A Critical Analysis of Full-Body Interaction Learning Environments: Toward Novel Design and Evaluation Methods

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ABSTRACT

Full-Body interaction represents a branch of research in embodied interaction that mainly addresses the use of the whole body to interact with the physical and digital environment. In this context, several researchers have suggested its potential to support learning processes and an increasing number of Full-Body Interaction Learning Environments (FUBILEs) have been developed over the last years.

Nonetheless, the increasing importance of the field demands going beyond the initial novelty factor and technological optimism, in order to better understand the specificities of this medium. Starting from this perspective, this thesis focuses on exploring research methods that can allow a deeper understanding of FUBILEs in order to inform their design and their evaluation. Specifically, it addresses the effort of contextualizing, critically analyzing and proposing methodological approaches to evaluate meaning construction and learning in these environments.

For this purpose, the thesis will combine knowledge derived from theoretical and critical analysis with knowledge proceeding from empirical evaluation. Its contributions will mainly address the quest for appropriate methods to design and evaluate FUBILEs. In this context, specific contributions will focus on the definition of design guidelines, the proposal of a methodological framework for the evaluation of FUBILEs and the definition of a set of qualities that can be helpful to support experiential learning in environments based on Full-Body interaction.

RESUMEN

La Interacción de Cuerpo Entero representa una rama de investigación en *embodied interaction* que se refiere principalmente a la utilización de todo el cuerpo para interactuar con el entorno físico y digital. En este ámbito, diversos investigadores han sugerido su potencial para apoyar los procesos de aprendizaje y, en los últimos años, se ha desarrollado un número creciente de entornos de aprendizaje basados en la interacción de cuerpo entero (Full-Body Interaction Learning Environments, FUBILEs).

No obstante, el nivel de maduración de este ámbito requiere ir más allá de la fascinación y del optimismo tecnológico iniciales para poder comprender mejor las características específicas de este medio. A partir de esta perspectiva, esta tesis se centra en la exploración de métodos de investigación que pueden permitir una comprensión más profunda de los FUBILEs con el fin de

informar su diseño y evaluación. En particular, nuestro objetivo es contextualizar, analizar críticamente y proponer una serie de enfoques metodológicos que sirvan para evaluar la construcción de significado y el aprendizaje en estos entornos.

Con este propósito, la tesis combinará un análisis critico-teórico y una serie de estudios empíricos. Sus contribuciones se centrarán principalmente en la búsqueda de métodos apropiados para diseñar y evaluar los FUBILEs. En este contexto, las contribuciones específicas se centrarán en la definición de guías de diseño, en la propuesta de un marco metodológico para la evaluación y en la definición de un conjunto de cualidades que pueden ser útiles para apoyar el aprendizaje experiencial en entornos basados en la interacción de cuerpo entero.

RESUM

La Interacció de Cos Sencer representa una branca de recerca en *embodied interaction* que principalment fa referència a l'ús de tot el cos per a interaccionar amb l'entorn físic i digital. En aquest àmbit, diversos investigadors han suggerit el seu potencial per a donar suport als processos d'aprenentatge i, en els darrers anys, s'han desenvolupat un número creixent d'entorns d'aprenentatge basats en la interacció de cos sencer (Full-Body Interaction Learning Environments, FUBILEs).

No obstant, el nivell de maduració d'aquest àmbit requereix anar més enllà de la fascinació i de l'optimisme tecnològic inicials per tal de poder comprendre millor les característiques específiques d'aquest mitjà. A partir d'aquesta perspectiva, aquesta tesis se centra en l'exploració de mètodes de recerca que poden permetre una comprensió més profunda dels FUBILEs amb l'objectiu d'informar el seu disseny i avaluació. En particular, el nostre objectiu és contextualitzar, analitzar críticament i proposar una sèrie d'enfocaments metodològics que serveixin per a avaluar la construcció de significat i l'aprenentatge en aquests entorns.

Amb aquest propòsit, la tesis combinarà una anàlisi crítica i teòrica i una sèrie d'estudis empírics. Les seves contribucions se centraran principalment en la cerca de mètodes apropiats per a dissenyar i avaluar els FUBILEs. En aquest context, les contribucions específiques se centraran en la definició de guies de disseny, en la proposta d'un marc metodològic per a l'avaluació i en la definició d'un conjunt de qualitats que puguin ser útils per a donar suport a l'aprenentatge experiencial en entorns basats en interacció de cos sencer.

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Chapter 1

1 INTRODUCTION

This thesis aims at contributing to the quest for appropriate methods for the design and evaluation of Full-Body Interaction Learning Environments (FUBILEs). This research will be carried out from a critical and reflexive standpoint. Its main goal is to explore research approaches that can be appropriate to inform the design of these environments. Specifically, it addresses the effort of contextualizing, critically analyzing and proposing methodological approaches to evaluate meaning construction and learning in these environments and hence, guiding their design. For this purpose, the thesis is situated at the intersection between four main research areas: Full-Body interaction, embodiment, experiential learning and methodological research.

1.1 The Research Framework: Context and Goals

Full-Body interaction, understood as an interaction modality where users can interact with digital technology through the use of their bodies in the physical space, is becoming a relevant paradigm for the development of learning technologies. This research is mainly grounded on findings proceeding from embodied cognition and experiential pedagogies. These theoretical frameworks suggest the potential of physicality to support learning (Barsalou, 2008; Goldin-Meadow, 2011) and the importance of concrete experience in grounding knowledge (Kolb, Boyatzis, & Charalampos, 2001). Furthermore, the features of embodied interaction have been positively considered since they can offer specific pedagogical affordances such as enabling co-located collaboration, hands-on activities, multiple representations and direct manipulation (Antle, 2013; Dillenbourg & Evans, 2011). Building on this panorama, several FUBILEs, aimed at supporting diverse learning process, have been designed and evaluated in last years, tracing the path of a growing tendency in the area (Malinverni & Pares, 2014).

The increasing importance of the field, however, demands to go beyond the initial novelty factor and technological optimism, to better understand the specificities of this research area. Specifically, research has highlighted the limitations of a Technology-Driven approach, where the underlying theoretical framework is poorly understood (Antle, 2013). Often research in FUBILEs derives from a standpoint where only the surface features of embodiment and experiential learning are considered (e.g. move the body to interact with technology), without fully acknowledging the implications of these frameworks. As a consequence, the proposed solutions and the employed design and research methods often end up just superficially scratching the potential of this research area, hence providing only a limited understanding of it.

As Harrison, Sengers, & Tatar (2011) pointed out, in order to take full advantage of embodiment, it is necessary to carefully considering its epistemological roots and coherently framing our research in relation to them. This need implies a conscious acknowledgment of the implications of this framework and a quest for consistent design and evaluation. Within this context, several researchers have questioned the *methodological appropriateness*[1] (Patton, 1990) of the techniques and methods employed to design and research learning environments based on embodied interaction (Price & Jewitt, 2013a, 2013b). Specific criticisms addressed the lack of sensitivity of certain approaches to properly understand and be responsive to embodied learning (Jewitt, 2013) and the risks of applying conflicting criteria for validity (Harrison et al., 2011). This agreement on the needs for novel methodological approaches and the increased attention toward critically analyzing design practices (Sengers, Boehner, David, & Kaye, 2005) signals the need for reflexive stances within the community involved in this kind of research.

Starting from this perspective, this thesis has the following goals:

- Providing a comprehensive overview on the paradigm of embodiment in order to properly trace its roots and inform design research.
- Discussing on the methodological appropriateness of specific design and evaluation methods in order to critically reflect on their limits and potential.
- Proposing potential design and evaluation approaches that can address the identified

[1] Patton (1990) suggests that methodological appropriateness, understood as the recognition that different methods are appropriate for different situation, should constitute the primary criterion for judging methodological validity instead than relying of fixed and established procedures.

methodological shortcomings and inform the design process.

- Offering a reflexive standpoint on design and research practice in the context of FUBILEs

To achieve these goals, at a methodological level, the thesis will combine knowledge derived from theoretical and critical analysis with knowledge proceeding from empirical evaluation. Its contributions will therefore mainly address the enrichment of the available methods for designing and evaluating FUBILEs. In this context, specific contributions will focus on the definition of design guidelines, the proposal of a methodological framework for the evaluation of FUBILEs and the definition of a set of qualities that can be helpful to support experiential learning in environments based on Full-Body interaction. Nonetheless, our ultimate goal is not to prove that a specific method is more suitable or effective than other ones. Instead, we aim at improving, rather than proving, our methodological approach.

1.2 The Addressed Research Areas

We now describe the four main research areas that define the crossroad at which this thesis is situated: Full-Body interaction, embodiment, experiential learning and methodological research. A detailed analysis of these research areas will be reported in Chapter 2 and 3.

