Multimodal Methodological Approach for Participatory Design of Full-Body Interaction Learning Environments

Over the past years an increasing number of digital learning environments based on Full-Body Interaction have been developed. Research in this field is often based on Designer-Driven approaches and is only recently employing Participatory Design techniques. However, these participatory approaches have reported relevant challenges related to including users in the design of spatial and bodily qualities of interaction. These shortcomings require extending research methods to effectively focus on embodied resources in the essential design and evaluation processes. To address this issue, we propose a methodological approach that combines multimodal analysis with Participatory Design techniques to include embodied resources in the participatory design processes for Full-Body Interaction. The proposed approach is applied to the iterative design of two Full-Body Interaction Learning Environments. Through the analysis of the outcomes of these case studies, we discuss the affordances that multimodal analysis can offer to inform and guide the design process for embodied interaction.

**Keywords:** Participatory Design, Multimodal Analysis, Full-Body Interaction, Embodied Interaction, Design Methods

1. Introduction

The embodied cognition claim for considering tools, bodily movements and gestures as elements of thought (Kirsh, 2013) has encouraged the exploration of novel design opportunities for the development of interactive learning environments (Antle, 2013). Taking advantage of the potential of physicality to support learning (Barsalou, 2008; Goldin-Meadow, 2011) and of the importance of concrete experience in grounding knowledge (Kolb, Boyatzis, and Charalampos, 2001), several learning environments based on embodied interaction (Dourish, 2004) have been developed (AuthorA, 2014; Antle, Droumeva, & Corness, 2008; Price, 2004). A paradigmatic example of them can be found in Full-Body Interaction Learning Environments (FUBILEs). FUBILEs are interactive environments where users employ their whole bodies to interact with digital technology and to support thinking processes (AuthorA, 2014). At a theoretical level, these environments hold the potential to support learning (Revelle, 2013) and offer specific pedagogical affordances such as enabling conditions for learning by doing (Klemmer, Hartmann, and Takayama, 2006), allowing offloading of cognition in the environment (Antle, 2013) and facilitating collaboration (AuthorA, 2015).

The increasing number of FUBILEs developed for learning purposes (AuthorA, 2014), however, requires going beyond the quest for appropriate technological solutions and must
address the scoping and framing of the design of these experiences in greater depth. In particular, research has suggested the need for a better understanding of embodiment (Price and Jewitt, 2013) and for a greater inclusion of users in the design process (Alborzi et al., 2000; Landry et al., 2012; AuthorB, 2014; Taxon, 2004). Nonetheless, a relevant number of challenges related to involving users in design for embodied interaction have been reported (Ringel Morris et al., 2014; Hoff, Hornecker and Bertel, 2016). These threats suggest the need for appropriate methodological approaches capable of fully acknowledging the specificities of designing for these novel interaction modalities.

To address this need, we propose a methodological approach that combines multimodal analysis (Jewitt, 2013; Kress, 2010) with Participatory Design (PD) techniques to include users’ embodied forms of interaction in the design process and inform the design of FUBILEs. In the paper, we will first present a short overview of the most commonly employed methods to guide the design of FUBILEs. Subsequently, we will describe the proposed approach and report its application in two case studies. In the first case study, this framework is employed to inform the design of a FUBILE aimed at fostering social initiation in children with Autism Spectrum Disorder (ASD). In the second study, we applied this approach to guide the design refinements of a FUBILE aimed at supporting reflections on group behavior and collaboration between neurotypical children. The analysis of these case studies will serve as a foreground to discuss and reflect upon the affordances that the combination of multimodal analysis and PD can offer to inform and guide the design process for FUBILEs.

2. Methodological approaches in designing Full-Body Interaction Environments

FUBILEs designed in the last decade have typically been developed according to a Designer-Driven approach (AuthorA, 2014), in which all the design decisions are entirely defined by the researchers. This approach, however, can present some shortcomings in the development of end-user technologies (e.g. developing systems that require an extensive user-training (Wobbrock et al., 2009) or that fail in properly understanding users’ mental models).

