InterArt: Learning Human-Computer Interaction Through the Making of Interactive Art

Emanuel Felipe Duarte(✉) and M. Cecília C. Baranauskas(✉)

Institute of Computing, University of Campinas,
Av. Albert Einstein, 1251, Campinas, Brazil
{emanuel.duarte,cecilia}@ic.unicamp.br

Abstract. Technological advances are substantially changing what we understand as a computer. For Human-Computer Interaction (HCI) educators, it is a challenge to stay updated and prepare students to cope with the state of the art technology, interaction possibilities, and ever-growing sociotechnical challenges. We advocate that, besides traditional HCI topics, students should be encouraged to creatively engage and tinker with novel tools and technologies and design for open-ended scenarios. In this paper, we report on results of the InterArt project: HCI students explored tools and technologies from the maker culture to design and implement an interactive artwork. We detail our teaching methodology and the conducted activities; the products of these activities and feedback from students compose our results. Our approach made possible for students to creatively express themselves, be a part of a participatory design and collective sensemaking process, discover and practice socially aware design, and ultimately expand what they understand as HCI.

Keywords: HCI education · Interactive art · Evaluation
Socially aware design · Maker culture

1 Introduction

Recent technological advances such as personal mobile devices, artificial intelligence, and Internet of Things (IoT) devices are substantially changing what we understand as a computer, as well as how we interact with it. Nevertheless, each future technological advance has the potential to bring even more dramatic changes. When it comes to Human-Computer Interaction (HCI), technological advances also bring to researchers and practitioners alike the inevitable challenge of staying updated. Inevitably, the field of HCI has no option but to evolve in response to changes in the technological landscape, infrastructure and the expanding capacities and contexts of technology use [6,11,12].

According to True, Peeters and Fallman [27], education has an important role in molding and shaping people who will practice design, and designers, in turn, have the ability to shape the world. For HCI education in specific, it is a

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great challenge for an 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 be made available at some point in the future. These educational challenges point us towards our general research question in this paper:

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

We believe 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 technologies, such as Arduino and similar electronics gadgets, artificial intelligence APIs, and IoT devices. Furthermore, following the well-accepted notion that HCI research and practice is no longer limited only to well-defined and/or workplace problems [3,4,13,25], we also believe that (2) students should be encouraged to design solutions for elusive, open-ended scenarios. Building upon (1) and (2), we devise our specific research question:

> **Specific research question:** Can we teach HCI by employing novel technologies, such as Arduino and other devices, in the design of open-ended scenarios, such as the creation of interactive art?

In this paper, we report on how we promoted an articulation between art and science in a HCI education context. Besides studying and practicing what can be considered traditional topics within the field, 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 Computer Science and Computer Engineering students undertaking a HCI course with challenging (but open-ended) concepts and new technologies at the intersection of art and science. We believe that this approach may lead respectively to more open-minded HCI practitioners and higher awareness to novel forms of interaction.

The paper is structured as follows: in Sect. 2 we present our theoretical and contextual background; in Sect. 3 we present the InterArt project and related activities; in Sect. 4 we report our results from data collected throughout the course, including descriptions of the created interactive artworks; in Sect. 5 we discuss our results and main findings; and finally, in Sect. 6 we present conclusions by revisiting our research questions.

2 Background

In the literature, there seems to be no consensus on what topics precisely constitutes the field of HCI. In 1992, when attempting to establish a curriculum, Hewett *et al.* stated "There is currently no agreed upon definition of the range of topics which form the area of human-computer interaction" [14]. Even though the field has considerably evolved and matured in the following decades, in Churchill, Bowser and Preece's survey [6], the authors conclude that Hewett *et al.*'s observation was still valid in 2013. We understand this lack of consensus not as a flaw in HCI education, but as a sign of the diversity of thought in our field, as well as a response to the need of adapting HCI education to different contexts. Thereby, it is not our aim to communicate our approach as a universal solution, but instead as a possibility that made sense in our geographic, economic, technological and social context.

Literature also suggests a relative lack of detailed reports and formal discussion regarding practical approaches to HCI education. True, Peeters and Fallman [27] argue that there are numerous approaches to HCI education across existing programs worldwide. However, the inner workings of these programs are rarely discussed outside their own institutions. Moreover, Grandhi [11] argues that most discussions regarding HCI pedagogy are informal and done through social networks or in conferences. Thus, it is our intention to report our approach with as much detail as possible, including the rationale behind our choices.