1.2.1 Full-Body Interaction

Full-Body interaction represents a branch of research in embodied interaction that mainly addresses the use of the whole body to interact with the physical and digital environment (Fogtmann, Fritsch, & Aarhus, 2008). For the purpose of this thesis, we will focus specifically on multi-users Full-Body Interaction Learning Environments (FUBILEs) for children. We specified these environments according to three main features:

- They are digital/physical spaces where the body is the site of learning and the mediator of the interaction with digital technology
- They are designed for multiple co-located users.
- Their goal is to use the embodied experience with the system to support learning processes.

Within this context, the thesis will mainly address learning goals related to conceptual and procedural knowledge and will address target users between 8 and 11 years old.

1.2.2 Embodiment

Starting from the '70, the notion of embodiment introduced a relevant paradigm shift across several disciplines about how knowledge is constructed both at the level of individual experience as well as at the macroscopic level of philosophy of science (Garcia Canclini, 1973). Specifically, from the individual perspective, it questioned the Cartesian's position of separating mind and matter (Laakso, 2011) and reintroduced the role of the body and the environment as driving forces in the knowledge construction processes (Wilson, 2002). Complementarily, from the perspective of philosophy of science, it questioned the positivistic stance for an objective, mechanistic and apodictic truth, reintroducing the need for acknowledging the role of situated knowledge construction (Haraway, 1988).

Starting from this theoretical background, for the purpose of this thesis, we will focus on the two complementary strands on embodiment. On the one hand, its formulation in the context of embodied cognition (Glenberg, 2010) will allow informing research for Full-Body interaction. On the other hand, its epistemological standpoint will be employed to contextualize the quest for methodological appropriateness.

1.2.3 Embodied and Experiential Learning

In the last decades, many scholars expressed the need of focusing education toward learner-centered and active approaches, which allow people to construct understanding through active exploration, experimentation, discussion and reflections (Ackermann, 2004; Freeman et al., 2014; Grabinger & Dunlap, 1995; Papert, 1980; Resnick, 2002). Within this context, for the purpose of this thesis, we will focus especially on embodied learning (Freiler, 2008) and on experiential learning processes (Kolb et al., 2001). These frameworks will allow addressing learning processes that are supported by the lived experience of being in our bodies and consider how these concrete embodied experiences may be elaborated through reflection-on-action.

1.2.4 Methodological Research

Human-Computer Interaction represents a relatively recent research field, hence the definition of appropriate design and research methods is constantly under development. Starting from this perspective, the present thesis aims at researching on appropriate design and research methods for FUBILEs. This goal will be pursued from a post-positivistic standpoint oriented at exploring which methods can allow understanding more deeply the addressed phenomenon. We, therefore, do not aim at setting down prescriptive methods and standards that researchers have to follow, instead, our goal is to provide a descriptive account of successful approaches (Polkinghorne, 1983).

1.3 Research Questions

With the aim of contributing to the quest for appropriate design and evaluation methods in FUBILEs, the current thesis is framed around three main research questions:

> *1) Which design methods can be appropriate to design FUBILEs*?
>
> *2) Which evaluation methods can be appropriate to analyze meaning construction and learning in FUBILEs*?
>
> *3) Which qualities of Full-Body Interaction Learning Environments can support experiential learning processes?*

1.4 Methodology

At a methodological level, this thesis is situated within the framework of the "third paradigm of HCI" (Harrison et al., 2011). This refers to the rising of methods and approaches that propose a post-positivist viewpoint to research and address meaning making and interaction as being situated and co-constructed (Harrison, Tatar, & Sengers, 2007). Starting from this viewpoint, the thesis employs a broad set of methodological tools, derived from a similar epistemological substrate, to construct knowledge on the specific object of inquiry.

Specifically in the thesis, three main methods of constructing knowledge are employed: a detailed analysis of the theoretical framework (Chapter 2), a critical review of related works (Chapter 3) and, an empirical and situated methodological exploration (Chapter 4, 5, 6 and 7). These three strands of research offer complementary standpoints from which to look at research on design and evaluation methods for FUBILEs.

Specifically, the theoretical review is informed by an interdisciplinary background that merges philosophy, cognitive science, psychology, semiotics and learning sciences. This review has two main goals. First, it will offer a comprehensive panorama of the theoretical framework in order to confront its epistemological substrate with the epistemological substrates of the employed methodological approaches. Second, it will provide general concepts and theoretical lenses to guide reflection and practice in the subsequent critical analysis (Chapter 3) and empirical research (Chapter 4, 5, 6 and 7). At a methodological level, the goal of the theoretical review is not to provide concepts to be demonstrated through empirical analysis. Instead, following the model of the "third paradigm of HCI" (Harrison et al., 2007) it will serve as an informative, reflexive and argumentative instrument.

On the other hand, the critical review derives its methodological framework from critical analysis (van Dijk, 1993) and reflexive design practices (Agre, 1997; Friedman, Kahn, Borning, & Huldtgren, 2013; Schon, 1983; Sengers et al., 2005). It aims at reflecting on good practices, inconsistencies and values that are embedded in design and evaluation methods for FUBILEs. Furthermore, it aims at enabling conditions for learning from others and at informing our practice.

Finally, the empirical research employs methods mainly derived from Design-Based Research (Barab & Squire, 2004; Wang & Hannafin, 2005), Participatory Design (Druin, 2002a; Frauenberger, Good, Fitzpatrick, & Sejer Iversen, 2014; Muller & Druin, 2003) and Multimodal Analysis (Jewitt, 2013; Price & Jewitt, 2013a, 2013b). The goal of this part is to explore potential methodological approaches for FUBILEs and improve them through progressive approximations. Thus, from a methodological perspective, it applies the interventionist, iterative and process-oriented principles of design research to the definition of novel methodological approaches. Furthermore, it provides conditions for learning from experience through the interplay between concrete experimentation of specific methodological approaches and the reflection upon them.

To sum up, this mixed methodological approach and the interdisciplinary nature of the research aims at providing multiple perspectives and casting different lights (Bachelard, 2002) to better understand the objects of inquiry.

1.5 Main Contributions

This thesis addresses the exploration of appropriate design and evaluation methods for FUBILEs. To achieve this goal, we reviewed the underlying theoretical framework, critically analyzed relate works and conducted a series of studies aimed at exploring different methodological approaches for design and evaluation. This path led to the following contributions:

- We offered an extensive and systematic analysis of related works aimed at providing an encompassing panorama of this research area and discussing the employed design and evaluation methods.
- We described potential design approaches to combine interdisciplinary theoretical frameworks (e.g. embodiment, learning theories) with participants' contributions.
- We proposed a potential methodological approach and guidelines to properly address embodiment in participatory and iterative design processes.
- We proposed a set of Participatory Design techniques aimed at including users and their embodiment in the design process.
- We described an analytical framework that aims at evaluating learning and meaning construction in FUBILEs in order to guide design process.
- We proposed a set of design qualities (*expressiveness, consistency, relationality, salience* and *reflexivity)* aimed at guiding design and evaluation by stimulating reflection on one's own practice.
-

1.5.1 Publications

Published

- Malinverni, L., Ackermann, E., & Pares, N. (2016). Experience as an Object to Think with: from Sensing-in-action to Making-Sense of action in Full-Body Interaction Learning Environments. In *Proceedings of the TEI'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 332–339). ACM.

- Malinverni, L., & Pares, N. (2015). The Medium Matters: the Impact of Full-Body Interaction on the Socio-Affective Aspects of Collaboration. In *IDC '15 Proceedings of the 2015 conference on Interaction design and children*. ACM. doi:10.1145/2771839.2771849

- Schaper, M., Malinverni, L., & Pares, N. (2015). Sketching through the body: child-generated gestures in full-body interaction design. In *Proceedings of the 14th International Conference on Interaction Design and Children (IDC '15)* (pp. 255–258). ACM. doi:10.1145/2771839.2771890

- Malinverni, L., & Pares, N. (2014). Learning of Abstract Concepts through Embodied Interaction: a 10 years systematic review of Full Body Interaction Learning Environments. *Journal of Educational Technology & Society*, 17(04), 100-116.

- Malinverni, L., Mora-Guiard, J., Padillo, V., Hervas, A., & Pares, N. (2014). Pico's Adventure: A Kinect Game to Promote Social Initiation in Children with Autism Spectrum Disorder. In *ITASD 2nd International Conference on Innovative Technologies for Autism, Paris, France*.

- Malinverni, L., Mora, J., Padillo, V., Mairena, M. A., Hervas, A., & Pares, N. (2014). Participatory Design Strategies to Enhance the Creative Contribution of Children with Special Needs. In *IDC '14 Proceedings of the 2014 conference on Interaction design and children* (pp. 85–94). New York, NY, USA: ACM. doi:10.1145/2593968.2593981

- Mora, J., Malinverni, L., & Pares, N. (2014). Narrative-Based Elicitation: Orchestrating Contributions from Experts and Children. In *CHI '14 Extended Abstracts: ACM SIGCHI Conference on Human Factors in Computing Systems*. doi:10.1145/2559206.2581292

- Schaper, M., Malinverni, L., & Pares, N. (2014). Participatory design methods to define educational goals for full-body interaction. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology (ACE '14)* (p. 4). ACM. doi:10.1145/2663806.2663867

- Malinverni, L., Lopez Silva, B., & Pares, N. (2012). Impact of embodied interaction on learning processes: design and analysis of an educational application based on physical activity. In *Proceedings of the 11th International Conference on Interaction Design and*

Children (IDC '12). (pp. 60–69).

