive media: Embodied human-machine coupling beyond interfaces. *Leonardo*, 44(5):433–438, Sep 2011. ISSN 0024-094X. URL https://doi.org/10.1162/LEON_a_00244.

[113] Laewoo (Leo) Kang. Breaking andywall: Transgressive and playful exploration on the dynamic role of users in art and design. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3855–3858, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891100.

[114] Benjamin K. S. Khoo. User interface design pedagogy: A constructionist approach. *International Journal of Information and Communication Technology Education (IJICTE)*, 7(1):1–10, 2011. ISSN 1550-1876. URL https://doi.org/10.4018/jicte.2011010101.

[115] George (Poonkhin) Khut. Designing biofeedback artworks for relaxation. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3859–3862, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891089.

[116] Bran Knowles, Christopher N. Bull, Nigel Davies, Will Simm, Oliver Bates, and Niall Hayes. Examining interdependencies and constraints in co-creation. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, DIS '19, page 291–302, New York, NY, USA, 2019. Association for Computing Machinery. ISBN 9781450358507. URL https://doi.org/10.1145/3322276.3322317.

[117] Hiroki Kobayashi, Hiromi Kudo, Vicki Moulder, Michael Heidt, and Lorna Boschman. Fukushima audio census. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '17, pages 1393–1398, New York, NY, USA, 2017. ACM. ISBN 978-1-4503-4656-6. URL https://doi.org/10.1145/3027063.3052546.

[118] Laura Korte, Stuart Anderson, Helen Pain, and Judith Good. Learning by game-building: A novel approach to theoretical computer science education. *SIGCSE Bull.*, 39(3):53–57, June 2007. ISSN 0097-8418. URL https://doi.org/10.1145/1269900.1268802.

[119] Vassilis Kostakos. The big hole in HCI research. *interactions*, 22(2):48–51, February 2015. ISSN 1072-5520. URL https://doi.org/10.1145/2729103.

[120] Myron W. Krueger. Responsive environments. In *Proceedings of the June 13-16, 1977, National Computer Conference*, AFIPS '77, pages 423–433, New York, NY, USA, 1977. ACM. URL https://doi.org/10.1145/1499402.1499476.

[121] Thomas S. Kuhn. *The Structure of Scientific Revolutions*. Foundations of the unity of science. University of Chicago Press, Chicago, IL, USA, 1970.

[122] John Lasseter. John lasseter on the future of animation, May 2012. Future of Animation Panel at The Academy's Development of the Digital Animator: Available at: https://youtu.be/uFbOOjAC_Fg.

[123] Sang Won Lee and Georg Essl. Live writing: Gloomy streets. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '17, pages 1387–1392, New York, NY, USA, 2017. ACM. ISBN 978-1-4503-4656-6. URL https://doi.org/10.1145/3027063.3052545.

[124] Tuck W. Leong, Lalya Gaye, Atau Tanaka, Robyn Taylor, and Peter C. Wright. The user in flux: Bringing HCI and digital arts together to interrogate shifting roles in interactive media. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '11, pages 45–48, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0268-5. URL https://doi.org/10.1145/1979742.1979571.

[125] Yvonna S. Lincoln, Susan A. Lynham, and Egon G. Guba. *The SAGE Handbook of Qualitative Research*, chapter Paradigmatic Controversies, Contradictions, and Emerging Confluences, Revisited, pages 108–150. SAGE Publications, Inc, Thousand Oaks, CA, USA, fifth edition, 2017.

[126] Silvia Lindtner. Hackerspaces and the internet of things in china: How makers are reinventing industrial production, innovation, and the self. *China Information*, 28 (2):145–167, 2014. URL https://doi.org/10.1177/0920203X14529881.

[127] Kecheng Liu. *Semiotics in Information Systems Engineering*. Cambridge University Press, Cambridge, UK, 2000. ISBN 9781139425537.

[128] Xiaojia Liu. *Employing MEASUR Methods for Process Reengineering in China*. PhD thesis, University of Twente, Enschede, Netherlands, jun 2001.

[129] Jonas Löwgren. On the significance of making in interaction design research. *Interactions*, 23(3):26–33, April 2016. ISSN 1072-5520. URL https://doi.org/10.1145/2904376.

[130] Arlindo Machado. Waldemar cordeiro: o brasileiro precursor da arte mediada por computadores. *Revista Eco Pós*, 18(1):25–35, 2015. URL https://revistas.ufrj.br/index.php/eco_pos/article/view/2392.

[131] John Maeda. Artists and Scientists: More Alike Than Different, July 2013. URL https://blogs.scientificamerican.com/guest-blog/artists-and-scientists-more-alike-than-different/.

[132] Eitan Mendelowitz, Damon Seeley, and David Glicksman. Whorl: An immersive dive into a world of flowers, color, and play. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3871–3874, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL https://doi.org/10.1145/2851581.2891092.

[133] Michael Michalko. *Thinkertoys: A Handbook of Creative-Thinking Techniques*. Potter/TenSpeed/Harmony, Berkeley, CA, USA, 2010. ISBN 9780307757906.

[134] Giorgio Moscati. Waldemar Cordeiro e o uso do computador nas artes - Um depoimento sobre uma experiência pioneira. *Revista USP*, 1(24):124–135, February 1995. ISSN 2316-9036. URL https://doi.org/10.11606/issn.2316-9036.v0i24p124-135.

[135] Lizzie Muller, Ernest Edmonds, and M. Connell. Living laboratories for interactive art. *CoDesign*, 2(4):195–207, 2006. URL https://doi.org/10.1080/15710880601008109.

[136] Michael J. Muller, Jean Hallewell Haslwanter, and Tom Dayton. Chapter 11 - participatory practices in the software lifecycle. In Marting G. Helander, Thomas K. Landauer, and Prasad V. Prabhu, editors, *Handbook of Human-Computer Interaction (Second Edition)*, pages 255 – 297. North-Holland, Amsterdam, Netherlands, second edition edition, 1997. ISBN 978-0-444-81862-1. URL https://doi.org/10.1016/B978-044481862-1.50077-7.

[137] Jacob Nielsen and Gunver Majgaard. Constructionist prototype programming in a first semester hci course for engineering students. In Pedro Isaías and Katherine Blashki, editors, *Human-Computer Interfaces and Interactivity: Emergent Research and Applications*, Advances in Human and Social Aspects of Technology (AHSAT), pages 50–71. IGI Global, Hershey, PA, USA, 2014. URL https://doi.org/10.4018/978-1-4666-6228-5.

[138] Predrag K. Nikolic. Collective creativity: Utilizing the potentials of multimodal environments. In Raffaele Giaffreda, Dagmar Cagáňová, Yong Li, Roberto Riggio, and Agnès Voisard, editors, *Internet of Things. IoT Infrastructures*, pages 27–37, Cham, 2015. Springer International Publishing. ISBN 978-3-319-19743-2.

[139] Donald A. Norman. *The Design of Everyday Things*. Doubleday/Currency, New York, NY, 1990.

[140] Bruna Panaggio and M. Cecília C. Baranauskas. Explorando as possibilidades do sphero em um ambiente educacional. In *Anais do XXIII Workshop de Informática na Escola (WIE 2017)*, Porto Alegre, RS, Brasil, oct 2017. Sociedade Brasileira de Computação (SBC). URL https://doi.org/10.5753/cbie.wie.2017.245.

[141] Seymour Papert. *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books, New York, NY, USA, 1980.

[142] Seymour Papert and Idit Harel. Situating constructionism. In Idit Harel and Seymour Papert, editors, *Constructionism: Research Reports and Essays, 1985-1990*, pages 1–11. Ablex Publishing Corporation, New York, NY, USA, 1991.

[143] Nikolaos Partarakis, Iosif Klironomos, Margherita Antona, George Margetis, Dimitris Grammenos, and Constantine Stephanidis. Accessibility of cultural heritage

exhibits. In Margherita Antona and Constantine Stephanidis, editors, *Universal Access in Human-Computer Interaction. Interaction Techniques and Environments*, pages 444–455, Cham, 2016. Springer International Publishing. ISBN 978-3-319-40244-4.

[144] Evelyn Patsoule. Interactions around a multi-touch tabletop: A rapid ethnographic study in a museum. In Aaron Marcus, editor, *Design, User Experience, and Usability. User Experience Design Practice*, pages 434–445, Cham, 2014. Springer International Publishing. ISBN 978-3-319-07638-6.

[145] Celia Pearce, Gillian Smith, Jeanie Choi, and Isabella Carlsson. ebee: Merging quilting, electronics & board game design. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3877–3880, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL `https://doi.org/10.1145/2851581.2891099`.

[146] Joseph G. Ponterotto. Qualitative research in counseling psychology: A primer on research paradigms and philosophy of science. *Journal of counseling psychology*, 52 (2):126–136, 2005.

[147] Irene Posch. Crafting tools. *Interactions*, 24(2):78–81, February 2017. ISSN 1072-5520. URL `https://doi.org/10.1145/3038227`.

[148] Irene Posch and Ebru Kurbak. Crafted logic towards hand-crafting a computer. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3881–3884, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL `https://doi.org/10.1145/2851581.2891101`.

[149] Susan Reardon and Brendan Tangney. Smartphones, studio-based learning, and scaffolding: Helping novices learn to program. *Trans. Comput. Educ.*, 14(4):23:1–23:15, December 2014. ISSN 1946-6226. URL `https://doi.org/10.1145/2677089`.

[150] Heloisa Vieira Rocha and M. Cecília C. Baranauskas. *Design e avaliação de interfaces humano-computador.* Unicamp, Campinas, SP, Brazil, 2003.

[151] Yvonne Rogers. Hci theory: Classical, modern, and contemporary. *Synthesis Lectures on Human-Centered Informatics*, 5(2):1–129, 2012. URL `https://doi.org/10.2200/S00418ED1V01Y201205HCI014`.