Our study was conducted in a HCI undergraduate course during 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 the University of Campinas (UNICAMP), Brazil, participated. For group activities, students self-organized themselves at the beginning of the semester in 9 teams of 6 or 7 members. Regarding our pedagogical approach, we adopted a sociotechnical perspective to the design of interactive systems, making use of inclusive and participatory approaches [2,18,26]. We also adopted a just-in-time teaching methodology [22], which means that students were proposed with pre-class "warm-up" activities, designed to prepare them for the topic to be discussed in class. With Preece, Sharp and Rogers [16] and Rocha and Baranauskas [24] as the main bibliography, 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 concepts and methods;
6. (UI) design tools and environments; and
7. Selected subjects (*e.g.*, IoT interaction design, cultural aspects).

These topics were taught in a traditional classroom context, and students were evaluated with two tests and two hands-on projects they conducted along the semester. The first project was a more traditional approach to a 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 project included classic techniques and methods, 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 this paper. The project was entitled InterArt, and students had to design and build an interactive artwork.

In our study, we choose to work with art for two main reasons. First, the articulation of art and science has been an important source of innovation and ground-breaking contributions in many fields throughout history [29]. Considering John Lasseter's quote that "[...] art challenges technology, and technology inspires art" [17], we take the perspective that there is a two-way path of influences between art and science, and an articulation can be beneficial for both sides. As a second reason, in HCI art and science may be articulated through the overlapping concept of interactive art [9,10,21]. 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 to debate [1,15]. However, for the practical purposes of this paper, we consider interactive art to be broadly any form of art enhanced with any kind of computer-based interactivity.

The creation of interactive artworks, in turn, brings 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 [19] emphasizes the importance of a 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 [23], 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.

3 The Path Towards the InterArt Project

Even before formally presenting the project to the students, whenever possible we articulated the course's content with the InterArt design problem. Some of the proposed warm-ups and in-class activities conducted allowed students to discuss aspects that might intersect with art, such as perception, and to form their own definitions of interactive art. In the following subsection, we list all the activities that were somehow connected to the InterArt project.

3.1 Relevant Activities

Introductory Questionnaire. The first warm-up was a questionnaire aimed at better knowing the students and their motivations. 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 them to "Indicate an artist or artwork that you admire." In the following week, students named their teams after an artist or artwork of their liking.

Perception Warm-Up. As a warm-up 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). The class, however, 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 same group colleagues before responding. The design of the warm-up, which is illustrated in Fig. 1, was intended to discuss with students that perception is not only physiological but also socially informed.

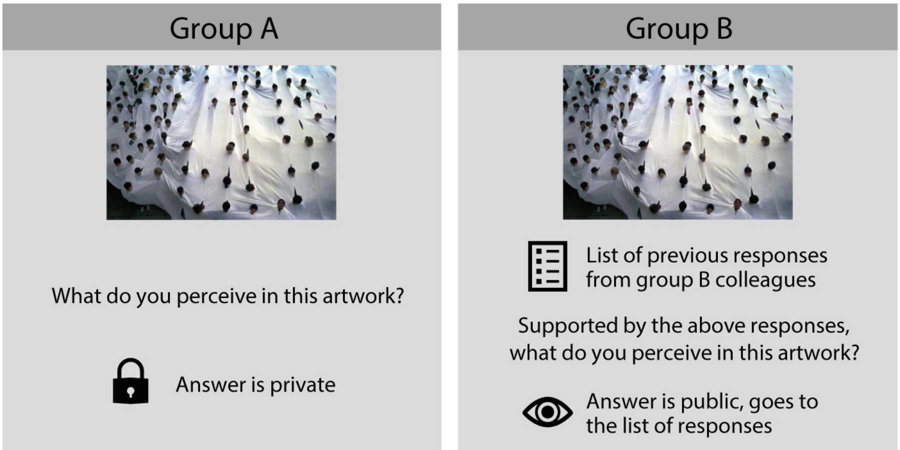


Fig. 1. Illustration of the design of the perception warm-up.