Accepted (in press)

- Malinverni, L., Mora-Guiard, J., Padillo, V., Valero, L., Hervás, A., & Pares, N. (2016, in press). An inclusive design approach for developing video games for children with Autism Spectrum Disorder. *Computers in Human Behavior*. doi:10.1016/j.chb.2016.01.018

- Malinverni, L., Mora-Guiard, J., & Pares, N. (2016, in press). Towards methods for evaluating and communicating participatory design: A multimodal approach. *International Journal of Human-Computer Studies*. doi:10.1016/j.ijhcs.2016.03.004

Submitted

- Malinverni, L., Schaper, M., & Pares, N. (2016). An Evaluation-Driven Design approach to develop Learning Environments based on Full-Body Interaction. *Educational Technology Research & Development*.

- Malinverni, L., & Pares, N. (2016). An Autoethnographic Approach to Guide Situated Ethical Decisions in Participatory Design with Teenagers. *Interacting with Computers.*

1.6 Thesis Structure

This thesis is structured according to four main parts: a theoretical overview, a critical analysis, an empirical research and a conclusive section.

In Chapter 2 we will provide a review on the theoretical framework of embodiment and experiential learning from a broad and encompassing perspective. This chapter has the goal of unpacking the implications of these frameworks in order to ground research on a robust understanding of them and avoid the risks of a poorly informed approach. For this purpose, the chapter will be divided into four main sections. In Section 2.1 we will trace the historical and cultural roots of embodiment and describe its instantiations in different disciplines. Its goal is to situate the philosophical epistemological roots of this framework in order to use them to guide the definition of appropriate methodological approaches later on. In Section 2.2, we will review relevant studies on embodiment in order to start tracing initial guidelines and concepts to guide the design for Full-Body interaction. In Section 2.3 we will introduce the research on meaning construction and experiential learning in order to delineate an initial panorama to guide the application of Full-Body interaction in learning contexts.

In Chapter 3 we will provide a systematic and critical review of studies in Full-Body Interaction Learning Environments. This review will be structured into two main parts. In Section 3.1 we will offer a general panorama of FUBILEs developed in the last years. This research will allow overviewing the employed theoretical backgrounds, design solutions and evaluation methods. It will, therefore, provide an initial starting point to identify gaps and good practices in the field. Subsequently, in Section 3.2 we critically review the employed evaluation methods. This research will set the basis for discussing methodological appropriateness for the evaluation of FUBILEs.

In Chapter 4, 5, 6 and 7 we will describe a series of studies conducted to explore appropriate design and assessment methods for FUBILEs. This part will be organized according to a chronological structure in order to make visible how the knowledge gained in one study informed subsequent research. Specifically, this part will be structured as follows:

- In Chapter 4 we will present two FUBILEs that we developed at the beginning of this thesis. Through the critical analysis of their shortcomings, we will therefore discuss their methodological weaknesses and set directions for future research. Starting from these initial reflections, the following chapters will present research oriented toward tackling some of the identified flaws.

- Chapter 5 we will address the methodological issues related to including children in the design of FUBILEs. Specifically, two case studies based on Participatory Design (PD) approach will be presented. The first study (Section 5.1) addresses methodological approaches aimed at integrating and merging the contributions of different stakeholders during the design process. The second study (Section 5.2), instead, proposes a methodological approach aimed at integrating children and experts' contributions in an iterative design process.

- In Chapter 6 we will describe research oriented toward defining methodological approaches to properly understand embodiment meaning making and integrate this understanding in PD processes. For this purpose, two case studies will be presented.

The first study (Section 6.1) will describe the employment of a multimodal analytical approach to analyze children's contributions during a PD workshop. The second study (Section 6.2) will further elaborate the proposed multimodal analytical approach in order to employ it to guide the iterative design process of a FUBILE.

- Finally, in chapter 7, we will go back to the first FUBILEs that we developed (see Section 4.1) and employ the lessons learned during this research process to deepen in its evaluation and research on indicators of learning displayed during in situ interaction.

This overall structure will allow us to trace the path of methodological approximations adopted through this thesis and will contribute to offer potential guidelines on appropriate design and evaluation methods.

To conclude in Chapter 8 we will summarize and integrate the knowledge gained through all the research in order to provide concrete guidelines and offer possible methodological approaches and design qualities to support experiential learning in FUBILEs

Chapter 2

2 A THEORETICAL PERSPECTIVE ON EMBODIMENT AND EXPERIENTIAL LEARNING

In this chapter, we will review the literature related to embodiment, embodied cognition and experiential learning. This analysis aims at facilitating the effort of bridging a relation between the employed theoretical frameworks and design research. It will, therefore, allow defining initial viewpoints to think about design, research and evaluation of FUBILEs.

The review will be structured as follows. In the first part (Section 2.1), we will briefly overview the rise and multiple instantiations of the notion of embodiment from a historical and interdisciplinary perspective. In the second part (Section 2.2), we will review relevant literature related to embodied experience and embodied understanding. This initial analysis will allow delineating the main resources available in Full-Body interaction experiences, hence providing some initial “tools-to-think-with” for practitioners. In the third part (Section 2.3), we will contextualize research on Full-Body interaction in relation with learning processes. Through the overview of constructivist and experiential learning theories, we will start to frame the reflection around how Full-Body interaction can be applied in Technology-Mediated Education. Each section will be introduced and concluded by contextualizing the reported research in relation to the thesis.

2.1 Embodiment: a Short Historical and Interdisciplinary Overview

In the next sections, we will present a general summary of the different disciplinary instantiations of embodiment. In particular, we will focus on tracing the rising and unfolding of this paradigm across philosophy, cognitive science, artificial intelligence, developmental psychology, learning science, philosophy of science and Human-Computer interaction.

This interdisciplinary perspective aims at properly contextualizing this construct within its historical path and stressing how its multiple facets may be indicative of a particular *zeitgeist* of our contemporary research context. Its goal is not to provide a unified view of embodiment but to describe how this concept has been signified through the perspectives of different discourses and disciplines.

In the context of this thesis, this overview has two main goals. First, it pursues delineating the multiple interpretations of this concept in order to inform and situate research. Second, it aims at providing interpretative and reflexive lenses through which we will discuss the notion of *methodological appropriateness* for FUBILEs.

From a broad perspective, the knowledge gained through this analysis will be applied as an argumentative instrument in Chapter 3, where a critical analysis of design and evaluation methods for FUBILEs will be reported. At the same time, it will, directly and indirectly, inform the research on methodological approximations reported in Chapter 4, 5, 6 and 7.

2.1.1 The Phenomenological Roots

In western culture, the notion of embodiment finds its roots in the phenomenological tradition settle down by Heidegger and Merleau-Ponty. Phenomenology, by researching the nature of consciousness and human experience, gradually moved away from Cartesian dualism. According to Descartes' philosophy mind and body are separated and the body only serves as a mere support of a disembodied consciousness that is detached from the material world (Trilles Calvo, 2008). Criticizing this position, Heidegger proposed the need of considering consciousness not as separated from the world but as a formation of the historically lived human experience

(Polkinghorne, 1983). As a consequence, humans cannot be studied as separated from being situated in the world (Laakso, 2011). This position was later extended by Merleau-Ponty, who emphasized on the embodied, spatial and temporal nature of human experience (Polkinghorne, 1983). Merleau-Ponty's rejection of Cartesian dualism moved away from considering the body as only a biological structure or as a sort of mechanical machinery. He, instead, proposed the notion of a double corporality: a body that is both biology as well as lived experience (Varela, Thompson, & Rosch, 1991).

This paradigm shift, reintroduced the body as a skilled subjectivity that helps knowledge construction (Shusterman, 2013). It, thus, questioned the discourse and research around how knowledge can be build both at the level of individual experience as well as at the macroscopic level of philosophy of science. Especially, in this latter context, Merleau-Ponty suggested the need of finding a middle ground between what he calls "objectivism" - understood as the positivistic stance for an objective, mechanistic and apodictic truth existing out there - and what he defines has intellectualism - understood as the detachment of knowledge from the world (Garcia Canclini, 1973). He, thus, claims for a situated perspective in knowledge construction, according to which knowledge about the world is inseparable from our standpoint in the world (Varela et al., 1991). In this context, both the disembodied observer that observes the world from a "god's eye view" (Haraway, 1988) as well as the decontextualized mind, which constructs reality "ex-nihil", constitute inadequate perspectives to understand the world and the human being (Varela et al., 1991). The definition of a middle ground that unifies mind and body, thus, claims embodiment both as an essential structure of human condition as well as a relational standpoint in research, capable of unifying the body as biological, cultural and psychological (Overton, 2004). Even if the legacy of Merleau-Ponty started to receive more attention only from the '70 (Garcia Canclini, 1973), his thoughts deeply influenced the development of a relevant paradigm shift across several disciplines.