[152] Thomas Röggla, Chen Wang, Lilia Perez Romero, Jack Jansen, and Pablo Cesar. Tangible air: An interactive installation for visualising audience engagement. In *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition*, C&C '17, page 263–265, New York, NY, USA, 2017. Association for Computing Machinery. ISBN 9781450344036. URL `https://doi.org/10.1145/3059454.3078708`.

[153] Elizabeth B.-N. Sanders and Pieter Jan Stappers. Co-creation and the new landscapes of design. *CoDesign*, 4(1):5–18, 2008. URL `https://doi.org/10.1080/15710880701875068`.

[154] Douglas. Schuler and Aki. Namioka. *Participatory Design: Principles and Practices*. Taylor & Francis, Abingdon-on-Thames, Oxfordshire, UK, 1993. ISBN 9780805809510.

[155] Jennifer Seevinck. Dichroic w. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 3889–3892, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4082-3. URL `https://doi.org/10.1145/2851581.2891094`.

[156] Phoebe Sengers and Chris Csikszentmihályi. HCI and the arts: A conflicted convergence? In *CHI '03 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '03, pages 876–877, New York, NY, USA, 2003. ACM. ISBN 1-58113-637-4. URL `https://doi.org/10.1145/765891.766044`.

[157] Orit Shaer, Consuelo Valdes, Sirui Liu, Kara Lu, Kimberly Chang, Wendy Xu, Traci L. Haddock, Swapnil Bhatia, Douglas Densmore, and Robert Kincaid. Designing reality-based interfaces for experiential bio-design. *Personal and Ubiquitous Computing*, 18(6):1515–1532, Aug 2014. ISSN 1617-4917. URL `https://doi.org/10.1007/s00779-013-0752-1`.

[158] Manoela Silva, Rafael Roberto, and Veronica Teichrieb. Evaluating an educational system based on projective augmented reality. In *Anais do XXIV Simpósio Brasileiro de Informática na Educação (SBIE 2013)*, Porto Alegre, RS, Brasil, nov 2013. Sociedade Brasileira de Computação (SBC). URL `https://doi.org/10.5753/cbie.sbie.2013.214`.

[159] Gavin Sim, Brendan Cassidy, and Janet C. Read. Crowdsourcing ideas for augmented reality museum experiences with children. In Arnold Vermeeren, Licia Calvi, and Amalia Sabiescu, editors, *Museum Experience Design: Crowds, Ecosystems and Novel Technologies*, pages 75–93. Springer International Publishing, Cham, 2018. ISBN 978-3-319-58550-5. URL `https://doi.org/10.1007/978-3-319-58550-5_4`.

[160] Ronald K. Stamper. *Information in Business and Administrative Systems*. John Wiley & Sons, Inc., New York, NY, USA, 1973. ISBN 0471820458.

[161] Andreja Istenic Starcic, Mara Cotic, and Matej Zajc. Design-based research on the use of a tangible user interface for geometry teaching in an inclusive classroom. *British Journal of Educational Technology*, 44(5):729–744, 2013. URL `https://doi.org/10.1111/j.1467-8535.2012.01341.x`.

[162] Lucy A. Suchman. *Plans and Situated Actions: The Problem of Human-machine Communication*. Cambridge University Press, New York, NY, USA, 1987. ISBN 0-521-33137-4.

[163] Olivia L. Tabel, Jonathan Jensen, Martin Dybdal, and Pernille Bjørn. Coding as a social and tangible activity. *Interactions*, 24(6):70–73, October 2017. ISSN 1072-5520. URL `https://doi.org/10.1145/3137099`.

[164] Chek Tien Tan and Sam Ferguson. The role of emotions in art evaluation. In Linda Candy and Sam Ferguson, editors, *Interactive Experience in the Digital Age: Evaluating New Art Practice*, pages 139–152. Springer International Publishing, Cham, 2014. ISBN 978-3-319-04510-8. URL https://doi.org/10.1007/978-3-319-04510-8_10.

[165] thatgamecompany. Journey. Game [Playstation 3], 2012. Sony Computer Entertainment Inc., Tokyo, Japan.

[166] Nicholas True, Jeroen Peeters, and Daniel Fallman. Confabulation in the time of transdisciplinarity: Reflection on hci education and a call for conversation. In Masaaki Kurosu, editor, *Human-Computer Interaction. Human-Centred Design Approaches, Methods, Tools, and Environments*, pages 128–136, Berlin, Heidelberg, 2013. Springer Berlin Heidelberg. ISBN 978-3-642-39232-0.

[167] Arthur B. VanGundy. Brain writing for new product ideas: An alternative to brainstorming. *Journal of Consumer Marketing*, 1(2):67–74, 1984. URL https://doi.org/10.1108/eb008097.

[168] Francisco J. Varela, Evan Thompson, and Eleanor Rosch. *The Embodied Mind: Cognitive Science and Human Experience*. Cognitive science: Philosophy, psychology. MIT Press, Cambridge, MA, USA, 1993. ISBN 9780262720212.

[169] Ron Wakkary and Erik Stolterman. Welcome: The significance of making. *Interactions*, 23(3):5–5, April 2016. ISSN 1072-5520. URL https://doi.org/10.1145/2909879.

[170] Viveka Weiley and Ernest Edmonds. The HCI researcher as artist and designer: Approaches to creativity and distance. In *Proceedings of the 8th ACM Conference on Creativity and Cognition*, C&C '11, pages 233–238, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0820-5. URL https://doi.org/10.1145/2069618.2069658.

[171] Mark Weiser. The computer for the 21st century. *Scientific American*, 265(3):94–104, 1991.

[172] Jon Whittle. How much participation is enough?: A comparison of six participatory design projects in terms of outcomes. In *Proceedings of the 13th Participatory Design Conference: Research Papers - Volume 1*, PDC '14, pages 121–130, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2256-0. URL https://doi.org/10.1145/2661435.2661445.

[173] Stephen Wilson. Art as research, 1996. Available at: http://userwww.sfsu.edu/swilson/papers/artist.researcher.html.

[174] Stephen Wilson. Science and art - looking backward/looking forward, 2003. Available at: http://www.artcenter.edu/williamson/neuro/exhibit/f_body_wilson.html.

[175] Terry Winograd and Fernando Flores, editors. *Understanding Computers and Cognition*. Ablex Publishing Corp., Norwood, NJ, USA, 1985. ISBN 0-89391-050-3.

[176] Yu-Chen Yang, Sheng-Tien Wang, Yi-Jen Tseng, and Hao-Chiang Koong Lin. Light up! creating an interactive digital artwork based on arduino and max/msp design. In *2010 International Computer Symposium (ICS2010)*, pages 258–263, Dec 2010. URL `https://doi.org/10.1109/COMPSYM.2010.5685506`.

[177] Rui (Juliet) Zhu and Ravi Mehta. Sensory experiences and consumer creativity. *Journal of the Association for Consumer Research*, 2(4):472–484, 2017. URL `https://doi.org/10.1086/693161`.

[178] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '07, pages 493–502, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-593-9. URL `https://doi.org/10.1145/1240624.1240704`.

Appendix A

Pincello: An Affordable Electronics Kit for Prototyping Interactive Installations

A.1 Introduction

The understanding of the interaction between a human and a computer has significantly changed since the beginning of the HCI field. The concept of a computer is constantly changing along technological innovation; besides the pervasiveness of personal computers and smartphones, we now have a wide variety of "things" and even environments embedded with computational technology, effectively rendering the computer "invisible", as foretold by Weiser [171]. Following Wieser's concept of ubiquitous computing, as the computer reaches out of the screen it becomes necessary for HCI researchers and practitioners to be able to design interactive artifacts and environments capable of sensing and actuating in varied ways. Consequently, HCI communities show a growing interest in pervasive DIY technologies, such as Arduinos, Raspberry Pis, and related gadgets.

Coincidentally, this growing interest in pervasive DIY technologies is aligned with how HCI has been expanding its boundaries with new waves of thought and is no longer limited to well-defined and/or workplace problems [21, 99, 151, 22]. In practical terms, HCI is now concerned with more than graphical user interfaces and user tasks, it is considering interactive artifacts and environments that encompass more aspects of life other than work, such as social relations, entertainment, art *etc.* In this paper, we focus on a context of practice that has been gaining attention among HCI researchers [56] and benefits significantly from pervasive DIY technologies, which is the creation of interactive art, and more specifically, interactive installations.

DIY technologies have been used in many creative ways in the creation of interactive installations for quite some time. Currently, perhaps the most popular of these technologies is the Arduino microcontroller. Gibb [92] discusses some of the main qualities that defined Arduino's success, which are: (i) its relatively low cost; (ii) it can be programmed via Universal Serial Bus (USB) through an easy to use Integrated Development Environment (IDE); and (iii) it is supported by an engaged community. According to Gibb [92], as the Arduino is introduced in art museums and galleries, it closely resembles the route taken by photography in the 1800s: at first, it was seen as a new technology that belonged only to science museums rather than art ones but is now easily featured in any art museum or gallery. The Arduino has evolved over the years both in terms of hardware and software, but perhaps the most important change is how the word "arduino" became a synonym to a wider range of devices (from other microcontrollers to single-board computers), platforms and sometimes even an entire technological DIY culture (*e.g.*, "the age of the arduino" [44]).

Although DIY technologies are already being used to create interactive installations, one challenge that hinders a more widespread use is how these resources are often documented with a technical language more suited for engineers and hobbyists, while tutorials often involve solving mundane well-defined problems (*e.g.*, home automation). There are commercial products that address this entry-barrier problem with electronic kits designed to simplify circuit making, however, these proprietary kits are often aimed at children in educational contexts, are relatively expensive (usually costing a few hundred US dollars for more complete versions), and lack the flexibility for being extended, modified, and used in unconventional ways, as is often the case of interactive installations. To address these challenges, in this paper we present Pincello, an affordable electronics kit designed specifically for the prototyping of interactive installations. With Pincello, the entry barrier is reduced through a documentation that is practical, illustrative, and not too technical, and the flexibility is ensured by a selection of universal components that can be installed and used in different ways. Pincello was already used in three case studies, InterArt, InstInt, and InsTime, which, combined, involved a total of 105 Computer Science and Computer Engineering undergraduate and graduate students attending HCI courses. The students succeeded in creating a combined total of 19 interactive artworks and installations with varied themes, aesthetics, and innovative approaches to interaction with computational systems.