To address these risks, a growing number of studies have proposed initial efforts to employ PD techniques (Muller and Druin, 2003) to involve end-users in the design of FUBILEs (Enyedy et al., 2012; Gronbaek et al., 2007; Höysniemi et al., 2005; Landry et al., 2012; AuthorB, 2014, 2015). Some studies (Enyedy et al., 2012; AuthorA, 2016a) have employed PD techniques developed for traditional WIMP interfaces (Windows, Icons, Menus, Pointer) to co-define content-related aspects. These approaches have been shown to be appropriate for understanding users’ interests and previous knowledge. Nonetheless, they may run the risk of assuming a
disembodied perspective and neglecting a proper understanding of how the body and tools can contribute to thinking and learning.

To address this issue, other researchers have started to investigate participatory methods to address embodiment during the design process (Buchenau and Suri, 2000; Iacucci and Kuutti, 2002; Simsarian, 2003) by using bodily-based techniques (e.g. bodystorming) or gesture-elicitation approaches (i.e. requiring users to propose specific gestures for the interaction). Despite the appeal of the idea of “sketching through the body”, people often tend not to be trained to intentionally use their body as an expressive medium. As a consequence, techniques such as bodystorming (Loke, Robertson and Sydney, 2013) or gesture-elicitation can be challenging for the laypeople or users may end up proposing gestures that mainly emulate mouse-based interaction and do not incorporate the potential of Full-Body interfaces (Ringel Morris et al., 2014; Hoff et al., 2016). These issues are especially critical when working with children. In these cases, the novelty of these tasks may run the risk of eliciting gestures that do not respond to the naturalness of the interaction but just to the willingness of doing something “original” or performing theatrical pantomime (AuthorB, 2016).

This overview highlights that while the inclusion of end-users in PD for embodied interaction represents a promising research field, it also presents a number of open challenges. Starting from this perspective, we propose a methodological approach oriented toward combining PD and multimodal analysis to understand the process of embodied meaning-making and inform design.

### 3. The methodological approach

The proposed methodological approach combines a PD based on the users-as-informants model (Nesset and Large, 2004) with an analytical framework derived from multimodal analysis (Jewitt, 2013; Kress, 2010). Its goal is to better understand meaning-making in embodied learning experiences in order to inform design refinements and include user’s contributions from a perspective that goes beyond the limits of verbal language.

The participation of users-as-informants represents a well-known technique to guide iterative design processes. It is based on involving users in an early stage of development to understand how they interpret and use an initial prototype of the system (Druin, 2002).

In the context of FUBILEs, besides allowing us to easily identify design refinements, this approach can also represent a useful strategy to avoid legacy biases (Ringel Morris et al., 2014; Hoff et al., 2016) that lead participants to think of interactive experiences only in terms of mouse-based / screen-based interaction. Furthermore, it permits the direct observation of users’ embodied meaning making and can provide an experiential starting point to ground users’ contributions on embodied interaction.
However, to properly collect and understand these latter aspects, it is necessary to go beyond the analysis of only explicit verbal feedback or usability issues. For this purpose, we suggest using multimodal analysis as an analytical lens to understand how users employ different modes to construct and express meaning.

Multimodal analysis focuses on communication and situated interaction from a perspective that goes beyond the limit of verbal language and encompasses the different resources that people use to construct meaning (Jewitt, 2013). At a theoretical level, it is grounded on the key concept of mode, which constitutes a set of socially and culturally shaped resources for making meaning, e.g. the ensemble of writing and images on a page (Jewitt, 2013). According to this framework, each mode has a set of modal affordances, which refers to “what is possible to express, represent or communicate easily with the resources of a mode and what is less straightforward or even impossible” (Kress, 2010).

Its application in research on embodied interaction has shown its suitability to analyze and understand user interaction in highly multimodal experiences (Crescenzi, Jewitt and Price, 2014; Price, Sakr and Jewitt, 2015; Price and Jewitt, 2013). We suggest that its application in the analysis of PD for FUBILEs can offer relevant contributions allowing observation and analysis of the meanings that are constructed through the different modes offered during these PD activities.