2.1.2 Embodiment in Cognitive Science and Artificial Intelligence: from Sensorimotor Intelligence to Grounding of Abstract Concepts

For several decades, cognitive science was framed around a disembodied view of cognition according to which cognitive processes were considered independent from sensorimotor processes, which merely constitute peripheral input and output devices (Laakso, 2011). Cognition, thus, was mainly considered and studied according to models based on the computation of symbolic and amodal representations (Varela et al., 1991).

The computational metaphor of mind and its corollary implications, shaped under its image both research in Cognitive Science as well as in the design and development of Artificial Intelligence (AI) systems (Agre, 1997). As a consequence, most of the traditional AI systems were based on frameworks that presuppose the creation of symbolic and abstract models of the reality in order to act in it. At the same time, most of the research in cognitive science was framed around the idea that cognition should be studied independently from perception and action (Laakso, 2011). This epistemological framework, which was a reflex of western tradition of dualism and metaphysics separation between mind and matter, started to be questioned in the '80. The arguments on the limits of the computational metaphor (John R Searle, 1980), the influence of Merleau-Ponty's phenomenology highlighted the need for novel models to understand and study cognition.

Paraphrasing the Jerry's Fodor's quote (in Varela et al., 1991) "*in intellectual history everything happens twice, first in philosophy and then in cognitive science*", the body was reintroduced in the research agenda. In AI, as a response to the symbol grounding problem, Brooks (1995) introduced the need of considering the physical structure of the system and its environmental context as fundamental aspects of its functioning. Under the claim of "*perception is cheap, representation is expensive*" (Haugeland, 1993), an increasing attention started to focus on the role of direct perception and actions in generating knowledge about acting and dynamically adapting to the environment. This conception, thus, introduced the role of perceptual system's abilities and environment's affordances in the AI agenda. Nonetheless, in its initial conceptualization, it mainly addressed embodiment as sensorimotor intelligence for task completions and skills acquisition.

This idea was later extended by research in cognitive science which increasingly addressed how, not only the cognitive processes linked to mastering sensorimotor contingencies meet their origin in embodied experiences, but also higher-level cognitive skills may arise from sensorimotor functions

(Wilson, 2002). This embodied standpoint suggests the idea that thoughts, concepts, emotion, attitudes and social interactions are influenced and determined by the role of the physical states, bodily structures (Barsalou, 2008; Glenberg, 2010) and experiential opportunities. According to the embodied cognition hypothesis, embodied experience serves as a basis for meaning construction and bodies do matter in cognition.

In this context, different approaches have been proposed. On the one hand, approaches based on simulation theory (Barsalou, 2008; Grafton, 2009) suggest that the perceptual, motor and introspective states lived during an experience in the world allow us to capture states across modalities and integrate them in multimodal representations (Barsalou, 2008; Niedenthal, 2007). This approach, thus, suggests that when knowledge is needed, the representations acquired through embodied experiences are re-activated and re-enacted. On the other hand, approaches grounded on enactivism, partially reject simulation theories and propose that, instead of mainly rely on representations, we strongly rely on direct perception in the moment-to-moment interaction with our social and physical environment (Fuchs & Jaegher, 2009; Paolo, Rohde, & Jaegher, 2007). Independently from the assumed perspective these theoretical frameworks gave rise to a wide range of studies aimed at exploring the role of sensorimotor functioning in cognition and gradually formalized embodied cognition as a mainstream position in cognitive science (Laakso, 2011).

2.1.3 Embodiment in Developmental Psychology and Learning Theories

Alongside with the reintroduction of the body in philosophy and cognitive science, the path of this paradigm shift can also be traced in the field of developmental psychology. In this context, Piaget carried out a pioneer work suggesting that cognitive skills may emerge from the sensorimotor interaction between the child and the environment (Wilson, 2002). According to Piaget, the baby, through a mechanism of circular reactions grounded in embodied experiences, gradually develops a set of schemata that determines her cognitive structuring (Perinat & Lalueza, 2007).

Building on the perspective that the body constitutes the baby's first way of interacting a communicating with the world, several studies have addressed the role of embodied experiences in the development of fundamental cognitive skills. An illustrative example can be found in the development of the semiotic function in babies. Semiotic activities, understood as the ability to become symbol-minded and making something stand for something else, constitute the benchmark of human learning (Karmiloff-Smith, 1995). In the developmental process, the rising of baby's semiotic function is deeply embodied and relational. The newborn baby, through her embodied interactions with the caregiver, starts using the elements of the sensitive plane (movements, rhythms, etc.) as vehicles of the semantic content (e.g. crying to call the attention of somebody). In this way, she therefore starts using embodied resources as signs that stand for something else.

At the same time, studies on the relation between sensorimotor experience and cognitive skills have shown important relationships between the acquisition of specific motor skills and the development of language (Iverson, 2010) or spatial cognition (Clearfield, 2004). Consistently with these finding, research has also shown the correlation between physical manipulation of objects and the development of the ability to categorize them (Smith, 2005).

Nonetheless, while Piaget recognized the central role of sensorimotor experience mainly in the first stages of development, subsequent research pointed out how the role of embodiment should not be limited to the first years of life. Instead, it suggested that embodiment might be crucial for a wide number of learning processes across the life span. Studies carried out under this perspective have reported relevant findings supporting the role of embodiment in facilitating learning. For instance, Goldin-Meadow (2011) showed how having children performing specific gestures during instructions can contribute to the understanding of mathematical concepts. At the same time, Kontra et al. (2012) performed a similar study with adults , obtaining analogous results. Finally, Glenberg et al. (2007) showed how children's manipulation of physical prompts supported a better recall of related narratives.

The evidence produced by these studies and the importance gained by constructive pedagogies led the educational community to suggest the need for approaches capable of actively and experientially involve the learners. Starting from the idea that learning is more fruitful when anchored to meaningful activities (Jonassen & Rohrer-Murphy, 1999) and that formal symbol are best understood when grounded on experience (Nathan, 2012) a wide variety of active and experiential learning approaches have been proposed (Kolb et al., 2001; Papert, 1980; Resnick, 2002). In this context, it is of particular relevance to linger on experiential learning theories. This framework proposes that learning is particularly effective when it arises from concrete and active hands-on experimentation (Kolb et al., 2001), which is subsequently transformed through reflection-in-action and reflection-on-action (Schon, 1983).

Systematic reviews of active learning approaches showed their effectiveness in improving learning with respect to traditional exposition-centered approaches (Freeman et al., 2014). Nonetheless, often mainstream education still tend to be framed around a disembodied approach (Kelan, 2010). Thus, while evidence from laboratory studies and from field research, showed the fundamental role of embodied experience in support learning, mainstream education still tends to be framed around a formalist and dualist approach, where symbolic knowledge proceed and is privileged over the applied one (Nathan, 2012). This tendency, however, is partially counteracted by research in informal educational contexts such as museums, where the primacy of concrete experience is widely recognized (Allen, 2004).

2.1.4 Embodiment and Philosophy of Science

Even if from a different perspective, the legacy of embodiment can also be extended and traced in the inquiry and criticisms related to the construction of scientific knowledge. In this context, most relevant contributions can be found in feminist philosophy of science. Starting from the phenomenological critique of the traditional notion of objectivity as "a view from nowhere" and responding to the need for a successor science (Harding, 1989), feminist critical theory proposed the notion of situated knowledge and standpoint epistemologies. In this context, Haraway (1988) used the metaphor of knowledge as vision to argue that the notion of knowledge cannot be separated from our embodied point of view. In other words, our perspective on knowledge is always partial and determined by our embodiment in specific socio-historical and personal circumstances. Acknowledging this position, thus, implies to place the researcher at the center of the research and recognizing the role of her embodiment and context in the construction of the scientific discourse.

This shift from a "god's eye view" to an embodied standpoint gives rise to the development of a wide range of research approaches that take into account embodied experiences as a legitimate source of knowledge. Examples of them can be found in the use of intersubjective experience (Espínola, 2010) or in approaches such as autoethnography (Montero-Sieburth, 2006). Both methods are based on intersecting personal autobiographical stories with theoretical frameworks derived mainly from sociology and anthropology through the use of a narrative approach (Allen & Piercy, 2005). Their purpose is to use personalized accounts of the author's experience at an intellectual, emotional and corporal level (Esteban, 2001) to extend sociological understanding

(Sparkes, 2000). These methods thus, by using one's lived experience as a way to understand culture, allow to employ and recognize our own emotional and embodied experience as a way to construct knowledge (Montero-Sieburth, 2006). These approaches have often received only a marginal attention in the academic field. However, it is relevant to notice that, as Harrison et al. (Steve Harrison et al., 2011) point out, with the rise of the "third paradigm of HCI", methods proceeding from feminist philosophy of science have been gradually incorporated into different field of research, such as, for instance Human-Computer Interaction (Bardzell & Bardzell, 2011).