This paper is structured as follows: in Appendix A.2 we provide, without exhausting the subject, an overview of relevant literature about the use of DIY technology in the creation of interactive installations; in Appendix A.3 we present Pincello, detailing what it is, its online documentation, and its components; in Appendix A.4 we discuss, as case studies, the three instances in which Pincello was used; lastly, in Appendix A.5 we present our conclusions.

A.2 Literature Review

Both Bannon and Ehn [10], and Kostakos [119] argue that HCI literature often shows a tendency to focus on results, products, and services instead of processes and practices. This is no different in the more specialized topic of interactive art, as Duarte, Gonçalves and Baranauskas [59] argue how the design processes and practices for the creation of interactive installations often lack thorough presentation and discussion in the literature. Although a scarce topic, in this section we will briefly discuss, without exhausting the subject, some academic works, and commercial products in the context of the explicit and at least mildly explained use of pervasive DIY technologies for the creation of interactive installations.

In the context of multi-modal installations, the work of Jaimovich [108] describes the use of an Arduino microcontroller to create an interactive sound installation called *Ground Me!*. The installation uses an electrically grounded floor in conjunction with copper poles hanged from the ceiling and connected to the positive side of low voltage batteries. The role of the microcontroller is to detect and communicate to a computer when a circuit is closed, which happens when a barefoot person standing on the floor (or with any other part of its skin touching the floor) touches a copper pole. The value that is detected by the Arduino microcontroller will vary according to skin conductivity and body impedance, and this value is used by the computer to generate a sound related to electricity, such as shocks and sparks. As no specific sensor was used, the author had to engineer the circuit from scratch with batteries, cables and other conductive materials, resistors, and multiplexers. As another example of a multi-modal installation, Yang *et al.* [176], in turn, describe the use of an Arduino microcontroller in their *Light Up!* interactive installation. The authors make use of a computer connected to the Arduino microcontroller to analyze both the volume and pitch of the music being played in the environment. There are also pressure sensors on the ground to capture the dance movements of the people experiencing the installation. After combining the data from the music and how people are dancing, the installation triggers multiple LEDs according to this data combination, creating visual feedback about both the music and the dancing taking place.

In the topic of cultural heritage, the work of Feng and Wang [82] describes the use of an Arduino microcontroller for the design of their *Urban Memory Accessor* interactive installation. The microcontroller is used to control the interactive process of creating a resin cube containing debris from demolished old buildings, intended as a form of preservation of urban culture. When someone activates the installation with a smartphone through a QR code, the Arduino microcontroller commands a series of servo motors responsible for inserting raw materials into a cube mold, injecting the resin, turning on a source of ultraviolet light to cure the resin for five minutes, and then releasing the completed cube. The mechanical complexity of this installation required a formal engineering approach to design the moving parts activated by servo motors. Also on the topic of cultural heritage, the work of Dimitropoulos *et al.* [50] discuss the use of Arduino sensors in the creation of an interactive simplified loom replica connected to an interactive digital application, intended at educating about the millennial weaving process. Although the authors mention design and prototyping, evaluation and testing, and technological tests (regarding microcontrollers, sensors, and connectivity) as steps of their research, they do not provide more detail about how the circuitry was built or which kind of sensor was used in the loom.

On the subject of promoting awareness, the work of Gardeli *et al.* [89] presents 8 projects in the theme of environmental awareness, of which 6 are interactive installations that make use of the Arduino microcontroller. The authors describe the use of varied components for the creation of the installations besides the Arduino microcontrollers, such as infrared motion sensors, Near-Field Communication (NFC) tags and readers, speakers, and even a valve and a small water pump. Also related to awareness, but in this case, real-time awareness of audience engagement during a talk, the work of Röggla *et al.* [152] describes the *Tangible Air* interactive installation. In their experiment, the authors provided the audience with a custom-built wireless Galvanic Skin Response (GSR) sensor, and the presenter wore a sweater with integrated sensors. The data collected from the sensors was shown in real-time to everyone, allowing awareness about the engagement of the audience as a whole, the individual engagement of 10 random people from the audience, and physiological data from the presenter. Besides stating that the wireless GSR sensor was custom-built, the authors do not explain why or how it was engineered.

From our literature review, we can highlight relevant technological challenges that emerge in the design of interactive installations. For instance, there is often a need to create a form of communication between microcontrollers and more powerful computers responsible for more computation-intensive tasks (*e.g.*, from projecting images and playing music to more complex data algorithms). Another aspect to be observed is how often there is a need to engineer electronic circuits and create custom-built components for specific purposes, which can be a complex and demanding task. At a first impression, some commercial products that simplify the use of electronics and the making of things seem to mitigate these challenges. For instance, Bare Conductive's touch board kit with electric paint[1] has many creative uses showcased in the company's website, Furthermore, other commercial options such as Circuit Scribe's circuit drawing kits[2] and LittleBits's maker kits[3] have a playful approach aimed mostly at children education. However, even though these products are suited for exploring, playing, and learning, products that are designed to be easily assembled and disassembled will often lack the flexibility for being extended, connected in unintended ways, tuned and modified. To illustrate, Bare Conductive's electric paint does not go much beyond touch detection, and both Circuit Scribe's and LittleBits's kits seem more useful to prototype toy gadgets, rather than designing interactive environments in which the technology becomes pervasive.

As our literature review shows, pervasive DIY technologies can be a substantial tool in the creation of interactive installations. However, even with a high number of commercial kits, documentation, and tutorials available online, these tools usually have at least one of two limiting factors: low flexibility, limiting what can be created to mostly reproductions of existing projects; or a documentation that is too technical and oriented towards the solution of well-defined day-to-day problems, such as home automation. These options may work fine for hobbyists and educational contexts, but they fall short for HCI researchers and practitioners interested in designing and prototyping open-ended interactive artifacts and environments, such as interactive art and installations. Therefore, it is our understanding that an electronics kit that is both flexible and well-documented, but also affordable, could be of interest to the HCI community.

A.3 Pincello

Pincello is an affordable electronics kit to support the design and prototyping of interactive art and installations. It is important to emphasize that Pincello is not a commercial product and is not being sold anywhere. It instead acts as a recommendation of components

[1]`https://bareconductive.com/`
[2]`https://circuitscribe.com/`
[3]`https://littlebits.com/`

that can be used together to compose an electronics kit. Anyone interested in creating interactive installations with these technologies can assemble a Pincello kit by individually buying the recommended components. The hardware will have an approximated cost between US$20.00 and US$60.00 depending on country, taxes and local availability of components. Pincello has two equally important parts: the hardware itself, and an accompanying original online documentation with practical tutorials[4].

The hardware is composed by two single-board microcontroller units, 12 different kinds of sensors, and 6 different kinds of actuators (there are also other components in Pincello, such as breadboards, jumper cables, and resistors, but we will not discuss these in detail in this paper as they are not pertinent to our HCI focus). We briefly describe all these components in the following subsections. The online documentation, in turn, has a kickstart tutorial aimed at creating an interactive artifact with physical and digital counterparts that is simple, illustrative, and easily modified and extended. Figure A.1 illustrates this interactive artifact, which can be used as a starting point to explore more sensors and actuators and extended into actual interactive installations. The kickstart tutorial is organized into three main steps:

1. The first step is the configuration of an online MQTT broker to mediate the communication between physical and digital counterparts. The recommended MQTT broker is shiftr.io[5], which is well documented, has a useful graph visualization of the connected clients and exchange of messages and is free to use;

2. The second step is the setup of the programming tools to write, compile and upload code to the microcontrollers. Although the Arduino IDE can be used without major problems, a more professional (yet still straightforward) setup with Sublime Text[6] and PlatformIO[7] is recommended; and

3. The third and final step is the creation of the physical and digital counterparts that will communicate through the Internet and the MQTT Broker. As illustrated in Figure A.1, the physical counterpart is a circuit created with a microcontroller, a sensor, and an actuator, while the digital counterpart is a webpage with information and controls. Each counterpart is well documented to be easily modified and extended, and more physical or digital artifacts can be included in the communication.

Furthermore, after the kickstart tutorial, the online documentation has also more technical, individual tutorials for every sensor and actuator in the kit. Always with a focus on HCI, these individual tutorials go deeper in explaining how the component works, how it can be used in interactive installations, how it should be wired to the microcontroller, as well as provide both minimal and more robust code examples that help explore and use the components.

[4] `https://efduarte.github.io/pincello`
[5] `https://shiftr.io/`
[6] `https://www.sublimetext.com/`
[7] `https://platformio.org/`

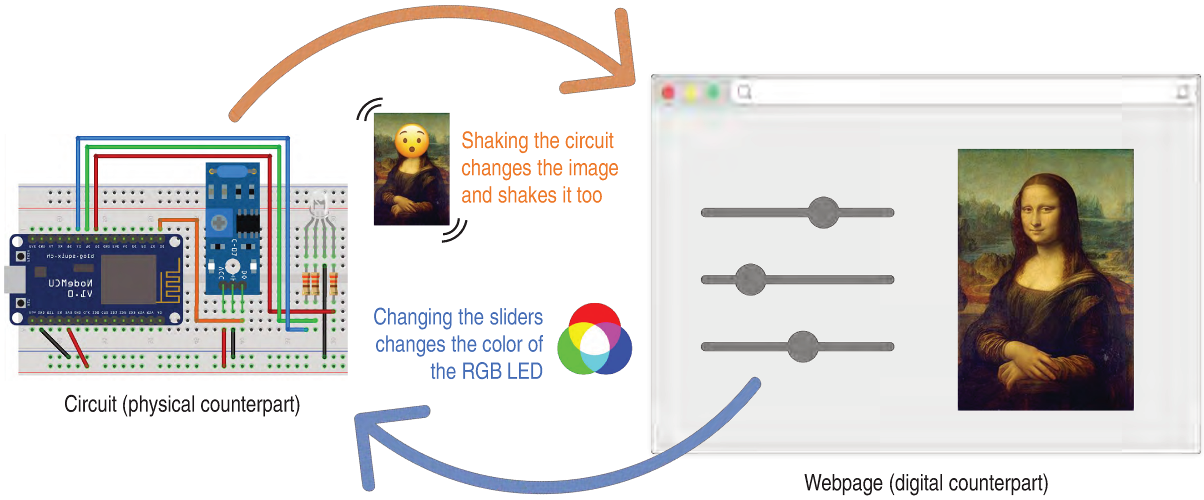


Figure A.1: Illustration of the interactive artifact created with Pincello's tutorial. Full tutorial available on: <`https://efduarte.github.io/pincello`>.