3.1 Combining user-as-informants and multimodal analysis

The participation of users-as-informants involves the display and usage of a wide variety of modes to construct and express meaning. In our case, children were asked to physically interact with a FUBILE, verbally report on it and produce sketches about their experience and eventual design refinements. These different modes offered specific affordances related to what meaning could be created and expressed through them (Kress, 2010). In order to properly understand these meanings, we focused on observing, analyzing, integrating and interpreting the following resources:

1. Sensorimotor exploration, understood as the ways in which users physically become engaged, explore and use the physical-digital environment during in situ interaction. This analysis encompasses both the affordances offered by the system (e.g. its physical configuration, the available physical/digital objects, etc.) as well as the embodied forms of interacting with it. Specifically, in the proposed case studies we analyzed the following variables: the paths that users follow to explore the environment, the variations and repetitions in their sensorimotor enactments, their usage of the available physical/digital elements, their focus of attention, and their reciprocal proxemics and social relations. To carry out this analysis we employed the video recordings of in situ interaction of users with the system focusing on the
aforementioned variables. The videos were first transcribed using a narrative approach and then each variable was addressed through a frame-by-frame visualization of the video in order to create annotated maps. These annotated maps coded children’s behavior during in situ interaction (Figure 3). The involved researchers then discussed and interpreted these materials.

2. *Verbal interactions*, understood as the analysis of children’s spontaneous or elicited speech acts (Searle, 1969) both during in situ interaction and after the experience. Speech acts occurring during in situ interaction were transcribed on the annotated maps. Instead, verbal interaction during PD activities were transcribed and analyzed through a grounded approach (Corbin and Strauss, 1990) aimed at spotting out children’s core meanings, representations and interests.

3. *Children’s productions*, understood as the analysis of drawings, written reports or any other type of production made by the children during post-tasks of the PD activities. This analysis was carried out from a multimodal perspective and using a grounded approach oriented toward identifying main concepts and ideas, which could be indicative of children’s understandings of the experience.

Data from these resources were combined and interpreted according to a model based on the experiential learning cycle (Kolb et al., 2001). Specifically, we focused on identifying:

1) The ways of becoming engaged with an experience; i.e. what captures children’s attention and which elements they consider relevant or salient to build their understanding of the experience;

2) The ways of exploring the system; i.e. how children experiment with it and make it work according to their own purposes:

3) The ways of transforming the experience; i.e. how children re-elaborate and transform the experience by connecting it with their already existing structures of meanings and by building and retaining specific representations of it.

4. *Case studies*

In the following sections, we describe the application of the proposed approach during the iterative design process of two FUBILEs: the “Lands of Fog” project and the “BetweenBodies” project.
4.1 Participatory Design of the “Lands of Fog” project

“Lands of Fog” is an open-ended FUBILE designed for children with Autism Spectrum Disorder (ASD). The experience has the goal of promoting exploration and scaffolding social initiation. Its set-up is based on a 6-meter diameter floor projected virtual environment (Figure 1), which is covered by virtual fog. Users explore and interact with the environment using a butterfly net that allows them to open peepholes in the fog and discover what is hidden underneath. A detailed description of the final design of the system is available in (AuthorC, 2016b).

![Figure 1. Physical configuration of the full system of Lands of Fog](image)

4.1.1 The PD workshop

In the initial stage of development, we conducted a PD workshop based on the “children-as-informants” model with four children with ASD (all males, mean age: 11). The workshop lasted for one and a half hours and aimed at analyzing how children interacted with and interpreted the initial design proposal.

During the workshop, we employed a prototype that presented only a very simplified version of the main landscape of the experience, which was covered with virtual fog. Children could interact with it by using a butterfly net that allowed them to open peepholes in the fog and see a small portion of the underlying world (Figure 2). In this prototype, we did not include any specific content or game mechanics in order to provide space for children’s contributions.

At the beginning of the workshop, children were divided into pairs. Each pair received one of two roles, namely: “explorers” or “detectives”. The children assigned to be “explorers” were invited to enter the floor projection area (Figure 2). One of them was given a camera and instructed to take pictures of anything that captured his interest. The other, instead, was given
the butterfly net and instructed to use it as a magic wand to open the fog. In parallel, the children assigned to be “detectives” were taken to a balcony in the upper floor that overlooked the entire room. Together with two researchers, the two children were asked to try to imagine what the environment looked like, what possible creatures could inhabit it, and what their peers acting as “explorers” should do in their exploration. After 15 minutes children swapped roles; i.e. those acting as “explorers” became “detectives” and vice versa.

Subsequently, all children were asked to draw whatever they would like to see hidden under the fog. The children were invited to produce drawings on white paper, where only a circular shape, representing the digital environment, was provided. After finishing, they explained the drawings to their peers.