2.1.5 Embodiment and Human-Computer Interaction

The concept of Human-Computer-Interaction, as we know it today, developed from research on U.S. military aviation during the Cold War. The multimedia interactivity, therefore, was the product of the research of the SAGE laboratory (Semi-Automatic Ground-Environment), which decided to include humans in the control of radar systems in order to carry out operations that computers were not able to perform (Penny, 2013). In this way, for the first time a human being was put in front of a keyboard, "light pen" and a monitor capable of displaying information in real time and to serve as an interface through which send commands to the machine. The construction of the paradigm "Human-Computer Interaction" in military doctrine and through *"the harnessing of flesh to machine"* (Penny, 2013), was a logical product of disciplinary approaches grounded on the predominance of logical-symbolic processing and on the prejudice of the existence of a hierarchy of values between intellectual activity and bodily activity.

This form of Cartesianism defines the users as "disembodied entities" whose activities are enclosed in a virtual space separated from physicality and material environment. As a consequence, the displacement of a wide range of activities outside the area of the body produced the exclusion of the physical experience as an instrument to construct knowledge in the interaction with technology. At the same time, it weakened the legacy of the cultural baggage related to the sensory-motor interaction. However, in the last decades, the rise of the embodiment paradigm set the ground to introduce the need of rethinking users technology under a post-Cartesian approach. This means to move away from its symbolic-oriented configuration and to include a wider range of human abilities in the interaction with computers (Buxton, 1986).

Recent technological developments have witnessed the explosion of post-desktop models of

Human-Computer interaction. In this context, the pivotal work of Dourish (2004) defined the concept of embodied interaction as "*the use of the physical world to interact with digital technologies*". This innovative approach set a research agenda aimed at gradually moving away from the dominant paradigm of separating computation and physicality in order to merge digital technology with material culture. This shift opened the path for moving HCI toward approaches capable of capitalizing our physical skills and our familiarity with the material world (Fogtmann et al., 2008).

Building on this framework, several novel technological solutions have been proposed such as Tangible Users Interfaces, Gesture-Based Interaction, Kinesthetic Interaction, Full-Body interaction, etc. These approaches have gained an increasing relevance in the design community thanks to their potential benefits such as: enabling conditions for thinking and learning by doing (Antle, 2013; Klemmer, Hartmann, & Takayama, 2006), allowing to offload cognition in the environment (Antle, 2013), facilitating collaboration (Dillenbourg & Evans, 2011), involving users at different levels (i.e. sensorimotor experience, cognitive aspects, affective factors), etc. These features have encountered fertile terrains of application in different fields such as health applications, educational technologies, workplaces' systems, etc. In particular, the paradigm of embodiment as received an increased attention in the field of Technology-Mediated Education. According to Yarosh et al. (2011) between 2002 and 2010 more than the 20% of papers that address learning presented at Interaction Design & Children Conference where based on embodied cognition framework. This tendency, thus, indicates the need for deepening into the effort of understanding and researching the specificities of this design and research approach.

2.1.6 Implications for this Thesis

The presented overview described how the rise of the notion of "embodiment", in its various instantiations, constituted a relevant paradigm shift across several disciplines. This broad panorama delineated embodiment as a multifaceted term, where multiple significations coexist (and often collide). Despite some fundamental differences, all these approaches propose to move research and practice from a focus on symbolic and abstract processing toward conceptualizations deeply grounded on the role of experience and contextual opportunities. Furthermore, they illustrate how embodiment constitutes a transversal epistemological reflection on how knowledge is constructed both in scientific practice as well as at the level of individual experience.

These two complementary dimensions inform this thesis at two levels. On the one hand, the phenomenological standpoint on embodiment offers lenses and concepts to help framing the argument around *methodological appropriateness* for FUBILEs. These aspects will be specifically addressed at a theoretical level in Chapter 3 and at an applied level in Chapter 4, 5, 6 and 7. On the other hand, the findings on the embodied nature of cognition, derived from cognitive science and developmental psychology, set the ground to formulate and reflect on the relation between Full-Body interaction, embodied experience, meaning construction and learning. They, therefore, inform the definition of design qualities and approaches.

2.2 From Embodiment to the Design of Embodied Experience: Being Embodied and Being Embedded

The interdisciplinary overview of the different instantiations of the notion of embodiment allowed spotting out its main tenants and theoretical contributions. Building on this perspective, in the next sections, we will focus on the role of embodiment in constructing knowledge at the level of the individual experience. For this purpose, we will review relevant studies that stress how cognition is shaped by our bodies and by our relation with the social and material environment.

This analysis has the goal of delineating some key concepts that can guide the task of bridging between this theoretical framework and the design of Full-Body interaction experiences. Specifically, in Section 2.2.1, we will overview the aspects of our surrounding can be understood through embodiment and how this process may unfold. This overview will allow starting to conceptualize what areas of knowledge can be more suitable to be addressed through Full-Body interaction and how embodied interaction may be designed to support knowledge construction. Subsequently, in Section 2.2.2, we will focus on analyzing the role of our surroundings in shaping our experience and understanding. This analysis will allow starting to delineate the role of the resources of the environment, hence providing initial conceptual guidelines to distinguish the network of elements that may shape a Full-Body interaction experience (e.g. spatial features, social interaction, etc.). From a broad perspective, the knowledge derived from this review will be applied as interpretative lenses to observe the role of embodied interaction and embedded resources in the design and evaluation of FUBILEs.

2.2.1 Being Embodied: Expressing, Understanding and Constructing Meaning through Embodiment

Our bodies are our first support in the world, our first way to express ourselves and to understand other people and our surroundings. From a developmental perspective, the body covers a fundamental role in communication, where it conveys semantic, pragmatic and emotional information (Antes, 1996). At the same time, it has a central function in determining the way in which we construct meaning and interpret our surrounding since its features and structure support, facilitate or limit what we can perceive, act on and understand (Overton, 2004).

As mentioned in Section 2.1.2 embodied experience allows us to construct knowledge about the world. This knowledge construction processes may assume different forms, which range from more procedural aspects (i.e. understand how to use an object) to more complex processes. Building on this perspective, several studies have been dedicated to exploring how embodied understanding may unfold. In this context, several researchers (Barsalou, 2008; Niedenthal, 2007; Wilson, 2002), suggested that this process may emerge from the interplay between *online* embodied cognition and *offline* embodied cognition.

Online embodied cognition constitutes one of the mechanisms upon which knowledge is constructed. It unfolds during in situ experiences and refers to meanings that people generate acting and perceiving in a specific concrete experience (Wilson, 2002). According to this hypothesis, the most pregnant perceptual, motor and introspective states lived during an experience in the world, tend to gain weight and become engrained as lasting impressions and multimodal representations that are then re-enacted in situations perceived as calling for a similar handling (Barsalou, 2008). This notion is thus consistent with Piaget's theory of circular reactions (Perinat & Lalueza, 2007), which suggests that the babies' interactions with the physical and social environment, allow them to build their first structural invariants, which constitute the basis upon which they will understand and construct meaning in the world.

Thus, according to this hypothesis, in situ embodied experiences shape our understanding by creating specific sets of multimodal representations. A relevant example of this process can be found in the role of gestures and actions in facilitating learning processes. For instance, Goldin-Meadow (2011) showed that telling children to perform specific gesture before or during instructions make them more likely to profit from instructions. A possible explanation for these findings suggests that the performed physical activity may provide embodied representations that make easier to think about abstract concepts.

On the other hand, if we widen the implications of this idea, a paradigmatic example of the role of in situ embodied experience in shaping our system of representations can be found in Bowlby's theory of attachment (Ainsworth & Bowlby, 1993). According to attachment theory, the early experiences that the baby has with the caregiver - which are highly embodied in their nature - then shape the relational and attachment patterns of this person in his future relationships.

The embodied construction of these enduring multimodal representations, thus, constitutes the foreground of *offline embodied cognition*. Specifically, *offline* embodied cognition refers to the uses of previously acquired embodied knowledge in tasks that do not involve a specific physical experience or a physical re-enactment of the experience (Wilson, 2002). A possible mechanism behind this process has been identified in a partial embodied simulation that may occur in our nervous system.

The simulation hypothesis has been deeply investigated in the field of social cognition. In this context, the mirror neuron theory hypothesized that we are able of partially simulating the other in our own nervous system (Grafton, 2009). Thus, when we see somebody grasping a glass, we activate our neural circuitry for grasping objects (Iacoboni, 2009). At the same time, when we see a sad expression or hear a sad story, we connect it with our feelings of sadness. This theory, thus, suggests that our embodied perception of the other (Grafton, 2009) and the knowledge that we have of our own bodies, allow us to understand and interpret other people's intentions and mental states (Gallese, 2007); i.e. since I know (because I experienced it) what it means to be sad, I can understand your sadness.