A.3.1 Microcontrollers

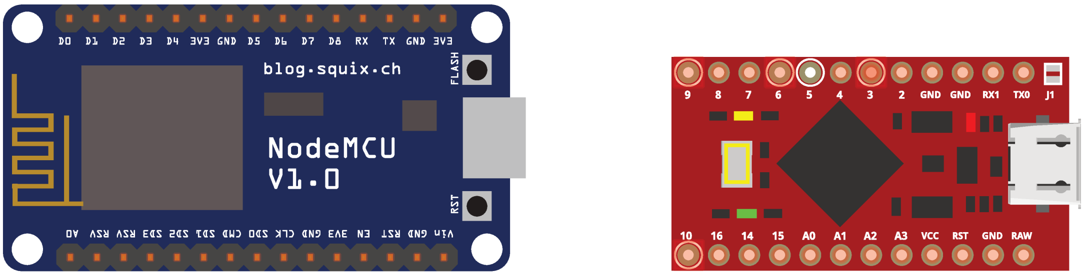
Microcontrollers usually have a relatively low processing power, which means they are more suited for simple tasks, such as receiving information from sensors and sending information to actuators and other devices. This limitation, however, can be worked around with the use of wireless communication and Internet access. For instance, a microcontroller may not be able to project and play high-definition images and sounds, but it can communicate with a computer that will be able to do these tasks. With an emphasis on versatility and low cost, we chose two different microcontrollers to be included in Pincello, they are:

NodeMCU DEVKIT 1.0

This single-board microcontroller, illustrated in Figure A.2a, has built-in Wi-Fi, allowing wireless communication and Internet access. The NodeMCU DEVKIT 1.0 can be used to create artifacts that not only have sensors and actuators but are also able to wirelessly communicate with other devices and the world through the Internet. Furthermore, its low size and energy consumption allow the use of mobile power sources (such as a power bank) to create devices that are relatively portable and low-profile. For instance, if an interactive installation needs to be composed by multiple components (*e.g.*, physical objects that can be picked up and played with, projections, social media presence *etc.*), by embedding the NodeMCU DEVKIT 1.0 into physical objects, these components can all be connected through the Internet and communicate with each other. Lastly, while technically not an Arduino, the NodeMCU DEVKIT 1.0 can be programmed with the Arduino IDE and similar tools that use the Arduino language, benefiting on the high availability of documentation, tutorials, and software libraries online.

Arduino Pro Micro

This microcontroller, illustrated in Figure A.2b, complements the NodeMCU DEVKIT 1.0. Both microcontrollers are similar in size, appearance, and compatibility with the Arduino language and its libraries. Regarding differences, while the Arduino Pro Micro lacks built-in Wi-Fi, it can mimic the inputs of a mouse and keyboard when connected to a computer through USB. Considering that data sent through Wi-Fi and the Internet will inevitably have a delay (usually between tens and hundreds of milliseconds) and be subject to bad connections, this mimic is useful when there is a need for an extra-reliable, low-latency communication between the microcontroller and a computer, even though it is only a one-way channel. For instance, if an interactive installation needs to be instantly responsive to small events, even a sensor with dozens of readings per second can still be used with the Arduino Pro Micro to dynamically control the response with virtually no latency.



(a) NodeMCU DEVKIT 1.0.

(b) Arduino Pro Micro.

Figure A.2: Pincello's microcontrollers. Tutorials and further information available on: <`https://efduarte.github.io/pincello`>.

A.3.2 Sensors

Considering that Pincello emphasizes wireless communication over the Internet, every sensor from a device that takes part in this communication can be used in interactive installations built with Pincello. For instance, even the webcam of computer communicating with the NodeMCU DEVKIT 1.0 can be considered a sensor, and it can be used to detect objects, faces, emotions *etc.* In this section, however, we focus on the sensors from the electronics kit. With an emphasis on being able to capture a wide variety of human interactions, we selected the following 12 kinds of sensors to be included in Pincello:

Humidity & Temperature (DHT11)

This sensor, illustrated in Figure A.3a, uses a hygrometer and a thermistor to measure relative air humidity and temperature. It can be used to monitor the temperature and humidity of an ambient, but it can also detect some forms of human interaction. For instance, by directly blowing on the sensor, or even holding it in your hand, you will likely see an increase in both temperature and humidity. The downside is that the sensor is not very responsive to short interactions, as readings occur only every second.

Capacitive Touch Button (TTP223)

This sensor, illustrated in Figure A.3b, can be activated by touch regardless of the applied pressure. Besides its use as a button, this sensor can be used to create touchable surfaces or objects with the use of additional conductive material. For instance, by attaching a copper tape to the plating behind the sensor and then covering a tangible object with this tape, you can detect when someone touches that object.

Accelerometer & Gyro (MPU-6050)

This sensor, illustrated in Figure A.3c, contains both an accelerometer and a gyroscope in the same component. It captures in real-time both acceleration and rotation in the x, y and z axes. This sensor can be used in many ways, from simply detecting when a tangible object is picked up or laid down, to more complex tasks, such as detecting at which speed and direction an object (for instance, a crank) is being rotated or even tracking the absolute orientation of a physical object.

Ultrasonic Distance (HC-SR04)

This sensor, illustrated in Figure A.3d, uses the speed of sound to calculate distance, like the sonar system of a submarine, or the parking sensor of a car. Differently from the reflexive obstacle sensor presented next, this sensor can be used not only to detect something but also return a numeric distance. For instance, the sensor can be used to detect when someone approaches an interactive installation, but also respond in different ways according to how far (or close) the person is.

Reflexive Obstacle (FC-51)

This sensor, illustrated in Figure A.3e, detects anything that reflects light (someone's hand, or any object that is not black) positioned a few centimeters from the sensor. Differently from the ultrasonic distance sensor presented above, this sensor can only be used to return a binary detection and not a numeric distance. For instance, the sensor can be used to detect if an object was placed in a specific position right in front of a sensor, or even if someone waived his/her hand over it.

Digital Luminosity (LDR)

This sensor, illustrated in Figure A.3f, detects if the luminosity is above or below a certain threshold, adjusted in the included potentiometer. Differently from the analog LDR presented next, this sensor returns only a binary value according to the threshold, and not a numeric luminosity value. Besides the luminosity of an ambient, this sensor can be used to detect touch-less interactions. For instance, certain actions from a person (like placing his/her hand in a specific spot) may block light from reaching the sensor, and therefore be detected by it.

Analog Luminosity (LDR)

This sensor, illustrated in Figure A.3j, changes its resistance according to the amount of light it is exposed to. Differently from the digital luminosity sensor presented above, this sensor provides a numeric luminosity value that ranges from 0 to 1023 when used with the NodeMCU DEVKIT 1.0. Besides the luminosity of an ambient, this sensor can be used to detect touch-less interactions. For instance, certain actions from a person (like pointing a smartphone flashlight towards an object) may increase the amount of light reaching the sensor and therefore result in increased values.

Hall Effect (A3144)

This sensor, illustrated in Figure A.3g, detects the presence of magnetic fields. The output can be both digital or analog, and the precision can be adjusted in the included potentiometer. This sensor can be used to detect if a magnet is close to the sensor (a small magnet will need to be at least a few centimeters away). For instance, by embedding magnets into tangible objects of an interactive installation, these objects can then be used to activate the interactivity by positioning them near the sensors.

Vibration (SW-420)

This sensor, illustrated in Figure A.3h, detects vibrations above a certain threshold, adjusted in the included potentiometer. It only detects the presence or absence of vibration, not its intensity. This sensor can be used as a motion detector that is both simpler and easier to use when compared to an accelerometer, with the downside of not detecting any details about the motion. For instance, by embedding this sensor into a tangible object (like a rattle), it becomes possible to detect when this object is picked up and shaken.

Sound (KY-038)

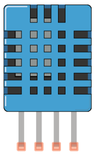
This sensor, illustrated in Figure A.3i, uses an electret to detect sound. The output can be both digital or analog, and the precision can be adjusted in the included potentiometer. It does not make distinctions between different kinds of sounds, and it may require fine calibration to avoid background noise, but it may be useful in musical installations. For instance, the sensor can be placed inside a drum to detect when someone is playing that instrument with the precision of detecting every beat.

Tilt (SW-200D)

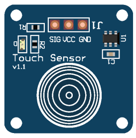
This sensor, illustrated in Figure A.3k, uses gravity to detect if it is turned upwards or downwards. This sensor can be used in interactive installations to detect the change of orientation of tangible objects. For instance, by embedding the sensor into a tangible object over a table it becomes possible to detect when that object is flipped over.

Push Button

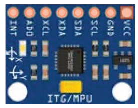
Push buttons, illustrated in Figure A.3l, close a circuit when they are physically pressed. Besides their use as traditional buttons, these sensors can be used to create pressable surfaces with a satisfying “click” (tactile and sound) feedback. For instance, by gluing cardboard surfaces with different textures on the top of push buttons, it is possible to create tactile pressable surfaces that look and feel much more interesting than conventional buttons.