4.1.2 The analytical approach

To analyze these activities, we employed the analytical framework defined above. Following this model, we focused on analyzing in situ interaction and collecting children’s retrospective interpretations of the experience. To analyze sensorimotor exploration we focused on: (1) children’s exploration of the space (their position, paths, pauses and relative speed), (2) the movements performed with the butterfly net, (3) their gaze and the pictures they took during the interaction with the system. This analysis was carried out on the first minute of the children’s interaction while holding the net and exploring the environment. We chose to perform a fine-grained analysis of this first stage of exploration, in order to gather insights about which aspects immediately called their attention and curiosity. As an outcome, we produced an annotated map for each child (Figure 3). Subsequently, verbal interactions and children’s productions were analyzed according to a grounded approach. The different sources were later combined for interpretation. A detailed description of the overall study is available in AuthorA et al. (2016).
Figure 3. Maps showing the exploration of physical/digital space by children (blue line), the movement of their net (red line) and salient actions (square inserts). These maps were produced by manually tracking children’s displacements and actions in the space.

Figure 4. a) Representation of the overall displacements of children (left); b) Map of pictures taken by the children of the virtual environment with a camera (right). We produced the first figure by superimposing the children’s paths (Figure 3) on the image of the virtual environment. The second was produced by mapping the positions of their pictures on the image of the virtual environment.
4.1.3 Outcomes

The combined analysis of in situ interaction and PD activities allowed us to get a deeper understanding of how children engaged with the system, experimented and understood it. From their sensorimotor exploration, we found that the children were particularly interested in exploring areas that depict borders between different types of landscape (e.g. borders between a blue area and a green area of the environment). These observations were derived from the distribution of their overall paths of exploration of the space and from the topological analysis of the distribution of the pictures they took (Figure 4).

These findings suggest that the children tended to focus their attention on detailed and border areas, where some salient visual changes were present. This interest led three out of four children to interpret the underlying environment as a geographical map representing a large space such as a continent or a state. These interpretations were reflected both in their explanations during the “detective” activity and in their drawings, where mainly detailed natural elements were depicted.

Alongside their interest in detailed areas, the children also showed several behaviors related to exploring the possibilities of using the butterfly net to open peepholes in the fog. Children performed several pauses oriented toward changing the patterns of the net’s movement in order to explore how it affected the visual changes in the fog (e.g. semicircular movements on a side or in front of the body, dragging of the net on the floor to draw figures in the fog). From an interpretative perspective, the act of moving around with the net was associated with the task of hunting or collecting something. Interestingly, during the detective activity, all children explained this action according to a strictly functional perspective (e.g. “You have to collect animals to make points”). These functional explanations suggest the tendency to understand the environment according to a goal-oriented and reward-orientated approach, which can probably be attributed to their gaming culture. The influence of videogames was also transversal to almost all of their proposals during the drawing activity, suggesting its crucial role as a cultural reference for understanding the system.

Finally, while the children showed a sustained interest in the FUBILE, the experience was poorly associated with the initial goal of promoting social initiation. Specifically, during interaction with the system, all children’s gazes were completely drawn toward the digital environment and did not look at the surroundings or to their peers. Furthermore, in their proposals, none of them mentioned the possibility of collaborative or shared tasks.

4.1.4 Informing design
The performed analysis allowed us to identify some relevant aspects to be addressed in future design iterations. First, the use of the virtual fog showed to be an effective design choice to promote exploration. Specifically, it elicited the interest to discover what was hidden under it and promoted different sensorimotor enactments related to experimenting with its visual appearance. Within this context, future design iterations can eventually address the refinements of the fog’s behavior to enrich the possibilities for sensorimotor exploration (e.g. producing different visual outcomes according to children’s movements). At the same time, to enhance children’s engagements with the experience, relevant insights can be derived from their interests in detailed representations and videogames. These findings suggest that a realistic and videogame-like graphical style may be adequate to capture children’s attention and foster exploratory behaviors.