This process can cover a functional role in facilitating teamwork and collaboration (Hindmarsh & Pilnick, 2002) and enabling empathy (Grammer, Kruck, & Magnusson, 1998; Iacoboni, 2009; Vacharkulksemsuk & Fredrickson, 2012). Thus, if we know the context, the subtle gestures or expressions of the others can be indicative enough to guide our subsequent behavior or reactions, i.e. the tacit coordination of surgeons in the operating theater (Hindmarsh & Pilnick, 2002). At the same time, the embodied understanding of the others enables us to empathically respond to certain situations. A paradigmatic example of this phenomenon can be found in a study conducted by Bargh et al. (in Iacoboni, 2009). In this research, the group of people who was primed with words related to elderly stereotypes (e.g. *gray, Florida, bingo*), after end of the experiment was reliably slower in walking than the subjects who had not been primed. This study showed that even verbal

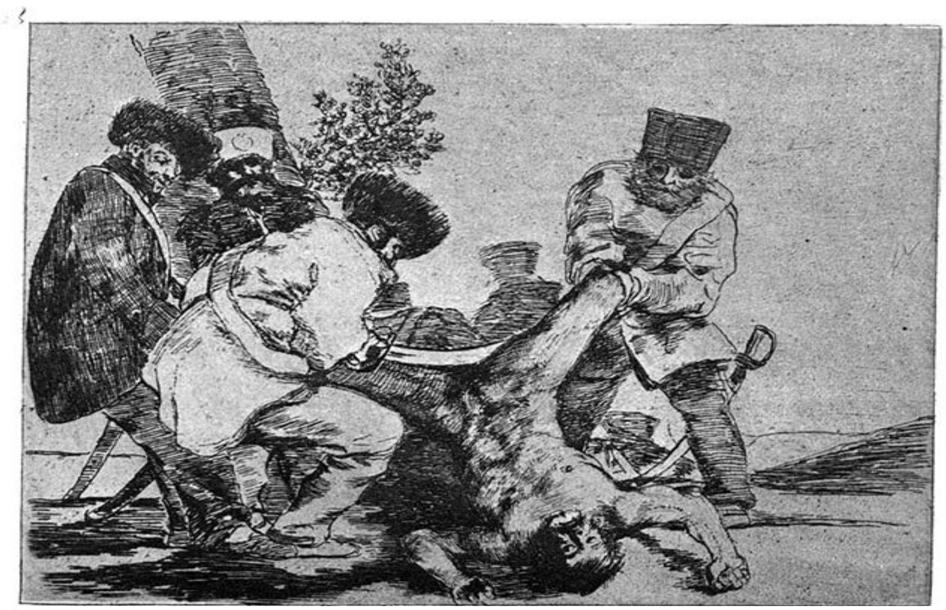


Figure 1. Goya's Desastre de guerra

prompts that entail specific connotations about “how the other is” may trigger a partial embodied simulation. It, hence, pointed out how our bodies constitute a privileged channel through which we understand the others, their behaviors, feelings and emotions.

Nonetheless, the hypothesis that embodied understanding may be grounded on a partial simulation is not limited to the field of social cognition. Instead, it has also been extended to fields such as art experience and understanding of abstract concepts. In this context, Freedberg and Gallese (2007) suggested that aesthetic experience may be grounded on a partial embodied simulation of actions, emotions and corporal sensations. Taking as examples different artworks, they suggested that our understanding of them unfolds in the relationship between the embodied empathetic feelings of the observer and the representational content of the works in terms of actions, objects and emotions depicted, i.e. we understand the struggle of the characters of the Goya’s “Desastre de guerra” engraving (Figure 1) by embodying the representations of the picture.

At the same time, similar accounts have been proposed as possible mechanisms to support the understanding of a wider range of artifacts and concepts. In this context, Papert suggested the notion of body syntonicity (Papert, 1980) to describe the understandings that derive from the knowledge that we have about our bodies**.** Thus, it may be possible that even in the understanding of some mechanical device or structure we are partially projecting our bodies / incorporating the artifact in order to make sense of how it works (e.g. to understand a gears' mechanism I may project myself into it in order to incorporate its functioning).

Similarly, research on the understanding of mathematical and linguistic concepts suggested their potentially embodied nature. Specifically, Lakoff and Nuñez (2000) hypothesized that some kind of mathematical understandings may be grounded in our embodied experience. At the same time, Johnson (1987) suggested that certain linguistic concepts may have evolved from our embodied experience and that we may rely upon it to properly understand them. This hypothesis is supported by the fact that the understanding of the meaning of a concept involves the ability to imagine this action and this simulation may use the same neural substrate necessary to perform the action (Gallese & Lakoff, 2005). For instance words such as 'lick', 'pick' and 'kick' automatically activate the motor system in a somatotopic manner (Pulvermüller, 2005).

To sum up, this overview pointed out how embodiment helps the construction of novel multimodal representations during in situ experiences. At the same time, it suggested how our already acquired embodied knowledge helps in making sense of experiences and of abstract concepts. In particular, we pointed out the role of embodied knowledge in the understanding of socio-emotional aspects, aesthetic experiences, artifacts and different abstract concepts. Within that, a possible explanatory process has been identified in the partial simulation that we may perform in our nervous system.

2.2.2 Being Embedded: In Situ Embodied Experiences

In the last centuries, developmental psychology has gradually included the role of the social context and the physical environment in the research related to children's development. This approach was initially delineated by Piaget and further extended by Vygotsky. In particular, his socio-constructivist theory highlighted the role of the social environments, tools, cultural artifacts and peers as active agents in children's development (Vygotsky, 1979). Subsequently, under the influence of the complex systems paradigm, these ideas have been formalized in Bronfenbrenner's systemic theory, which currently constitutes one of the most influential research framework in developmental psychology (Perinat & Lalueza, 2007).

Bronfenbrenner's theory proposes that children's development is situated within a series of settings, each one characterized by specific activities, roles and social relationships, which shape the possible trajectories of children development (Perinat & Lalueza, 2007). According to this systemic model, children's development strongly depends on the interplay occurring between the child as a system and the existing external systems, both at a socio-cultural and biological level. This model is supported by a vast amount of research which shows how the qualities of the socio-cultural and physical environment have not only effects on behavioral or psychological features, but also at a biological and structural level, i.e. children raised in conditions of material and affective neglect tend to develop abnormal brain structure (Glaser, 2000). The importance of the role of contextual factors points out the need of carefully considering the role of the social and material environment in shaping embodied experience and cognition.

2.2.2.1 The role of the socio-cultural environment in shaping in situ embodied experience

"*Cada hombre es todos los hombres"* (Borges, 1944)

Social psychology has dedicated much of its research efforts in analyzing how our socio-cultural environment may shape our behaviors, perceptions, opinions, beliefs, the definition of the self and embodied experiences. Several studies explored the influence of social groups and social values on people's behavior and cognition. A paradigmatic example of this research can be found in the famous Asch conformity experiment (Asch, 1956). In this study, the influence of a group of confederates led the experimental subjects to wrongly change his opinions on simple perceptual tasks (i.e. estimating the size of a line) in order to conform to the opinion of the majority. Similarly, Bruner and Goodman (1947) explored how socially established values may shape our perception. In their study, they asked to a group of children to compare a set of circular shapes with some referential models of different sizes. Children, when they were presented with circular shapes made of cardboard tended to correctly match the size of the cardboards with the related models. Instead, when they were exposed to coins, children tended to over-estimate the size of the coin with respect to the model. Moreover, this overestimation was correlated with the socio-economical status of the child.

Alongside with this research line, studies aimed at exploring social influence from an embodied cognition perspective pointed out how the bodily states of the others influence our social perception, behavior and learning processes. This phenomenon does not only support the unfolding of meaningful social relations but also influences more complex behavioral and cognitive aspects. An illustrative example of that can be found in the tendency toward generating mimicry and behavioral alignment in situations of social interaction. This aspect has been recognized as one of the potential mechanisms behind empathy (Iacoboni, 2009) and also has been widely exploited in socio-cultural contexts aimed at generating shared understandings and beliefs, i.e. military or religious practices were body synchrony is employed to create the feeling of "oneness" and shared ideologies (Csordas, 2009).

At the same time, studies related to the influence of the other people's embodied experience on our cognitive processes have shown that, for instance, even seeing somebody gesturing while giving an explanation may support learning processes in children better than explanations given without gesturing (Goldin-Meadow, 2011). Consistently with these findings, Glenberg et al (2007) also showed that seeing a peer mimicking a story is as effective as mimicking the story by oneself in order to facilitate recall.

These studies, by tracing the complex network of socio-cultural influences that shape us, highlight two main aspects that need to be taken into account when considering embodied experiences. First, it points out the impossibility of clearly separate between nature and nurture and between what is individual and what is social (Overton, 2004). Consequently, it highlights that embodied experience cannot be considered as a phenomenon enclosed in an "isolated body" but instead as shaped by the contextual, social and historical conditions that surround us. Second, by rephrasing the longstanding philosophical question about "where the mind/body starts and where the world begins", they question the limits of the notion of embodiment. In other words, if I may learn also through the body of other people (i.e. their gesturing or enactment), does it make any sense to consider embodiment as a notion enclosed to the limits of my physical body or it should be extended to encompass my relation with the world? Addressing this question in the design of Full-Body interaction experiences suggest the need of considering the opportunities related to learning and understanding through the bodies of others. This implies both to consider instances and patterns of collaboration as well as the way in which the behavior of specific users may influence her peers' understanding and vice versa.