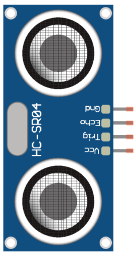
(a) Humidity & temp.



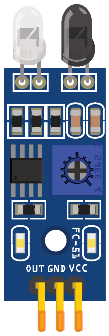
(b) Capacitive touch.



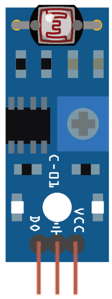
(c) Accelerometer & gyro.



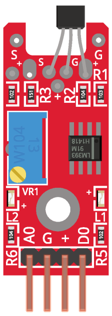
(d) Ultrasonic distance.



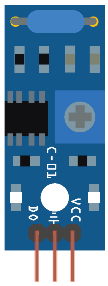
(e) Reflexive obstacle.



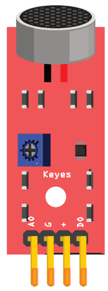
(f) Digital luminosity.



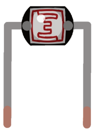
(g) Hall effect.



(h) Vibration.

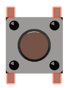


(i) Sound.



(j) Analog luminosity.

(k) Tilt.



(l) Push button.

Figure A.3: Pincello’s sensors. Tutorials with wiring, coding and further information available on: <`https://efduarte.github.io/pincello`>.

A.3.3 Actuators

In the same way as with sensors, every actuator from a device that communicates with the NodeMCU DEVKIT 1.0 can be considered an actuator to be used in interactive installations build with Pincello. For instance, a computer may display images through a projector, or play high-definition sounds through a set of speakers. In this section, however, we focus on the actuators from the electronics kit. With an emphasis on being able to impact and influence the physical world beyond the use of screens, we chose the following 6 kinds of actuators to be included in Pincello:

LED

This actuator, illustrated in Figure A.4a, is present in the following colors: red, green, blue, yellow, and white. Differently from the RGB LEDs presented next, a common LED does not change its color, but its brightness can be controlled. LEDs can be used in interactive installations in various ways, such as decoration, indicators of system status, or as feedback for human actions.

RGB LED

This actuator, illustrated in Figure A.4b, differently from the common LEDs presented above, can be changed to any color in the RGB spectrum (except for black, as black is the absence of color in light sources). RGB LEDs can be used in interactive installations in various ways, such as decoration, indicators of system status, or as feedback for human actions.

Relay

This actuator, illustrated in Figure A.4c, uses a magnetic switch to turn on or off high voltage devices. While Arduinos and similar electronics usually operate between 3.3 and 5V, most domestic devices operate between 100 and 250V, therefore this actuator is intended to bridge the difference by using low voltage devices to control high voltage devices. For instance, in interactive installations, the relay can be used to control almost anything that is powered by a conventional power outlet, such as lamps, motors, sound systems *etc.*

Buzzer

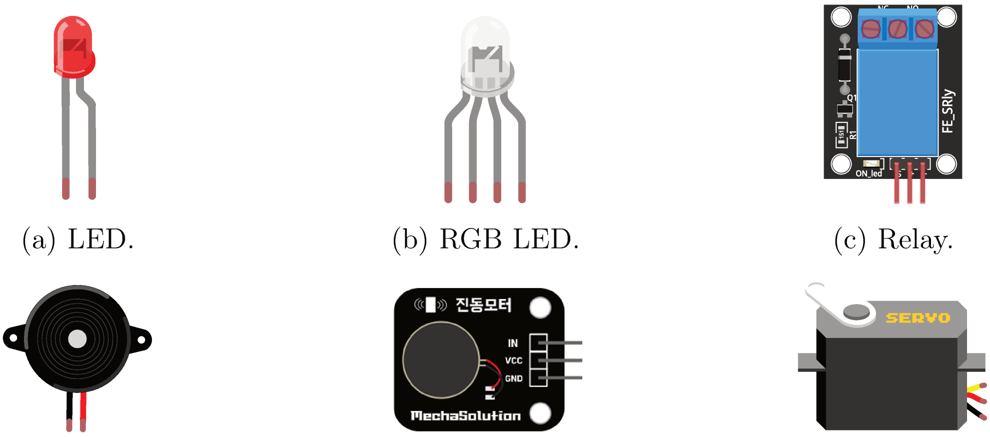
This actuator, illustrated in Figure A.4d, uses the piezoelectric effect to make sounds. The actuator is very limited in which kind of sounds it can create (mostly high-pitched sounds), but it can play simple notes that can be used as feedback. For instance, when a specific action is performed in an interactive installation a corresponding simple melody can be played.

Vibration Motor

This actuator, illustrated in Figure A.4e, uses an asymmetric weight attached to a small motor to create vibrations. This actuator can be used to create haptic feedback in interactive installations. For instance, the vibration motor can be attached to an object that is supposed to be picked up, and it can vibrate in different intensities according to how that object is manipulated.

Micro Servo (SG90)

This actuator, illustrated in Figure A.4f, uses a motor with a gear train to provide precise angle control over a shaft. This actuator can be used to create controllable physical motion in interactive installations. For instance, an object can be attached to the shaft of the micro servo to allow this object to be rotated to different angles within the 180° range of the servo.



(a) LED. (b) RGB LED. (c) Relay.

(d) Buzzer. (e) Vibration motor. (f) Micro servo.

Figure A.4: Pincello's actuators. Tutorials with wiring, coding and further information available on: <`https://efduarte.github.io/pincello`>.

A.4 Case Studies

Pincello has already been used in three case studies in the context of undergraduate and graduate HCI courses, and we received positive feedback from the students regarding Pincello in all of them. These three case studies are named: InterArt [55]; InstInt [59]; and InsTime [65]. In the following subsections, we will present a brief overview of each case study, with emphasis on how Pincello was used and what kind of interactive installation was created with it.

A.4.1 InterArt

The InterArt case study took place in the first semester of 2017 at the Unicamp. A total of 55 Computer Science and Computer Engineering undergraduate students attending an

HCI undergraduate course, distributed into 9 teams, designed and constructed 9 interactive artworks based on a theme of their choosing [55]. Within a comprehensive design process with many design activities, Pincello was presented to the students along some interactive artifact examples to inspire them by illustrating a kind of interaction design that goes beyond the computer screen. Each of the 9 teams received a Pincello kit to be used throughout the semester. Only one team opted for not using Pincello (its use was not mandatory), and instead focused on the use of a Microsoft Kinect. At the end of the semester, the teams presented their projects, and, as illustrated in Figure A.5, some of these installations (Monolito, Lobo-Guará, and Memoção) were later exhibited at the Exploratory Science Museum of Unicamp [62]. A brief summary of the interactive installations created in the InterArt case study is presented in the following list:

- **500cc**: a sensory dancing platform with a visual drawing of the dancing;
- **Autorretrato**: a dynamic display of famous self-portrait paintings based on physiological measurements of the audience;
- **Loneliness**: a "notgame" exploring the concept of social isolation;
- **MusicBoard**: a musical instrument for people without musical skills;
- **Monolito**: a monolith to interact with the projection of a psychedelic scene from Kubrick's 2001: A Space Odyssey;
- **Lobisomem Atacando o Galinheiro**: a farm mock-up to explore storytelling involving chickens and a werewolf;
- **Lobo-Guará**: an interactive maned wolf designed for museums;
- **Nychos**: an interactive interpretation of famous Nychos' dissections; and
- **Memoção**: a tactile exploration experience based on Internet memes.

Except for the team that used the Microsoft Kinect (500cc), all the installations have wireless communication between the NodeMCU DEVKIT 1.0 microcontroller and a computer responsible for displaying images and playing sounds (during this case study, Pincello did not have yet the alternative Arduino Pro Micro microcontroller, and it was later added due to the need of some of these installations for a more low-latency one-way communication). Regarding sensors, the students used all the sensors available in Pincello at the time of this case study, which were: humidity & temperature, accelerometer & gyro, reflexive obstacle, vibration, sound, analog luminosity and push buttons. With regard to actuators, with the exception of the buzzer which was not used at this time, the students used the other two actuators available in Pincello at the time: LEDs and RGB LED. The usage of components included creative uses, such as a proximity (reflexive obstacle) sensor on the head of the interactive maned wolf in the Lobo-Guará installation to detect attempts to pet it, or covering push buttons with rectangular surfaces with different textures to create a tactile installation, namely the Memoção installation. The teams also used sensors that were not included in Pincello, such as heart rate and gesture, highlighting how Pincello is flexible and can be customized.

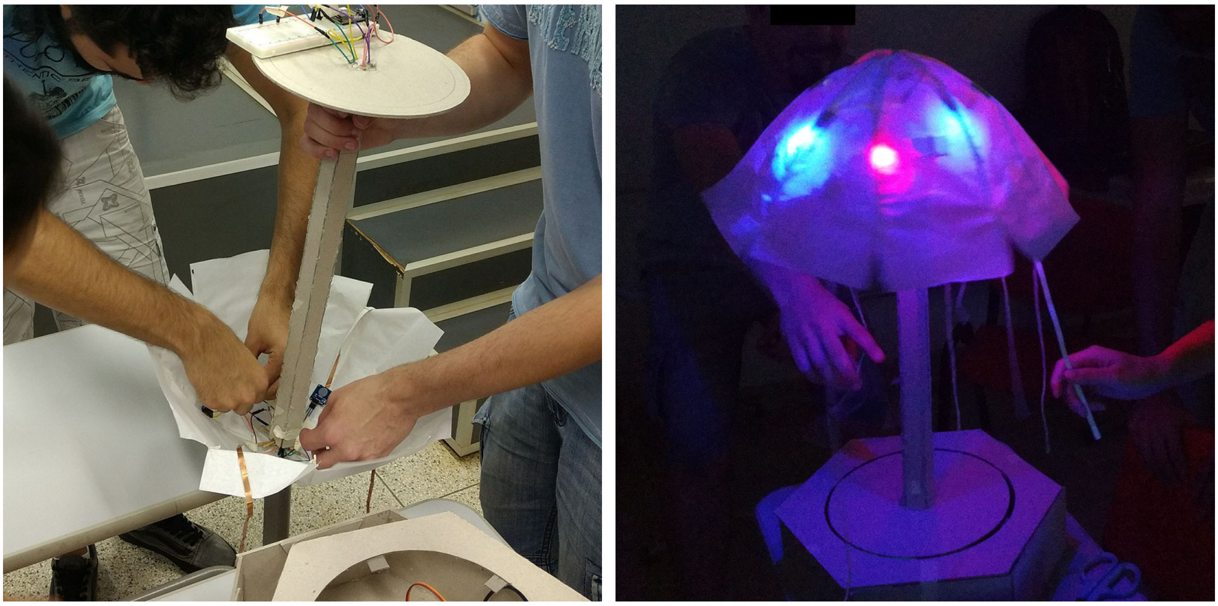
(a) Memoção. (b) Lobo-Guará.