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-min seminars, including at least one illustrative example, and describing their research process. After the class, we asked in an online form: "Did watch your colleague's presentations somehow aggregate or modified your initial concept of interactive art? Please justify your answer." Instead of imposing some arbitrary definition, our objective was to have students form their own understanding of the subject and to expand their understanding by sharing it with each other.

Ideation Techniques for InterArt. We proposed three ideation techniques to help teams come up with ideas for an interactive artwork. The first technique, "challenging existing assumptions", was adapted from Michalko [20, pp. 43–52]. 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 [28], in which the team selected their favorite ideas from the previous activity and collaboratively wrote a proposal on how to make the reversal of that idea come true. A third technique, "translating sensory experiences", is based on the reported influence of sensory experiences on creativity [30], and consists of listing non-visual sensory elements and trying to give them a visual representation. The third technique could not be conducted in class due to time constraints but was still presented to the students.

InterArt Requirements. 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 [18, pp. 26–35]. The Semiotic Framework can be described as a "ladder" with six "steps": (1) physical world; (2) empirics; (3) syntactic; (4) semantics; (5) pragmatics; and (6) social world. Each step 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, we had already discussed with students the inner workings of some interactive art examples, exploring topics such as emotion recognition APIs, sensors, actuators, microcontrollers, and connectivity.

After the Semiotic Ladder, students also created a diagram that we named "Communicational Map". In this diagram, they represent both physical and virtual components from the Semiotic Ladder, as well as involved human actors, and illustrate how these components communicate with each other. The diagram should represent what are the paths in which the information travels, and what kind of information travels through each path. For instance, a vibration sensor may be triggered by shaking the sensor; this information reaches a microcontroller through wires; the microcontroller uses Wi-Fi to broadcast the information, and a web page is notified of the new value for the vibration variable.

Hands-On Workshop with Electronics Kit. To support the project 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 [8]). The kit, properly presented with a set of slides to which we will refer to as "kit slides", was composed of:

- Controller: NodeMCU (Arduino-compatible, with built-in Wi-Fi);
- Sensors: temperature & humidity, light dependent resistor, sound, reflexive obstacle, vibration and push buttons with colorful covers;
- Actuators: assorted single-color LEDs, RGB LEDs and buzzer; and
- Other components: organizer box, breadboard, jumper wires and resistors.

The kit was accompanied by custom documentation on every component, 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, a LED could be turned on or off from a web page, and a virtual representation of the *Mona Lisa* shook when the vibration sensor was shaken. Students had an entire 2-h class dedicated to exploring the kit, following the tutorial and asking any questions that might arise in the process. Furthermore, students could keep the kit in their possession until the end of the semester. After the hands-on workshop, there were two more 2-h classes dedicated to using the electronics kit, but this time for prototyping the interactive artwork the teams had been designing up to that moment.

InterArt Peer Review. After the teams finished a functional prototype, we conducted a session of peer review. Students set up their prototypes inside the classroom, and, in a circular manner, each team experimented with and evaluated the prototype of the next team in the alphabetical order. To support the evaluation, students used Costello and Edmond's Pleasure Framework [7]—we opted for this framework instead of more classical HCI evaluation methods because of the nature of the project: in our context, to analyze aspects of playful interaction could yield more meaningful and helpful results than a usability test. However, we complemented the Pleasure Framework with a part of the (SAM) [5]: 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 evaluators had to justify their answers in writing. Afterwards, the teams gathered the results of the peer review and used it 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.

InterArt Final Presentation and Feedback Questionnaire. At the end of the semester, each team presented their project in a 10-min, 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 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, students had the option to fill it anonymously if they wanted to.

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 for reference and are a free translation from Brazilian Portuguese.

4.1 Teams and Interactive Artworks

The teams and their projects are listed in alphabetical order in Table 1.