2.2.2.2 The role of artifacts and physical environment in shaping in situ embodied experience

Alongside with the role of our socio-cultural environment, other fundamental aspects that need to be considered in order to properly understand in situ experience are the specific qualities of the material context, its affordances, features and configuration. Research on the role of artifacts and physical environment on cognition and behavior have been tackled by different disciplines.

Norman's analysis of the design of everyday objects showed how specific designs, through their affordances (either based on ergonomics principles or on socio-cultural values) may suggest specific forms of usage and models about their functioning. On the other hand, research and practice have also addressed the way in which specific spatial configurations or physical qualities may affect complex cognitive and behavioral aspects such as customers and citizen behavior, social relationship and learning. For instance store design, interior design and urbanism have largely relied on knowledge related to the effect of spatial configurations in shaping behavior and emotions. Examples of them can be found in the specific layout of certain stores and in urban redesign aimed either at reconfiguring the usage of a space or at modifying more complex aspects of the socio-cultural identity of a territory (Augé, 1994)

Similarly, from the perspective of social relationship development, studies in social psychology have shown that even small changes in the spatial configuration of the environment may drastically change the establishment of social relationships. As an example, in their famous study Festinger, Schachter and Back (1950) compared the friendship relationships developed between neighbors in a block of house build in a U-like shape. According to their findings, people whose entrance was not placed towards the yard developed fewer relationships than those facing the yard.

Finally, pedagogical research deeply explored the influence of the configuration of the physical environment. Studies related to the spatial configuration of learning environments has pointed out how even minor changes in the physical setting of a classroom could produce changes in student behavior and in learning gains (Knapp, 1982). In this context, the importance of the spatial configuration has been widely applied in pedagogical models such as the Reggio Emilia approach and exhibition design. At the same time, research on the influence of material artifacts has been strongly formalized in pedagogical approaches such as Montessori's artifacts or Froebel's gifts (Zuckerman, 2009).

The Reggio Emilia approach, for instance, proposes to consider the physical environment as a "third teacher" (Strong-Wilson & Ellis, 2007), suggesting that the spatial arrangement is a key source for learning. At the same time, in museum exhibitions, the specific layout of the space constitutes a fundamental factor to facilitate learning, exploration and fostering the construction of conceptual knowledge (Allen, 2004). Following a similar philosophy, research on the design of manipulative (i.e. Froebel and Montessori) showed how specific affordances and configurations of material artifacts, by embodying specific concepts, may facilitate learning processes by allowing offloading cognition in the physical object.

To sum up, the reviewed studies point out how space and artifacts cover a crucial role in shaping different kinds of behavior and understandings. Furthermore, their affordances may allow people to use them to offload and distribute cognition in the environment (Hollan, Hutchins, & Kirsh, 2000)., i.e. the cane of a blind man, the use of a notebook or a mobile phone to offload our memory. According to this perspective, cognitive properties do not only emerge from the interaction with the world but, also, cognition is distributed into others and in the environment.

2.2.3 Implications for this Thesis

The studies reviewed in Section 2.2.1 and 2.2.2 focused on tracing the complex intertwined relation existing between mind/body/environment. Specifically, in Section 2.2.1 we addressed the role of embodiment in shaping understanding and constructing knowledge. Instead, in Section 2.2.2 we addressed the role of the social and material context in shaping meaning construction during in situ experiences.

The analysis reported in Section 2.2.1 pointed out three main concepts that will be employed to inform research. First, the overview of the role of embodied cognition in different cognitive processes and in the understanding of different concepts informs on the areas of knowledge that may be addressed through Full-Body interaction. This idea will be explored in the studies reported in Chapters 4, 5 and 6 and summarized in Section 8.3. Second, the analysis of the interplay between *online* and *offline* embodied cognition offers a starting point to conceptualize how embodied experience may be transformed into an object of knowledge. This notion will feed the interpretative framework employed in the study described in Chapter 7. Finally, the overview of the role of simulation suggested how our embodied understanding should be grounded on a certain degree of similarity between our embodied experience and our object of knowledge (e.g. I walk slower to understand elderly; I may lean my body to figure out the configuration of a certain structure). This idea will be explored in the studies reported in Chapter 4, 5 and 6 and summarized in Section 8.3.

On the other hand, Section 2.2.2 allowed informing on the way in which the specific conformation of the environment shapes the experience. Specifically, in Section 2.2.2.1, we highlighted the role of the socio-cultural environment in shaping perception, behavior and understanding. Through this analysis, we pointed out how group interactions, cultural values and the bodies of the others may strongly influence our embodied experience and sense making. Complementarily, in Section 2.2.2.2, we described how the qualities of the physical environment shape understanding, behavior, learning and social relationships. Finally, the overall review showed that in the study of meaning construction we cannot separate the individual from her surroundings but we need to carefully consider the role of contextual elements. This review, therefore, provides a conceptual grounding to guide the design and evaluation of the social and environmental resources of Full-Body interaction experiences. First, the analysis of the role of the social environment will inform research on the collaborative construction of meaning in FUBILEs. This analysis will be pursued in the studies reported in Section 6.2 and 7.1. Second, the analysis of the role of the physical environment in shaping the sense making of the experience will inform research related to the role of the physical affordances of the system in supporting learning. This area will be addressed in the studies reported in Section 6.2 and 7.1. Finally, from a broad perspective, the review will provide lenses to embrace complexity in the design and evaluation of FUBILEs.

2.3 Supporting learning through in situ embodied experiences

In the previous sections, we reviewed research related to the role of embodied experience in shaping cognition and constructing meaning. This analysis allowed delineating some initial considerations for guiding design and evaluation practices. Nonetheless, when addressing the design of environments aimed at supporting learning, further reflections should focus on the way in which we define learning and on the aspects involved in this process.

For this purpose, in the next sections, we will introduce Constructivist and Experiential learning theories and review relevant studies that can guide the design of educational materials. This analysis has the goal of contextualizing the research in relation to learning processes. Furthermore, it will provide conceptual instruments to guide the design and evaluation of FUBILEs.

2.3.1 Constructivist and Experiential Learning

"Mirad el más sencillo de los objetos. Tomemos, por ejemplo, una vieja silla. Parece que no es nada. Pero pensad en todo el universo que incluye: las manos y los sudores cortando la madera que un día fue árbol robusto, lleno de energía, en medio de un bosque frondoso en las altas montañas, el trabajo amoroso que lo construyó, la ilusión que la compró, los cansancios que ha aliviado, los dolores y las alegrías que habrá aguantado…" (Tàpies, 1971)

A motorcycle functions entirely in accordance with the laws of reason, and a study of the art of motorcycle maintenance is really a miniature study of the art of rationality itself. I said yesterday that the ghost of rationality was what Phædrus pursued and what led to his insanity, but to get into that it's vital to stay with down-to-earth examples of rationality, so as not to get lost in generalities no one else can understand. Talk about rationality can get very confusing unless the things with which rationality deals are also included (Pirsig, 1999).

In the last centuries, learning has received a wide variety of definitions, depending on its underpinning epistemological frameworks. At the same time, it has been characterized through different taxonomies and categorizations (Krathwohl, 2002).

For the purpose of this research, we will focus specifically on constructive and experiential learning processes. Constructive learning describes processes based on the comprehension and attribution of meaning (Pozo, 1989). For its features, it offers a more effective strategy to support long-lasting changes, conceptual understanding and strategic reasoning (Pozo, 1989). It distinguishes itself from other learning approaches since it does not imply to just store information in our memory (i.e. rote learning) or establishing contingency associations between elements (i.e. behaviorist learning). Instead, it requires understanding the information, attributing a meaning to it, connecting it with previous knowledge and reflecting on this process. Its effectiveness, thus, deeply depends on the way in which the learners attribute meanings to novel experiences and relate them to their own already existing mental structures. Within this framework, the current research especially addresses experienced-based constructive learning processes, understood as those processes where learning emerges from in-situ embodied interaction with the world.

The two introductory quotes, one proceeding from the world of art (Tàpies, 1971) and one proceeding from the world of philosophical fiction (Pirsig, 1999) illustrate the way in which phenomenological, sensorial or embodied experiences may be recast and interpreted through a vast number of paths. Pirsig (1999), in his book, uses the embodied experience of repairing a motorbike as an object of thought through which he can speak about epistemology, philosophy of science and life. On the other hand, Tàpies (1971) expands his perception of a simple chair to the whole network of cultural, affective and narrative meanings that may surround it.

These two examples point out how, during in situ experiences, meaning is constructed in the encounter between the experiencer and the world. In other words, meaning emerges in the *"potential spaces"* where the individuals recollect phenomena from the world and use them in relation to the network of meanings that belong to their personal reality (Winnicott, 1971). At the same time, these examples show how, in the act of attributing meaning to an experience, two fundamental aspects come into play. On the one hand, the way in which we get involved and engaged with the experience by connecting it with our interests, needs and previous knowledge. On the other hand, the way in which through this process, we manage to transform embodied experience into an object of thought, from which novel inferences for action and reflection may be build.