Figure A.5: Two examples of interactive installations from the InterArt [55] case study, exhibited at the Exploratory Science Museum of Unicamp.

A.4.2 InstInt

The InstInt case study took place in the second semester of 2017 at Unicamp. A group of 5 Computer Science graduate students with different backgrounds attending an HCI graduate course co-designed and constructed a small-scale interactive installation for public spaces [59]. Within a comprehensive design process with many design activities, as in the InterArt case, Pincello was presented to the students along some interactive artifact examples to inspire them by illustrating a kind of interaction design that goes beyond the computer screen. Each of the 5 students received a Pincello kit to be used throughout the semester in a co-design process [59]. At the end of the semester, the students presented their project, illustrated in Figure A.6. The installation, which has a physical form that resembles something between a large umbrella and a carousel with ribbons attached around it, initially plays an instrumental music at a low volume (played from a computer), blinks some colorful lights (with the use of LEDs) and spins at a low speed (with the use of a micro servo) as it waits for interaction. When a person approaches, this person can touch the ribbons (activated by capacitive touch buttons extended with conductive copper tape). Touching each ribbon controls the volume of a different instrument in the music also changes the blinking of lights, which follows the music.

This interactive installation also required a wireless communication between the NodeMCU DEVKIT 1.0 microcontroller and a computer responsible for playing the music. Regarding sensors and actuators, this interactive installation used only the capacitive touch button as a sensor (the specification for the real-scale installation also specifies the use of the ultrasonic distance, but it was not used in the small-scale prototype), and LEDs and the micro servo as actuators. The use of capacitive touch button sensors extended with conductive copper tape illustrates how Pincello is flexible and can be used in creative, unforeseen ways. Furthermore, one design solution illustrates another important aspect of Pincello that emerged in this case study: the participants first envisioned an installation that continually rotates in the same direction, like a carousel. However, when experiment-



(a) Prototype being constructed. (b) Small-scale interactive installation.

Figure A.6: Construction and final physical artifact of the small-scale interactive installation from the InstInt [59] case study.

ing with the available micro servo motor that can only rotate 180 degrees, participants ended up implementing it to rotate back and forth in a semicircle, resembling a waltz dance that further corroborated to the captivating experience provided by the small-scale installation. Therefore, Pincello is not only a tool to build predetermined interactive installations, but it is also a tool that is supposed to be part of the design process of interactive installations.

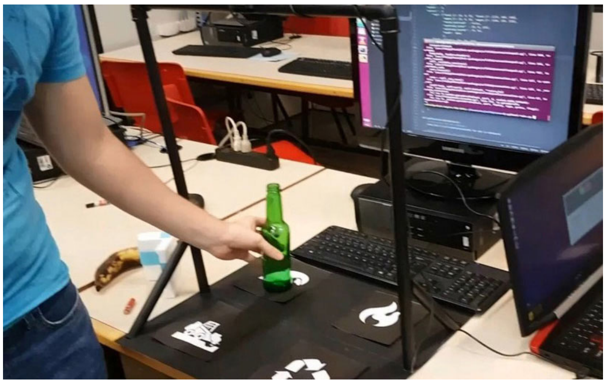
A.4.3 InsTime

The InsTime case study took place in the first semester of 2018 at Unicamp. A total of 45 Computer Science and Computer Engineering undergraduate students attending an HCI undergraduate course, distributed into 9 teams, designed and constructed 9 interactive installations based on the theme of "deep time" [65]. Within a comprehensive design process with many design activities, Pincello was presented to the students along some interactive artifact examples to inspire them by illustrating a kind of interaction design that goes beyond the computer screen. Each of the 9 teams received a Pincello kit to be used throughout the semester. At the end of the semester, the teams presented their deep time projects. Two examples of the final projects are illustrated in Figure A.6. Similarly to what happened in the InterArt case study, some of these installations (CronoBit and Temporário) were also later exhibited at the Exploratory Science Museum of Unicamp. A brief summary of the interactive installations created in the InsTime case study is presented in the following list:

- **Chronos**: an interactive mock-up of a timeline with five geological periods;

- **CronoBit**: a set of drums to play with how humans can drastically accelerate natural processes that would otherwise take much longer;
- **De Volta Para o Futuro**: a memory game that plays with how we perceive the passage of time when we are concentrated or having fun;
- **General Purpose Timer**: an interactive mock-up to play and learn about the impacts of different methods of garbage disposal;
- **Limbo**: a hand crank to control a visual simulation of earth's history;
- **Looper**: a blowable miniature windmill to play with the age of the universe;
- **Rolex**: a set of light bulbs of different technologies and increasing power efficiency, turned on by ironic applause;
- **Temporário**: an educational video display that is aware about how many people are watching it, and adjusts the playback accordingly; and
- **Time**: a mock-up city about the positive and negative sides of nuclear energy.

(a) CronoBit.



(b) General Purpose Timer.

Figure A.7: Two examples of the interactive installations from the InsTime [65] case study, openly addressing the theme of "deep time".

Because InsTime was chronologically the third case study in which Pincello was applied, it benefited from lessons learned and improvements to the kit and the online documentation. For instance, this is the first case study in which the Arduino Pro Micro alternative microcontroller was used, and it was fundamental in allowing the CronoBit installation, illustrated in Figure A.7a), to be highly responsive, capable of detecting every beat of the drums regardless of how fast was the drumming. Besides the De Volta Para o Futuro memory game installation that also used the Arduino Pro Micro to have low-latency input, the other seven teams created installations with wireless communication through the NodeMCU DEVKIT 1.0 microcontroller. Regarding sensors, the students used the following components available in Pincello: capacitive touch button, accelerometer & gyro, ultrasonic distance, reflexive obstacle, vibration, sound, and push buttons.

With regard to actuators, with the exception of the vibration motor which was not used at this time, the students used the other five actuators available in Pincello at the time: LEDs, RGB LED, relay, buzzer, and micro servo. The usage of components included creative uses. For instance, in the Limbo interactive installation, the accelerometer & gyro was attached to a hand crank (recycled from a bicycle pedal) to calculate angular velocity and acceleration, which controlled a virtual visualization of earth's history.

A.5 Conclusion

Considering how the field of HCI is increasingly interested in interactions that go beyond work-related and well-defined problems, the use of pervasive DIY technology by researchers and practitioners is a substantial step towards the design and construction of more open-ended physical interactive artifacts and environments. In this context, Pincello has achieved its objective of being a relatively easy-to-use and flexible tool for the creation of interactive installations. As has been evidenced in the three case studies, the feedback from the involved students was positive and the resulting interactive installations were varied in theme, aesthetic, and innovative approaches to interaction with computational systems. Finally, Pincello also achieved its objective of being relatively affordable when compared to commercial kits. With these positive results, we see Pincello as a promising tool for the HCI community that is now openly available to be explored, learned, modified and transformed.

Appendix B

Lobo-Guará's Technical Specifications

Lobo-Guará (Maned Wolf, in English) is an interactive installation named after the paintings *Lobo-guará I* and *Lobo-guará II* by Brazilian artist Felipe Abranches. Lobo-Guará was originally created by a group of students during the InterArt design study presented in Chapter 3, and was later improved and further prepared for the situated practices presented in Chapters 6 and 7. As illustrated in Figure B.1, the artifact is an interactive cardboard maned wolf covered with synthetic fur and designed for educational museums. The maned wolf artifact has hidden buttons in important parts (head, body, leg, and tail) that, when pressed or touched, send a wireless signal to a computer to present relevant information about the wolf. The participants must manipulate the artifact to find the hidden buttons, and the artifact provides auditory and visual feedback through a television or projector connected to the computer and positioned behind the physical artifact. There is also a proximity sensor in the wolf's head to detect an attempt to pet him. When petted, his eyes become red and he barks, a behavior that is explained by the wolf being a wild and dangerous animal.

(a) Teacher interacting with Lobo-Guará. (b) Screen capture of the display of the artifact.

Figure B.1: The two counterparts of the lobo-guará interactive artifact.

B.1 Circuit & Wiring Diagram

The interactive artifact was built with the Pincello electronics kit [58], presented in Appendix A. As illustrated in Figure B.2, the components are wired as recommended by Pincello's documentation, with the addition that the LEDs of same color are wired in parallel to simplify the circuit. The artifact uses:

1. A NodeMCU DEVKIT 1.0 microcontroller for wireless communication;
2. A reflexive obstacle (FC-51) sensor to detect attempts to pet the wolf in the head;
3. Four push buttons (with 10$k\Omega$ resistors) for different parts of the wolf;
4. Two white and two red LEDs (with 330Ω resistors) for the wolf's eyes; and
5. A breadboard and jumper wires to make the connections.