4.2 Perception and Interactive Art Concept Warm-Ups

For the perception warm-up, there were 28 responses from group A and 24 from group B. 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, Fig. 3 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, for instance:

> *"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." (Response #12 from Group A)* (Q1)

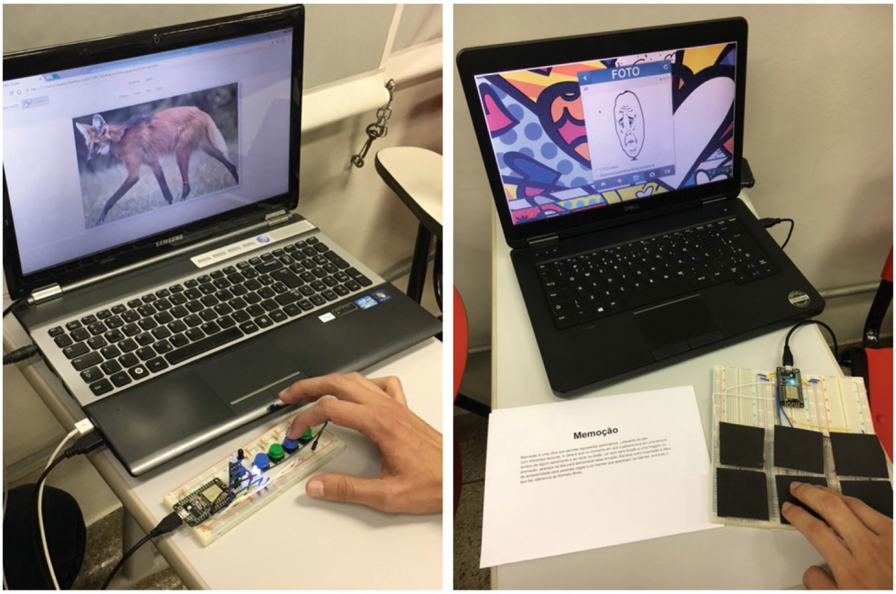
> *"The work portrays the participation of the individual as part of something greater. In this case, it is a work of art of a neo-creative artist. However, the analogy can expand to the participation of being in Society." (Response #11 from Group B)* (Q2)

For the task of forming a concept of interactive art, the teams conducted a free research on the subject and collected a wide range of what they considered interactive art examples. After the presentations, 46 students answered the follow-up question. 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 reported different perspectives they had not thought about before, as can be seen in this sample of three answers:

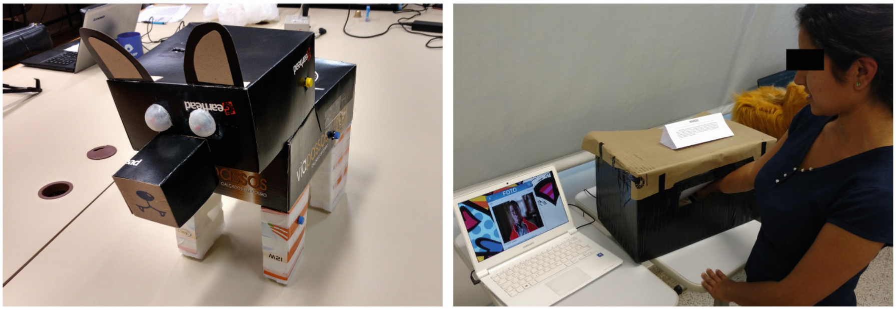
> *"Acquiring other perspectives and examples of Interactive Art. For example, taking accessibility into account in art"* (Q3)

Table 1. Teams and their respective interactive art projects.

