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

Emanuel Felipe Duarte[1], Vanessa R. M. L. Maike[1], Yusseli Lizeth Méndez Mendoza[1], Camilla Valéria de Lima Tenório Brennand[1], M. Cecília C. Baranauskas[1]

[1]Institute of Computing – University of Campinas (UNICAMP)
Av. Albert Einstein, 1251 – Campinas – SP – Brazil

{emanuel.duarte, vanessa.maike, yusseli.mendoza
camilla.brennand, cecilia}@ic.unicamp.br

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.*

1. Introduction

Drawing on the seminal concepts of ubiquitous computing [Weiser 1991] and tangible user interfaces [Ishii and Ullmer 1997], recent advances in Human-Computer Interaction (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* [Dourish 2001]. 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 [Panaggio and Baranauskas 2017], and revisiting long-lasting concepts such as the idea of learning through action [Duarte et al. 2018]. 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

DOI: 10.5753/cbie.wie.2019.501

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 [Varela et al. 1993], 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 2 we present our background on learning through action and enactivism, in Section 3 we report on our case study "The Magic of Science" and its results, in Section 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 5 we present our conclusions.

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 1962] 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 1896] 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 [Varela et al. 1993], the concept of *enactive systems* [Kaipainen et al. 2011] 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 1964], 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*" [Francis et al. 2016, p. 6]. Indeed, such idea is consistent with the enactive approach from [Varela et al. 1993], with the description of sensorimotor coordination with the candle flame from [Dewey 1896], and with the concept of embodied interaction from [Dourish 2001]. 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 [Duarte et al. 2018]. 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.

3. Case Study: "The Magic of Science"

Our case study took place on April 21, 2018, at the Exploratory Science Museum of the University of Campinas (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 [Duarte and Baranauskas 2018] 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 1 and described as follows:

Figure 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 interactive 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)

Figure 2. The construction of “magic potions” and “magic wands”.

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 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 [Hassenzahl et al. 2003], 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 [Hayashi et al. 2016], an adaptation of the Self-Assessment Manikin (SAM) [Bradley and Lang 1994], 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.

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.

3.1.1. 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 [Glaser et al. 1968], 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 [Duarte et al. 2019].

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 [Duarte et al. 2018], 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.

3.1.2. 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.

4. Discussion

Going back to Heidegger's example of a hammer, that we presented in Section 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 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.

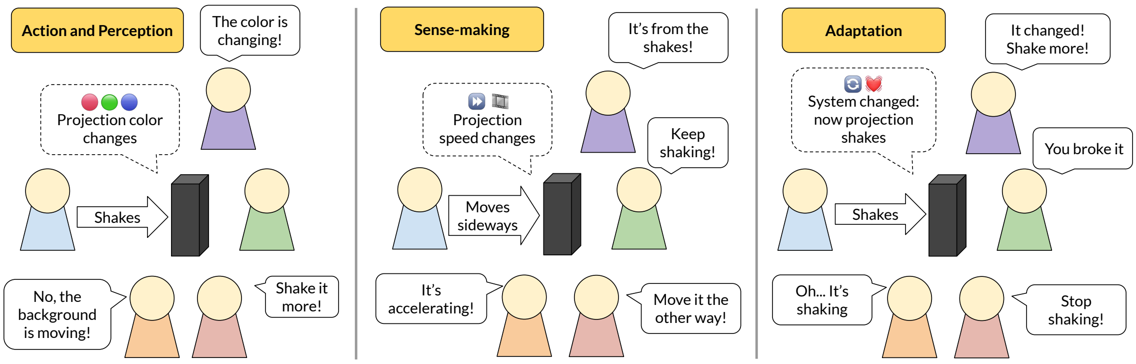

Figure 3. Monolito as a socioenactive system.

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".

Acknowledgments

This study was financially supported by the National Council for Scientific and Technological Development (CNPq) grant #306272/2017-2, São Paulo Research Foundation (FAPESP) grants #2015/16528-0, #2015/24300-9, #2017/06762-0, and Coordination for the Improvement of Higher Education Personnel (CAPES) grant #2017/173989.

References

Bradley, M. M. and Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, 25(1):49 – 59.

Bruner, J. S. (1964). The course of cognitive growth. *American psychologist*, 19(1):1.

Dewey, J. (1896). The reflex arc concept in psychology. *Psychol. Rev*, 3(4):357–370.

Dourish, P. (2001). *Where the Action is: The Foundations of Embodied Interaction*. MIT Press, Cambridge, MA, USA.

Duarte, E. F. and Baranauskas, M. C. C. (2018). Interart: Learning human-computer interaction through the making of interactive art. In Kurosu, M., editor, *Human-Computer Interaction. Theories, Methods, and Human Issues*, pages 35–54, Cham. Springer.

Duarte, E. F., Maike, V. R. M. L., and Baranauskas, M. C. C. (2018). "Maned wolf in the museum": a case study on learning through action. In *Anais do XXIV Workshop de Informática na Escola (WIE 2018)*. Sociedade Brasileira de Computação (SBC).

Duarte, E. F., Maike, V. R. M. L., Mendoza, Y. L. M., de Lima Tenório, C. V., and Baranauskas, M. C. C. (2019). A hands-on experience with interactive art within a museum scenario. Technical Report IC-19-03, Institute of Computing (IC), University of Campinas (Unicamp).

Francis, K., Khan, S., and Davis, B. (2016). Enactivism, spatial reasoning and coding. *Digital Experiences in Mathematics Education*, 2(1):1–20.

Glaser, B. G., Strauss, A. L., and Strutzel, E. (1968). The discovery of grounded theory; strategies for qualitative research. *Nursing Research*, 17(4).

Hassenzahl, M., Burmester, M., and Koller, F. (2003). Attrakdiff: Ein fragebogen zur messung wahrgenommener hedonischer und pragmatischer qualität. In Szwillus, G. and Ziegler, J., editors, *Mensch & Computer 2003: Interaktion in Bewegung*, pages 187–196, Wiesbaden. Vieweg+Teubner Verlag.

Hayashi, E. C. S., Posada, J. E. G., Maike, V. R. M. L., and Baranauskas, M. C. C. (2016). 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. ACM.

Heidegger, M. (1962). *Being and time*. SCM Press, London, UK.

Ishii, H. and Ullmer, B. (1997). 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. ACM.

Kaipainen, M., Ravaja, N., Tikka, P., Vuori, R., Pugliese, R., Rapino, M., and Takala, T. (2011). Enactive systems and enactive media: Embodied human-machine coupling beyond interfaces. *Leonardo*, 44(5):433–438.

Panaggio, B. and Baranauskas, M. C. (2017). Explorando as possibilidades do sphero em um ambiente educacional. In *Anais do XXIII Workshop de Informática na Escola (WIE 2017)*. Brazilian Computer Society (Sociedade Brasileira de Computação - SBC).

Varela, F. J., Thompson, E., and Rosch, E. (1993). *The Embodied Mind: Cognitive Science and Human Experience*. Cognitive science: Philosophy, psychology. MIT Press, Cambridge, Massachusetts, United States.

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