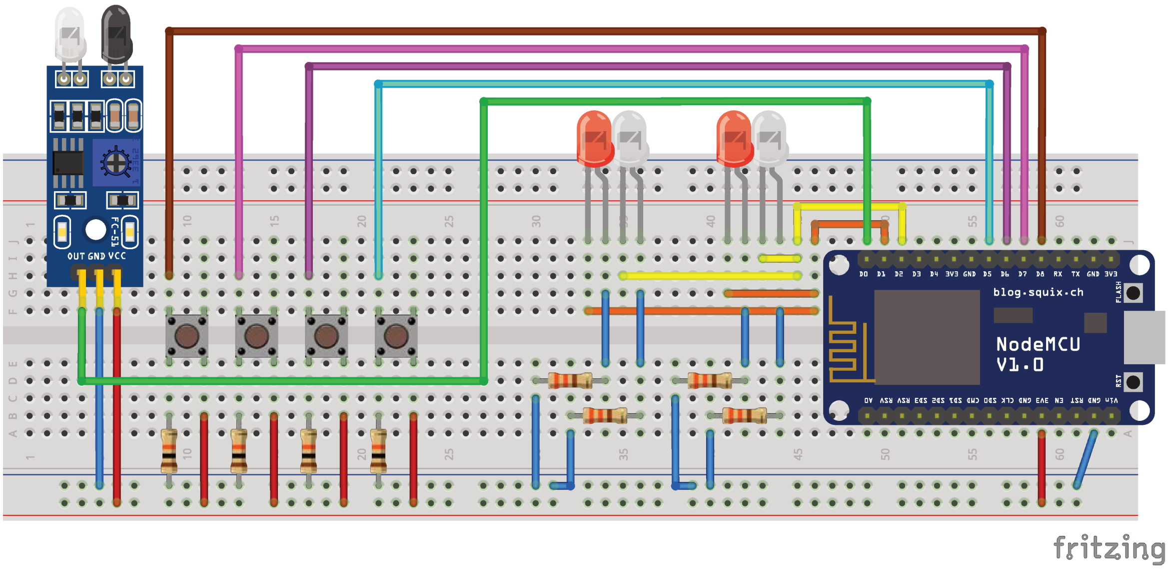


Figure B.2: Lobo-Guará's Circuit & Wiring Diagram.

B.2 Microcontroller Programming

The programming of the microcontroller involves the use of three libraries: Thomas O. Fredericks' `Bounce2`[1] for more reliable push button sensing, Ivan Grokhotkov's `ES8266WiFi`[2] for Wi-Fi communication, and Joël Gähwiler's `MQTTClient`[3] for MQTT messaging. Keeping in mind the circuit & wiring diagram presented above, the NodeMCU DEVKIT 1.0 microcontroller is programmed to initially configure inputs and outputs according to the

[1] `https://github.com/thomasfredericks/Bounce2`
[2] `https://github.com/esp8266/Arduino/tree/master/libraries/ESP8266WiFi`
[3] `https://github.com/256dpi/arduino-mqtt`

used sensors and actuators, and to connect and maintain a connection with a Wi-Fi network for internet communication, and with a MQTT broker to exchange messages. When a button or the head sensor is activated, the corresponding message is broadcast to the internet through the MQTT broker, therefore becoming available to be read by the web page responsible for displaying visual and audible information. The microcontroller is programmed with the following code (Wi-Fi credentials in lines 5 and 6, MQTT credentials in line 48 and MQTT Broker Hostname in line 85 need to be filled in):

```
1 #include <Bounce2.h>
2 #include <ESP8266WiFi.h>
3 #include <MQTTClient.h>
4
5 const char ssid[] = ""; //Wi-Fi SSID
6 const char pass[] = ""; //Wi-Fi Password
7
8 WiFiClient net;
9 MQTTClient client;
10 int QoS = 2;
11
12 const int proximity_pin = D0;
13 const int buttonCabeca_pin = D5;
14 const int buttonCorpo_pin = D6;
15 const int buttonPata_pin = D7;
16 const int buttonCauda_pin = D8;
17
18 const int olhoVermelho_pin = D1;
19 const int olhoBranco_pin = D2;
20
21 unsigned long lastMillis = 0;
22 unsigned long olhoVermelho_timer = 9000;
23 int olhosVermelhos = 0;
24
25 Bounce proximity_debouncer = Bounce();
26 Bounce buttonCabeca_debouncer = Bounce();
27 Bounce buttonCorpo_debouncer = Bounce();
28 Bounce buttonPata_debouncer = Bounce();
29 Bounce buttonCauda_debouncer = Bounce();
30
31 const int debouncerInterval = 5;
32
33 void connectWIFI()
34 {
35   Serial.print("Connecting to WiFI ");
36   WiFi.begin(ssid, pass);
37   while (WiFi.status() != WL_CONNECTED)
38   {
39     delay(500);
40     Serial.print(".");
41   }
42   Serial.println("WiFi connected!");
43 }
44
45 void connectMQTT()
46 {
47   Serial.println("Connecting to MQTT");
48   while (!client.connect("lobo-arduino", "", "")) //MQTT Credentials (Client ID, Username
       , and Password)
49   {
50     delay(500);
51     Serial.print(".");
52   }
53   Serial.println("MQTT connected!");
54 }
55
```

```
void setup()
{
  Serial.begin(115200);

  pinMode(proximity_pin, INPUT);
  pinMode(buttonCabeca_pin, INPUT);
  pinMode(buttonCorpo_pin, INPUT);
  pinMode(buttonPata_pin, INPUT);
  pinMode(buttonCauda_pin, INPUT);

  pinMode(olhoVermelho_pin, OUTPUT);
  pinMode(olhoBranco_pin, OUTPUT);

  digitalWrite(olhoBranco_pin, HIGH);
  digitalWrite(olhoVermelho_pin, LOW);

  proximity_debouncer.attach(proximity_pin);
  buttonCabeca_debouncer.attach(buttonCabeca_pin);
  buttonCorpo_debouncer.attach(buttonCorpo_pin);
  buttonPata_debouncer.attach(buttonPata_pin);
  buttonCauda_debouncer.attach(buttonCauda_pin);

  proximity_debouncer.interval(debouncerInterval);
  buttonCabeca_debouncer.interval(debouncerInterval);
  buttonCorpo_debouncer.interval(debouncerInterval);
  buttonPata_debouncer.interval(debouncerInterval);
  buttonCauda_debouncer.interval(debouncerInterval);

  connectWIFI();
  client.begin("", net); //MQTT Broker Hostname
  connectMQTT();
}

void loop()
{
  if (olhosVermelhos == 1 && millis() - lastMillis > olhoVermelho_timer)
  {
    olhosVermelhos = 0;
    digitalWrite(olhoBranco_pin, HIGH);
    digitalWrite(olhoVermelho_pin, LOW);
  }

  if (WiFi.status() != WL_CONNECTED)
  {
    connectWIFI();
  }

  client.loop();
  delay(10);

  if (!client.connected())
  {
    connectMQTT();
  }

  proximity_debouncer.update();
  buttonCabeca_debouncer.update();
  buttonCorpo_debouncer.update();
  buttonPata_debouncer.update();
  buttonCauda_debouncer.update();

  /***********************************************************
  PROXIMITY ************************************************
  **********************************************************/
  if (proximity_debouncer.fell())
  {
    Serial.println("Proximity rose!");
```

```
    client.publish("/lobo/proximidade", "1", false, QoS);

    olhosVermelhos = 1;
    digitalWrite(olhoBranco_pin, LOW);
    digitalWrite(olhoVermelho_pin, HIGH);

    lastMillis = millis();
  }

  /*********************************************************
  BUTTON CABECA *********************************************
  *********************************************************/
  if (buttonCabeca_debouncer.rose())
  {
    Serial.println("Cabeca button rose!");
    client.publish("/lobo/cabeca", "1", false, QoS);
  }

  /*********************************************************
  BUTTON CORPO **********************************************
  *********************************************************/
  if (buttonCorpo_debouncer.rose())
  {
    Serial.println("Corpo button rose!");
    client.publish("/lobo/corpo", "1", false, QoS);
  }

  /*********************************************************
  BUTTON PATA ***********************************************
  *********************************************************/
  if (buttonPata_debouncer.rose())
  {
    Serial.println("Pata button rose!");
    client.publish("/lobo/pata", "1", false, QoS);
  }

  /*********************************************************
  BUTTON RABO ***********************************************
  *********************************************************/
  if (buttonCauda_debouncer.rose())
  {
    Serial.println("Cauda button rose!");
    client.publish("/lobo/cauda", "1", false, QoS);
  }

}
```

B.3 Web Page Programming

The physical artifact communicates with a computer, which in turn is connected to a television or projection to display visual and audible information about the maned wolf. On the computer end, this communication and display of information is done through a custom web page running locally (no web server needed) in a common web browser in full-screen mode. The web page is connected to the MQTT broker, and receives messages that are published by the microcontroller, triggering the respective responses. For instance, when the web page receives a message that the tail button was pressed, it displays a closer image of the tail of the maned wolf and presents relevant information about the animal in audio form, but also with subtitles. The web page is composed of the following files:

- audio/
    - graw.mp3
    - rosnado.mp3
- css/
    - img/
        - lobo.jpg
        - loboativo.jpg
        - lobocabeca.jpg
        - lobocauda.jpg
        - lobocorpo.jpg
        - loboincomodado.jpg
        - lobopata.jpg
        - wallpaper.jpg
    - style.css
- js/
    - script.js
- index.html

Except for audio (growl sounds made by the maned wolf) and image files (general and close-up pictures of the maned wolf), in the following sections we briefly present the HTML, JavaScript and CSS documents that compose the web page.