Team	**Interactive Artwork**
500cc (*cinquecento*), after a moment of the Renaissance, in specific the 16th century.	A sensory dancing platform with a visual 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. The computer then projects an abstract painting being generated by capturing the motion of anyone dancing over the platform.
Autorretrato (self-portrait), after the category of artworks in which the artists portray himself.	A dynamic display of self-portraits based on physiological measurements. There are 16 self-portraits, categorized according to brightness, color temperature, and movement. Vibration, heart rate (not included in the kit, but borrowed) and temperature sensors collect data from the audience, which is used to modify a self-portrait (*e.g.*, making it warmer and brighter), or to bring up another self-portrait more aligned with the inferred emotional state of the audience.
Gabe Newell, after the BAFTA Fellowship Award-winning game developer known for *Half-Life*.	A "non-game" exploring the concept of loneliness. Based on the *Loneliness* non-game by Jordan Magnuson, the audience uses gestures to control a virtual character that tries to approach new friends, but inevitably repels everyone, leading to a loneliness feeling. As the feeling of loneliness increases, it is accompanied by the *Dark Was the Night, Cold Was the Ground* song by Blind Willie Johnson.
Guns, after the hard rock band Guns N' Roses.	A digital musical instrument for composing songs without the need of knowing how to play musical instruments. With a curated set of rhythms from various instruments, the audience can shake the artifact and press buttons on it to change instruments and their rhythm. There is also an algorithm that automatically keeps the instruments synchronized to ensure a harmonious melody.
Kubrick, after the Academy Award-winning film director Stanley Kubrick, known for *2001: A Space Odyssey*.	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. An accelerometer and gyroscope (not included in the kit, but borrowed) capture the movement, used to control the projection accordingly (*e.g.*, speeding or slowing down the playback rate and adding a red filter proportional to the speed).
Lobisomem Atacando o Galinheiro (Werewolf Attacking the Chicken Coop), after the painting by Brazilian artist Felipe Abranches.	A farm mock-up with sensors to control an 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, which, based on the original painting, addresses the contrast between urban and rural settings and way of life.
Lobos-Guará (Maned Wolves), after the paintings *Lobo-guará I* and *Lobo-guará II* also by Felipe Abranches.	An interactive cardboard maned wolf designed for educational museums. The maned wolf artifact, which can be seen in Figure 2, 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 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.
Nychos, after the urban/graffiti artist and illustrator known for his "dissections" of animals and other famous pop culture characters.	An interactive interpretation 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.
Romero Britto, after the Brazilian artist known for his use of vibrant colors and bold patterns.	A sensory black box, which can be seen in Figure 2, with textures inside, that evoke emotions associated with Internet memes. Inside 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 emotion.



(a) Lobos-Guará's prototype. (b) Romero Britto's prototype.



(c) Lobos-Guará's final artifact. (d) Romero Britto's final artifact.

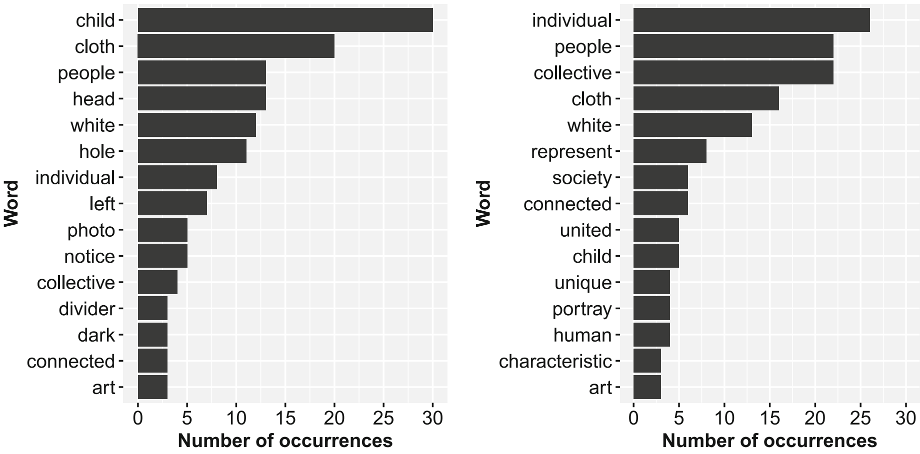
Fig. 2. Prototypes used for peer review and presented final versions of the artifacts from the teams Romero Britto and Lobos-Guará.

> *"The idea that interactive art is metaphorically a symbiosis between the artwork and the viewer because it exists with his participation."* (Q4)

> *"I did not consider some types of art as capable of interactivity."* (Q5)

4.3 Questionnaire Responses

There were 51 responses to the introductory questionnaire. We will focus our analysis on the last question, regarding an admired artist or artwork.



(a) Group A. (b) Group B.

Fig. 3. Top 15 most frequent words from the perception warm-up, by group.