Nonetheless, some design challenges also emerged. On the one hand, children’s tendency to interpret the environment as a large space (i.e. a continent) highlighted issues related to defining an adequate scale of the experience (e.g. will the child be a “giant” in the environment or will the environment be proportional to the child?). On the other hand, children’s lack of interest toward their peers requires design improvements to promote more collaborative ways of interacting during the experience. To tackle this latter issue, possible design solutions can use videogames mechanics as motivators of social interaction. The children showed a strong interest toward considering the space as “actionable” with video game-like tasks. This priming role of videogames can act as a hook to scaffold children’s interest to interact with others. However, their videogames culture also points out challenges related to properly defining the experience. These children were mainly used to games in which players compete and fight against enemies or other players. However, these game mechanics were in conflict with the educational goals of our experience. As a consequence, when defining appropriate game mechanics, relevant research challenges should aim for a balance between children’s expectations on “what a game is” and the values that we want to pursue.

4.2 The participatory design of the “Between Bodies” project

“Between Bodies” is an application designed for neurotypical children between 10 and 12 years old. Its goal is to offer a collaborative drawing experience that can serve as a starting point to guide a discussion and reflection upon group dynamics and cooperation. For its design, we gathered requirements from experts and children. Subsequently, we developed a prototype of the application to be tested with two interfaces: a Floor Projection of 4x3 meters (Figure 5) and a Vertical Screen of 3x2 meters (Figure 6).
In both prototypes, the application was designed for four players and was based on a narrative that describes the world of “Pimpis”, the inhabitants of a faraway planet. This world has been destroyed due to conflicts between different tribes of Pimpis, each one characterized by a different color (blue, yellow, red, and green). Due to the extreme situation of their planet, the different tribes decided that they needed to work together in order to reconstruct their environment. The children had to help the characters to rebuild their planet by freely drawing a novel environment.
4.2.1 The PD workshop

To inform the design of the experience and the definition of the features of the physical interface, we conducted a PD workshop, based on the “children-as-informants” model with 24 neurotypical children from a local school (Mean age= 10.35; Female = 12; Male = 12). After their arrival at the university, the children were separated into groups of four members each (2 boys and 2 girls) and assigned to two conditions: (a) Vertical Screen (VS) or (b) Floor Projection (FP). One group at a time was taken to the facilities where either the VS or the FP was set up. Each group was given a letter that asked them to help the aliens to reconstruct their planet.

For this design stage we employed a preliminary prototype that presented an almost empty scenario, where only four characters of different colors were present. In both conditions, each child controlled one character and moved it across the environment by using a small hand-held lantern. A computer vision system tracked the lantern’s position and moved one of the characters accordingly. To be able to draw, two children needed to bring their characters close to one another. When the two characters were sufficiently close to each other, a drawing line appeared. If the children now jointly moved through the space and maintained the physical contact between their characters, the drawing line followed their paths and they could draw whatever they wanted.

Subsequently, the children were asked to propose a possible title for the game and discuss whether it could be possible to learn something from this experience. Children were then asked to work in groups to improve the experience by building a new game using a reduced-scale model of the space and paper cut figures of the characters. Finally, each group presented their ideas to the others.

4.2.2 The analytical approach

To analyze these activities, we employed the proposed analytical framework. Specifically, the analysis of sensorimotor exploration focused on (1) their paths of exploration, (2) the variations and repetition of bodily movement and (3) their proxemics and collaborative relations. This analysis was performed on the video recordings of the children playing either with the FP or the VS. A total of four videos were analyzed (2 for the FP and 2 for the VS). Each video lasted for 5 minutes, corresponding to the playing time of the children. The analysis was performed individually for each child (n = 16, 8 boys, 8 girls, 8 in FP and 8 in VS) on annotated maps (Figure 7). Subsequently, verbal interactions and children’s drawings were analyzed using the video of the overall experience (play activity and design activities).

4.2.3 Outcomes
The combined analysis of the multiple resources highlighted relevant differences in the exploration and understanding of the two interfaces and offered meaningful insights to guide design. The analysis of sensorimotor exploration pointed out that, in the FP, the children tended to experiment more with their bodies than in the VS. In the FP, children walked backward or forward, in circles and semi-circles, waved their arms, jumped, changed the walking speed, walked sideways, spun around, played "Ring Around the Rosie" with other children, stepped over some digital elements, etc. While, in the VS, their movements were limited to using one arm to make lines, circles and semicircles. Furthermore, in the FP, the children explored the overall projected space, by moving around it and covering almost its whole surface. Instead, in the VS, the children tended to explore mainly the area where they were standing and most of them did not change their initial position in front of the screen (Figure 7). Within this area, they tended to use mostly the upper part of the screen, which corresponds to the nearest positions that can be covered by arm movements without displacing the body.