B.3.1 HTML

The `index.html` file is the canvas in which the content is displayed and played. This web page is rather simple, being responsible mostly for referencing the other CSS and JavaScript resources used in the web page, including two JavaScript libraries linked remotely (meaning that internet connection is necessary, but it would already be needed for MQTT messaging anyway): `mqtt.js`[4], and `responsivevoice.js`[5].

```
<!DOCTYPE html>
<html>
    <head>
        <meta charset="UTF-8">
        <title>Lobo-Guará</title>
        <link rel="stylesheet" href="css/style.css">
    </head>

    <body>

        <div id="lobo"></div>
```

[4] https://github.com/mqttjs/MQTT.js
[5] https://responsivevoice.org/

```

        <div id="subtitle"></div>

        <script src="https://unpkg.com/mqtt@2.11.0/dist/mqtt.min.js"></script>
        <script src="https://code.responsivevoice.org/responsivevoice.js"></script>
        <script src="js/script.js"></script>

    </body>
</html>
```

B.3.2 JavaScript

The `js/script.js` file scripts the behavior of the web page, including connecting to the MQTT broker (credentials, hostname and client ID need to be filled in lines 1 and 2), receiving messages and triggering the respective visual and audible responses in the web page. For instance, when the script receives the message that the tail button was pressed in the physical artifact, it will execute the commands responsible for displaying a closer image of the tail of the maned wolf and presenting relevant information about the animal in audio form, as well as the respective subtitles. There are also keyboard shortcuts (space and the four keyboard arrows) to simulate each action, so the web page can be tested regardless of the physical artifact. In line 7, there is a a variable that defines whether this testing with keyboard shortcuts occurs online (*i.e.*, through the internet and the MQTT broker, useful for testing and debugging the MQTT messaging), or offline (*i.e.*, directly manipulating the content of the web page without using the internet, useful for demonstrating how the web page works without the need for any setup).

```
1  var url = ""; //MQTT Credentials and Hostname "mqtt://username:password@hostname"
2  var client = mqtt.connect(url, {clientId: ""}); //Client ID
3  var QoS = 2;
4
5  //offline: keyboard shortcuts work regardless of internet and MQTT connection
6  //online: keyboard shortcuts require internet and MQTT connection to work
7  var status = "offline";
8
9  responsiveVoice.setDefaultVoice("Brazilian Portuguese Female");
10 var audio = new Audio();
11
12 var lobo_element = document.getElementById("lobo");
13 var subtitle_element = document.getElementById("subtitle");
14
15 function communicate(cssClass, description, timeout, sound = null)
16 {
17
18     if(responsiveVoice.isPlaying())
19     {
20         responsiveVoice.cancel();
21     }
22
23     subtitle_element.innerHTML = "";
24     lobo_element.className = "";
25
26     if (!audio.paused)
27     {
28         audio.pause();
29     }
30
31     if (sound != null)
32     {
33         audio.src = "audio/" + sound + ".mp3";
```

```
        audio.play();
    }
    lobo_element.classList.add(cssClass);
    if (description != "")
    {
        responsiveVoice.speak(description);
        subtitle_element.innerHTML = description;
    }
    setTimeout(function()
    {
        if (sound != null)
        {
            audio.pause();
            audio.currentTime = 0;
        }
        subtitle_element.innerHTML = "";
        lobo_element.classList.remove(cssClass);

    }, timeout);
}

function executeProximidade()
{
    communicate("latido", "", 1000, "graw");

    setTimeout(function()
    {
        communicate("incomodado", "O lobo-guará é um animal silvestre. Se você tentar
    fazer carinho ele pode te morder.", 8000, "rosnado");
    }, 1000);
}

client.on("connect", function()
{
    console.log("MQTT Connected!");
    client.subscribe("/lobo/proximidade", { qos: QoS });
    client.subscribe("/lobo/cabeca", { qos: QoS });
    client.subscribe("/lobo/corpo", { qos: QoS });
    client.subscribe("/lobo/pata", { qos: QoS });
    client.subscribe("/lobo/cauda", { qos: QoS });
});

client.on("error", function(e)
{
    console.log(e);
});

function publishFeed(feed, valor)
{
    client.publish(feed, valor, { qos: QoS, retain: false });
    console.log("Published: " + feed + ": " + valor);
}

client.on("message", function(topic, message)
{
    console.log("New message:", topic, message.toString());

    if (topic == "/lobo/proximidade")
    {
        if (parseInt(message) == 1)
        {
            executeProximidade();
        }
    }

    if (topic == "/lobo/cabeca")
    {
```

```
        if (parseInt(message) == 1)
        {
            communicate("cabeca", "O formato da cabeça do lobo-guará se parece com o de uma raposa. O focinho é esguio e as orelhas são grandes. Como os outros canídeos, sua boca tem 42 dentes.", 15000);
        }
    }

    if (topic == "/lobo/corpo")
    {
        if (parseInt(message) == 1)
        {
            communicate("corpo", "A pelagem do lobo-guará varia do vermelho-dourado ao laranja e os pelos da nuca e patas são pretos. A parte inferior da mandíbula e a ponta da cauda são brancos.", 14000);
        }
    }

    if (topic == "/lobo/pata")
    {
        if (parseInt(message) == 1)
        {
            communicate("pata", "As pegadas deixadas pelo lobo-guará têm entre 7 e 9 centímetros de comprimento e entre 5 e 7 centímetros de largura.", 12000);
        }
    }

    if (topic == "/lobo/cauda")
    {
        if (parseInt(message) == 1)
        {
            communicate("cauda", "O lobo-guará é o maior canídeo da América do Sul, atingindo entre 95 e 115 centímetros de comprimento, com uma cauda medindo entre 38 e 50 centímetros e atingindo até 90 cm de altura.", 19000);
        }
    }

});

document.body.onkeydown = function(e){
    if (e.keyCode == 32) //SPACE
    {
        e.preventDefault();
        if (status == "online")
        {
            publishFeed("/lobo/proximidade", "1");
        }
        else if (status == "offline")
        {
            executeProximidade();
        }
    }

    if (e.keyCode == 37) //LEFT ARROW
    {
        e.preventDefault();
        if (status == "online")
        {
            publishFeed("/lobo/cabeca", "1");
        }
        else if (status == "offline")
        {
            communicate("cabeca", "O formato da cabeça do lobo-guará se parece com o de uma raposa. O focinho é esguio e as orelhas são grandes. Como os outros canídeos, sua boca tem 42 dentes.", 15000);
        }
    }
```

```

    if (e.keyCode == 38) //UP ARROW
    {
        e.preventDefault();
        if (status == "online")
        {
            publishFeed("/lobo/corpo", "1");
        }
        else if (status == "offline")
        {
            communicate("corpo", "A pelagem do lobo-guará varia do vermelho-dourado ao laranja e os pelos da nuca e patas são pretos. A parte inferior da mandíbula e a ponta da cauda são brancos.", 14000);
        }
    }

    if (e.keyCode == 40) //DOWN ARROW
    {
        e.preventDefault();
        if (status == "online")
        {
            publishFeed("/lobo/pata", "1");
        }
        else if (status == "offline")
        {
            communicate("pata", "As pegadas deixadas pelo lobo-guará têm entre 7 e 9 centímetros de comprimento e entre 5 e 7 centímetros de largura.", 12000);
        }
    }

    if (e.keyCode == 39) //RIGHT ARROW
    {
        e.preventDefault();
        if (status == "online")
        {
            publishFeed("/lobo/cauda", "1");
        }
        else if (status == "offline")
        {
            communicate("cauda", "O lobo-guará é o maior canídeo da América do Sul, atingindo entre 95 e 115 centímetros de comprimento, com uma cauda medindo entre 38 e 50 centímetros e atingindo até 90 cm de altura.", 19000);
        }
    }
}
```

B.3.3 CSS

Lastly, the `css/style.css` file defines the visual appearance of the web page, including referencing and formatting the images of the maned wolf that are then displayed or hidden by the controlling `js/script.js` file. The `css/style.css` also defines the animation that is played when the head sensor is triggered and the appearance of the subtitles.

```
html {
  background-image: url("img/wallpaper.jpg");
  height: 100%;
  overflow: hidden;
}

#lobo {
  max-width: 1120px;
  /*height: 750px;*/
  height: 535px;
```

```
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
  background-image: url("img/lobo.jpg");
  background-repeat: no-repeat;
  background-position:  top center;
  background-size: cover;
  border: solid 8px;
  border-bottom-color:#ffe;
  border-left-color:#eed;
  border-right-color:#eed;
  border-top-color:#ccb;
}

#lobo.latido {
  max-width: 1120px;
  /*height: 700px;*/
  height: 500px;
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
  background-image: url("img/loboativo.jpg");
  background-repeat: no-repeat;
  background-position: top center;
  background-size: cover;
  animation: shake 0.1s infinite;
}

#lobo.incomodado {
  max-width: 1120px;
  /*height: 750px;*/
  height: 535px;
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
  background-image: url("img/loboincomodado.jpg");
  background-repeat: no-repeat;
  background-position: top center;
  background-size: cover;
}

#lobo.pata {
  max-width: 1050px;
  height: 380px;
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
  background-image: url("img/lobopata.jpg");
  background-repeat: no-repeat;
  background-position: center center;
  background-size: cover;
}

#lobo.cabeca {
  max-width: 900px;
  /*height: 600px;*/
  height: 500px;
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
  background-image: url("img/lobocabeca.jpg");
  background-repeat: no-repeat;
  background-position: center center;
  background-size: cover;
}

#lobo.corpo {
  max-width: 1100px;
  /*height: 550px;*/
  height: 500px;
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
```

```
  background-image: url("img/lobocorpo.jpg");
  background-repeat: no-repeat;
  background-position: center center;
  background-size: cover;
}

#lobo.cauda {
  max-width: 460px;
  /*height: 600px;*/
  height: 500px;
  /*margin: 145px auto;*/
  margin: 70px auto 145px auto;
  background-image: url("img/lobocauda.jpg");
  background-repeat: no-repeat;
  background-position: top center;
  background-size: cover;
}

@keyframes shake {
  10%, 90% { transform: translate3d(-5px, 5px, 0); }
  20%, 80% { transform: translate3d(10px, -10px, 0); }
  30%, 50%, 70% { transform: translate3d(-20px, 20px, 0); }
  40%, 60% { transform: translate3d(20px, -20px, 0); }
}

#subtitle {
  text-align: center;
  margin: -100px auto;
  width: 1000px;
  border-radius: 6px;
  font-size: 200%;
  /*text-shadow: -1px 0 black, 0 1px black, 1px 0 black, 0 -1px black;*/
  background-color: #ffe;
}
```

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