The answers were considerably varied among respondents. Some students 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. Margin, Carlos Drummond de Andrade) or cinema (*e.g.*, Dennis Villeneuve, Bill Murray), but also other trades, such as industrial design (Jonathan Ive) or video game development (Falco Girgis). Three responses, however, stood out and caught our attention (it is worth noting that the student from (Q8) had shown interest in digital games in a previous question):

"none" (Q6)

"I did not think of any" (Q7)

"I'm not very attached to art" (Q8)

For the course feedback questionnaire, in turn, there were only 12 responses. This drop in the number of responses can be attributed to the questionnaire being optional and being sent only after final grades were attributed. Although the responses may not be 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 12 respondents answered "yes". To further explore the answers, quotations (Q9) and (Q10) are two justification examples from students who responded "yes", while quotation (Q11), in contrast, is from a student who responded "no":

> *"The projects of the other teams showed me the various interpretations of art and made me reflect that there really are several kinds of interaction between art, technology and human-computer interaction that I had never stopped to think about."* (Q9)

> *"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."* (Q10)

> *"I think that the way the topics were covered did not help to create the design notion needed for a computer engineer."* (Q11)

Regarding the methods and artifacts used to support the InterArt project along the semester, we provided 14 statements that students had to answer to 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 Fig. 4, there were 2 questions referring to ideation, 2 to requirements, 5 to evaluation and 5 to the electronics kit. In general, the feedback was mostly positive, and the responses are accompanied by qualitative feedback.

Feedback for Ideation Techniques. For the Challenging Existing Assumptions and BrainWriting techniques (questions A and B in Fig. 4, respectively) there were mostly positive responses. Quotation (Q12), for instance, highlights how the participatory nature of these activities facilitated engagement within the team and allowed the emergence of several different options for the project. The student from quotation (Q13), in turn, expresses how the Challenging Existing Assumptions technique had a major role for his team in determining the basic idea of the project. Lastly, quotation (Q14) contrasts with the previous two examples with the argument from the student that, in his opinion, the BrainWriting was not a suitable technique and led to a polluted design.

> *"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."* (Q12)

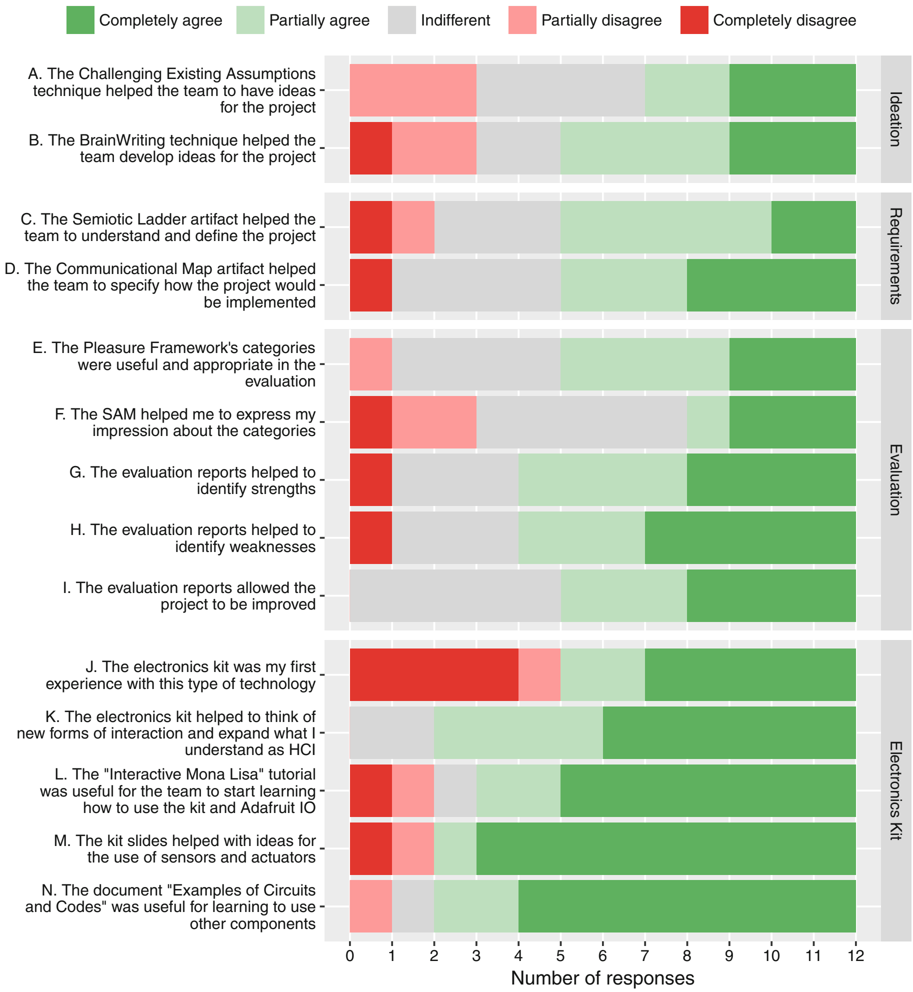


Fig. 4. Student feedback on the used methods and artifacts.