These patterns were reflected in their proxemics relations and in the collaborative interactions related to making contacts with other children and drawing together. The children in the VS performed a higher amount of contacts of their characters with respect to those in the FP. However, in the FP, the children displayed a higher variability in the selection of the play partner. Thus, while in the VS the children mainly interacted with the partner who was standing beside them, in the FP all children interacted with each other verbally or non-verbally (Figure 8). Furthermore, the broader range of variations of movements afforded by the FP, allowed children to perform more complex synchronized behaviors. This coordination was mainly framed around the unspoken establishment of a leading figure and a follower, in a sort of protodance pattern (e.g. one child started to move in a certain direction and the other followed her and emulated her displacements).

However, in both conditions, the children did not show a sustained pattern of engagement with the experience. All groups seemed initially engaged with the interaction but, toward the end of the game, they started to lose their interest. This loss of interest was mainly motivated by the difficulties related to drawing together. The children tended to approach the activity through fast-paced movements. This pace and the complexity of synchronizing with the others did not allow them to produce of any figurative drawings and only scribbles were created. These outcomes led the children to report their disappointment on the poor visual appeal of the graphical results. During the design activities, most children proposed design refinements related to making the generated outcomes more consistent with the game’s goal (i.e. being capable of easily creating buildings for the planet). These suggestions were mainly framed around the game’s narrative, which showed to be a crucial cornerstone of their meaning making processes. Specifically, 85% of the children suggested titles for the game mainly related to the underlying narrative structure (e.g. “Pimpi’s city”) or employed the narrative as the
4.2.4 Informing design

The analysis of the sensorimotor exploration pointed out how the physical affordances of the two interfaces, by eliciting specific kinds of embodied interactions, determined different ways of making sense of the experience and shaped social relationships. In the FP, the children did not have the perception of having “an assigned area”, but they acted as if the space “belonged and could be used by everybody”. Instead, the VS promoted explorations related to the notion of property and territoriality, which, in turn may end up limiting the collaborative potential of the system. Furthermore, the FP promoted variations in the sensorimotor activities, which facilitated the diversification of group interaction and avoided limiting collaboration to playing with a preferred partner.

These differences pointed out that, different physical configurations can promote diverse patterns of collaboration, which may be more or less aligned with our intentions (e.g. collaboration as a division of tasks or as emerging from negotiation). In our case the FP represented a more appropriate interface to promote collaboration, negotiation of the tasks and discussion on group behavior.
However, on the other hand, we also identified some relevant shortcomings. From the analysis of the children’s engagement, it was possible to notice that children’s disappointment on failing to produce consistent drawings led them to quickly lose their interest in the experience. This issue requires a critical reflection on the consistency between the nature of the proposed sensorimotor experience, the goal of the task and the digital outcomes offered by the application. In our design, we should therefore carefully reflect on “what really matters” in the experience and how we can enhance this focal point to make it stand as the real nucleus of meaning of the interaction.

In both interfaces, the central focus of the application was the proposed sensorimotor experience of drawing together through a shared motor control. This sensorimotor experience offered certain richness per se since it requires children to pay attention to their reciprocal embodiment and to take advantage of their sensorimotor resources for coordination and collaboration. However, the goal of drawing figurative elements and the mapping with the drawing lines made children focus on the effort of drawing something precisely. As a consequence, the proposed sensorimotor experience became poorly gratifying or dysfunctional to obtain a goal that could be better achieved through other media (e.g. interfaces that support fine-grain motor control). This limitation requires future design improvements oriented toward augmenting the richness and the value of the sensorimotor experience (e.g. making content creation easier and suitable for gross manipulation) instead of weakening it by trying to make it fit with an inadequate task. From this perspective, relevant possibilities can be identified in creating a stronger boundary between the visual output and the narrative of the game.

5. Discussion

The present research confirmed previous studies on the suitability of multimodal analysis for the evaluation of digital technologies (Jewitt, 2013) and widened its application to PD. We suggest that combining PD and multimodal analysis can contribute to address the challenges related to involving users in the design of embodied interaction.

The participation of users-as-informants allowed us to observe their embodied meaning making and offered them a concrete experience on which to ground their contributions. This approach reduced the challenges of directly asking users to design meaningful embodied interactions “from scratch”. Furthermore, combined with multimodal analysis, it avoided the risks of focusing only on intentional verbal communication or usability issues. It, hence, allowed us to grasp those meanings that cannot be expressed by words, such as those created in the physical interaction with the environment. This understanding is crucial to design embodied interaction since it allows us to focus on how the space and our bodies shape meaning-making.

At the same time, the proposed approach allowed us to assume a broad perspective to
analyze the multiple resources and modes that can be employed during PD workshops (e.g. enactments, drawings, discussions, etc.). This specificity can offer interesting benefits to PD. We suggest that relevant research directions can explore how requiring participants to translate the same idea across different modes or media (e.g. drawings, video recording written reports, etc.) can allow us to tap into different shades of their understandings. Nonetheless, in the selection of these activities, researchers should pay a careful attention to the affordances offered by different techniques. For instance, in the first study, the detective and explorer activities were very fruitful to obtain a diversified perspective on children’s understandings. While in the “BetweenBodies” project the posterior discussion offered poor materials for the analysis.

Finally, the proposed approach, by combining the analysis of *in situ interaction* and *retrospective interpretations*, permitted us to encompass both the observation of *reflection-in-action* (Schon, 1983), which is displayed during the embodied interaction with the system, and of *reflection-on-action*, which is materialized during the design activities. In this context, the proposed approach focused on analyzing children’s *ways of engaging* with the experience, *experimenting* with it and *transforming* it into an object of knowledge. These analytical lenses allowed us to identify: 1) what children consider interesting to be explored, remembered or shared with somebody else; 2) how the specific qualities of the environment shaped their behavior and contributed to build their understandings; 3) how children attributed meanings to their actions and to the experience by connecting them with their previous knowledge, cultural references and interests. This focus allowed us to take into account the affordances offered by the system and the users’ appropriations (Ackermann, 2007), whose interplay is fundamental to understand and inform design. This aspect is particularly relevant in the context of embodied interaction since it allows grasping how bodily interaction and the configuration of the physical/digital environment shape the experience and contribute to the construction of meaning.

To sum up, the combined use of PD and multimodal analysis provided researchers with a comprehensive viewpoint to understand the meanings that emerge in the embodied relation of the users with the environment. In the presented cases, it allowed us to identify effective design choices, challenges and shortcomings, from which design refinements can be derived. Furthermore, in the “BetweenBodies” project, it permitted us to effectively compare between different design options and spot out relevant differences that may have passed unnoticed with other analytical approaches (Kozma, 1994). Finally, from the perspective of designing for embodied interaction, the analysis of bodily resources may offer relevant contributions to properly understand what kind of play the system evokes and hence, frame the design around meaningful augmentations of this experience.

Therefore, the proposed approach can constitute a valuable contribution to research related to the involvement of users in the design of embodied interaction experiences.
Nonetheless, we consider that this framework should not be regarded as a prescriptive model. Instead, it constitutes a possible approximation and it can provide tools-to-think with and adaptable instruments that can be tailored to specificities of different contexts.

5.1 Limitations and future works

The presented approach proposed a contribution to research related to design methods for embodied interaction. Nonetheless, some limitations are still present. First, the studies were conducted only with a limited sample. Second, only the researchers carried out the interpretations, without verifying them with users. Third, the graphical annotation was carried out manually, becoming intensive in terms of time and resources. To tackle these issues, future research should address: 1) a deeper involvement of users in the interpretation stage; 2) the development of specific software to facilitate graphical annotations; 3) the definition of accessible and inspirational formats to report results to the whole design team.

6. Conclusion

The paper describes a methodological approach oriented toward better understanding meaning-making in embodied learning experiences in order to inform design refinements and include user’s contributions from a perspective that goes beyond the limits of verbal language. The approach is based on a combination of an analytical framework derived from multimodal analysis (Jewitt, 2013; Kress, 2010) and a participatory design process based on the users-as-informants model (Nesset and Large, 2004). Specifically, it focuses on understanding children’s ways of engaging with the experience, experimenting with it and transforming it into an object of knowledge. For this purpose, it analyzes a wide range of multimodal resources such as sensorimotor explorations, verbal interactions and children’s productions. The employment of this approach in the iterative design process of two FUBILEs, Lands of Fog and BetweenBodies, showed its suitability in understanding embodied meaning making and allowed spotting out the potential of employing multimodal analysis as an instrument to inform design.

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