"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." (Q13)

"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." (Q14)

Feedback for Requirements Artifacts. Regarding the Semiotic Ladder and Communicational Map artifacts (questions C and D in Fig. 4, respectively), most of the responses are positive for both artifacts. In quotation (Q15), the student argues how the Semiotic Ladder helped him to obtain a more holistic view of the project components, while in quotation (Q16), another student reported the Communicational Map's importance in planning the parts of the project. The student from quotation (Q17), in contrast, argue that these artifacts may not be helpful if there are already well-defined ideas for the project.

"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." (Q15)

"The map helped plan the parts of the project, improving the way we organized ourselves." (Q16)

"I believe that, with clear ideas, these artifacts provided little help." (Q17)

Feedback for Evaluation Artifacts. For the Pleasure Framework and SAM artifacts (questions E and F in Fig. 4, respectively), the former had mostly positive responses, while the latter had mixed feedback. Furthermore, the majority agreed that the evaluation reports helped in identifying strengths, weaknesses and allowed the project to be improved. Quotation (Q18) 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 quotation (Q19) emphasizes on how the Pleasure Framework can bring forth aspects overlooked by the team but reports that the SAM was overshadowed by written justifications. The student from quotation (Q20) argues how evaluation is essential in his understanding of interactive art, and that the peer review process was not only useful but necessary. In contrast, the student from quotation (Q21) argues that the SAM can be confusing and was not helpful during the evaluation process.

"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." (Q18)

"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." (Q19)

"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." (Q20)

"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." (Q21)

Feedback for 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 (question J in Fig. 4). Ten students agreed that the kit helped them to think of new forms of interaction and expand what they understood as HCI (question K), and no student disagreed. Lastly, most students agreed that the "Interactive Mona Lisa" tutorial, presentation slides and examples of circuits and code were useful (questions L, M, and N). The student from quotation (Q22) considered the kit to be the best experience in the course, and the student from quotation (Q23) praised the quality of the provided material. The student from quotation (Q24), in turn, reported how his concept of what can be an IoT system has been expanded during the course. Lastly, in contrast, the student from quotation (Q24) reported that a lack of previous technical experience could increase the project difficulty.

"It was definitely the best experience I've had in the course." (Q22)

"All the material was very well explained and was a great base for the creation of our project." (Q23)

"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." (Q24)

"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." (Q25)

5 Discussion

Even though there is no agreed consensus on what are the topics that compose the field of HCI, Hewett *et al.*'s [14] 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, should be taught to HCI students. It seems clear that design alone is not enough, and it needs both evaluation and implementation to form a full 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.

It is important to emphasize that we are not advocating against the design, evaluation, and implementation of more "traditional" interactive systems, designed for well-defined and/or work-related problems. In fact, as presented in Sect. 2, one of the projects of the HCI course addressed in this paper (the redesign one) involved what we consider a traditional system. We are, however, advocating that HCI educators could and should explore new ways of expanding student's perceptions of what can be an interactive system (which is likely to also expand our own). Our approach of inserting art in the course with an interactive art project, for instance, yielded the rich results we presented in Sect. 4, and that we will briefly discuss here. We can highlight the following main aspects:

- **Creative Freedom:** the high degree of freedom we provided students within the InterArt project had several positive effects. As can be seen in Table 1, by choosing their team name and freely designing the interactive artwork, students had the opportunity to express themselves, and represent and pay tribute to artists and artworks of their admiration (which also brought an unexpected cultural value that came from, for instance, appreciating local and relatively unknown artists). This freedom, in turn, also led to a high degree of engagement from students. It was noticeable how many of them cared for the project and felt proud after the final presentation.
- **Participation and Collective Sensemaking:** during the whole course we aimed towards a collective construction of knowledge. Instead of providing authoritative definitions that students would probably listen to in a passive manner, we designed the course's activities to encourage active participation. Students could initially research a subject on their own, but afterward, they would openly discuss it with the class. The perception and interactive art concept warm-ups are two examples if this approach and both led to meaningful

in-class discussions. Both 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. This effect can be seen in quotations (Q3), (Q4), (Q12), and (Q5).

- **Social Awareness:** during the course, we also encouraged students to think about the concept of socially aware design [2]. In the InterArt project, students could question 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? In the Challenging Existing Assumptions technique, for instance, some teams challenged the idea that a blind person could not properly visit a museum. 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, had accessibility as a central aspect in their project. Even though social awareness goes beyond accessibility, this was the students' first experience with the subject and resulted in an expanded view of the impact of working with and designing new technology. This effect can also be seen in quotations (Q3) and (Q13).
- **Expanded View of HCI:** the idea of bringing elements from maker culture to the classroom was intended to provoke and expand what the students previously understood as HCI. The answers to question K in Fig. 4, complemented by quotation (Q24), indicate that this objective was achieved. Quotations (Q22) and (Q23), in turn, indicate that our substantial effort of preparing an electronics kit with hand-picked components and writing meaningful documentation for each one of them was important for the success of the InterArt project. In the end, the projects tacitly explored 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 what can be HCI, inevitably we must also expand our view of what can be 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, as can be seen in (Q18) and (Q19). We, however, must emphasize that we opted for the Pleasure Framework due to the nature of the InterArt project. HCI researchers and practitioners should be able to critically assess the usefulness of different evaluation methods in different domains and contexts. This is especially important 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.

5.1 Limitations

Besides the positive results, our approach does not come without some limitations. Working with interactive art, for instance, may not resonate well with every student, and quotations (Q6), (Q7), and (Q8) indicate this possibility.

Participatory methods, in turn, may also not be well received by some students, as indicated by quotations (Q14) and (Q17). No approach, of course, will be universally accepted by all the students. The student from quotation (Q11), 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 (Q10) did not show interest in art at the beginning of the course but in the end reported an overall positive experience.

Another limitation is affordability and know-how of the required electronic components. In our study, we relied on relatively low-cost hardware. The electronics kit that students used, for instance, cost 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 if it is possible to directly import components from China without additional taxes. However, even though this value is relatively affordable, not every institution and program may have a budget available for providing students with this kind of material, especially in economically disadvantaged countries. Furthermore, some of these components are eventually going to need replacement, and there is a constant release of newer, better and/or cheaper alternatives. Besides the actual price, a substantial level of know-how is needed to both initially pick the components to compose a kit, as well as to keep the kits supplied and updated.

Lastly, considering the necessary physical components and the idea of active participation and collective sensemaking, it is possible that our approach may not be suitable for the expanding modality of virtual classes, such as in massive open online courses. Our close contact with the students, particularly during practical activities, seemed to be essential to the success of the InterArt project. Therefore, when necessary, a virtual classroom would need to emulate and/or find proper alternatives to our activities and methods.

6 Conclusion

Considering our specific research question, our study shows that it is possible to teach HCI by employing novel technologies and proposing the design of open-ended scenarios. As an example of an open-ended scenario, or study also shows that interactive art can be used to articulate art and science in a HCI classroom context. The technologies and tools we employed can be useful in expanding students' view on what can be an interactive system. Open-ended scenarios, in turn, may foster creativity and participation. Even though we cannot expect our approach to resonate well with every student (can any approach?), our articulation allowed a significant number of students to rethink their perception of art, technology, and HCI. Furthermore, our approach also provided a relatively open teaching environment for students to explore 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, we cannot predict the design problems our students will face in the next 5, 10 or 20 years from now. Nevertheless, we do believe that by exploring new tools and technologies to create novel, unconventional forms of interaction, and by practicing design in a socially aware manner, our students will be somehow prepared for the unforeseen challenges they may face in the future as researchers and practitioners. Nevertheless, 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 design challenges but may indeed play an active role in defining the technology and respective design problems of the future.

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