These two processes constitute the fundamental steps of experiential learning cycles (Kolb et al., 2001). According to this theoretical framework, learning emerges from grasping and transforming experience and it unfolds in the iterative cycle between concrete experience and reflection upon it (Figure 2). In the next sections we will provide a detailed description of the two fundamental stages of experiential learning: getting engaged with an experience and transforming it into an object of knowledge.

2.3.1.1 Getting engaged with embodied experience: experiences we care about

Experiential learning theories suggest that the prerequisite to support learning is constituted by the learner's engagement with the experience. This concept is consistent with the Gagne's model of nine events of instructions (Gagné, Briggs, & Wager, 1992), according to which the first step of a learning process is gaining the attention of the learner.

The learner's personal interests, hence, set the focus of attention on specific elements that we may consider salient or relevant. These elements are then selected and framed, constituting the foreground on which the learner builds her understandings and interpretations (Kress, 2010). This implies that the relation between personal interests and available stimuli constitutes the basic building blocks of the way people appropriate of an experience.

The design of instructional materials has repeatedly acknowledged this aspect and insisted on the importance of starting from the learner's interests and from what she already knows to build novel knowledge (Nathan, 2012; Rogoff, Matusov, & White, 1996). Within this research line, Papert (1980) has widely explored the importance of connecting learning with personal interests and ways of being. He, thus, showed that learning is more fruitful when we get emotionally involved with something and when learning materials enable different entry paths.

At the same time, research in developmental psychology has pointed out the fundamental role of the task's perceived relevance in modulating children reasoning process and understanding. In this context, Donaldson (in Perinat & Lalueza, 2007) showed that changing the narrative of the famous Piaget's experiment of the three mountains to a story more familiar for children (a child that steals candies) improved children's performance in the task. Similarly, Blaye et al. (1999) studied children's comprehension of negative sentences either by contextualizing them in an assertive mood (where the researcher made specific affirmations) or in an interrogative mood (where children were asked to help a woman with sight problems). In this second condition, by anchoring the task to a relevant goal such as helping somebody, children showed a better performance in understanding negative sentences.

These examples point out the fundamental role of learners' interests in determining the way of engaging and experimenting with the experience. They, thus, suggest considerations on the salience and relevance of the presented stimuli. Furthermore, they point out how connecting a task with personal experiences or socio-emotional values may help in setting the focus of attention, thus modulating children's involvement and understanding. At the same time, the constructivist claim for "grounding the new in the old" (Nathan, 2012) and generating continuity with familiar interests (Papert, 1980), highlight the need for a carefully understanding of users' previous knowledge and motivators.

These considerations, applied in the context of embodied learning – understood as learning processes where the body becomes the site of learning (Freiler, 2008) – suggest the importance of carefully combining the learners' interests and embodied experience. However, this aspect may confront with potential difficulties relate to our socio-cultural habits. Much of western education is distinctly disembodied (Kelan, 2010) and students have become inattentive to the potentiality of learning through the body since they are generally trained to focus on the mind. At the same time, as Varela et al. (1991) pointed out the mind-body relationship (or in other words, our capacity of being connected with our bodies) is not a fixed property but, instead, it can be deeply altered, i.e. we can operate in a sort of automatic pilot mode without paying attention to our bodies or surroundings.

2.3.1.2 Transforming experience into objects to think with

In the previous section, we overviewed the importance of getting involved and care about experiences in order to be able of constructing meaning and learn from them. Nonetheless, as experiential learning theories suggest, to construct meaning out of an experience, it may not be enough to just get immersed into it, instead learners need to become able of using it as an object of thought.

According to Broaders et al. (2007), learning can be considered as the ability to map from concrete experience to abstract knowledge. This definition is consistent with research in developmental psychology and studies on gestures, which pointed out that the relation between concrete experience and knowledge construction cannot be considered as an immediate and direct process but instead experience needs to be transformed in order to become available to use it to think about abstract concepts.

In this context, Karmiloff-Smith (1995) suggested a model of cognitive development based on subsequent levels. According to this model, procedural knowledge is gradually redescribed through different stages, in order to become explicit, accessible and available for its use. This model is consistent with studies on the relation between gestures and learning (Goldin-Meadow, 2011), which suggest that often gestures can reveal knowledge that is not yet accessible to children awareness and verbal report (Broaders & Goldin-Meadow, 2010), hence constituting an index of transition between concrete experience and abstraction.

From an applied perspective, these studies suggest that, when we are addressing embodied forms of learning, we cannot neglect the fact that embodied experience need to be transformed in order to meaningfully bridge with abstract concepts and explicit forms of knowledge.

This idea has been powerfully expressed by Papert (1980) [through the notion of 'objects-to-think-with', best understood as user-appropriated cognitive tools, or artifacts that provide a tangible and shareable mid-ground between sensorimotor and abstract knowledge. The author, taking as an example his own story, describes how he transformed his concrete experience of playing with gears into a lasting "privileged model" that allowed him to understand many abstract concepts, in many realms, such as in mathematics, physics, or music.

This notion, which could be tied back to Pirsig (1999) usage of "the motorcycle maintenance" as an object-to-think-about philosophy, points out the need of deepening on the possible processes that may lie behind the transformation of concrete experience into an object of thought, capable of carrying otherwise abstract meanings.

In this context, Kolb's theory of experiential learning proposes a model that starts from concrete experience and moves through reflective observation, abstract conceptualization and active experimentation (Figure 2). In this model, concrete experience is resignified through a reflective process that allows to transform it into abstract concepts from which new implications for actions can be derived (Kolb et al., 2001). This idea is further extended by Ackermann (2004), who suggests that, as they seek to reach new insights or understanding, even very young learners seem to "know" how to frame and reframe a task at hand by iteratively: (1) immersing themselves (dwell in); (2) stepping back and looking at things from afar (bird-eye view) or obliquely (through unusual angles or lenses); and (3) putting themselves in other people's shoes (adopting different stances, including other "voices").

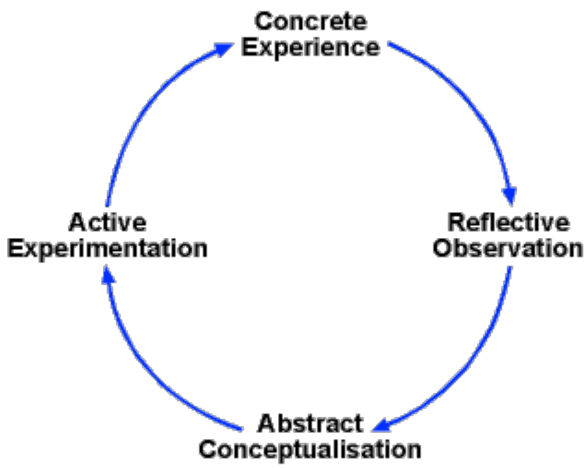


Figure 2. The Experiential Learning Cycle according to Kolb's theory

These two approaches suggest how the relation between grasping and transforming experience may be modulated by observational and reflective instances displayed both during in situ experience and/or after it. At the same time, they point out how the ability and opportunities to look at the experience from different perspectives may facilitate this reflective process. These considerations stress the fundamental role of metacognitive awareness during the task.

2.3.2 Implications for this Thesis

This section allowed situating our position in relation to learning theories. Furthermore, it provided initial guidelines to consider the affordances that the system may offer to support learning and it offered conceptual tools to guide the design and evaluation process.

From a broad perspective, this review will inform the overall structuring of the thesis. First, by highlighting the relational nature of meaning construction, it will inform the adopted research standpoint. . Specifically, the overall discourse of the thesis will be framed around analyzing the relation between what is offered by an experience - its affordances - and the way in which users interpret it - users' appropriation (Ackermann, 2007).

Second, the analysis of learners' engagement reported in Section 2.3.1.1 will inform the research on design and evaluation methods for FUBILEs. Specifically, in Chapter 5 we will explore possible participatory design methods to incorporate children's interest and previous knowledge in the design process. Subsequently, in Chapter 6 we will explore the relation between the affordances of the system and the attention toward embodied experience.

Third, the review of the role of reflection in transforming concrete experience (Section 2.3.1.2) will inform the interpretative framework employed for the study described in Section 7.1 and the discussion around possible design qualities to support reflection in-action and on-action (Section 8.3).

3 A SYSTEMATIC AND CRITICAL REVIEW OF RESEARCH IN FULL-BODY INTERACTION LEARNING ENVIRONMENT

In this Chapter, we will provide a systematic and critical review of studies in Full-Body Interaction Learning Environments. To structure this analysis we thus propose two review studies. In the first study (Section 3.1) we will report a systematic review of educational applications developed as Full-Body Interaction Learning Environments and aimed at fostering the learning of abstract concepts. This research will allow overviewing the employed theoretical backgrounds, design solutions and evaluation methods. It will, therefore, provide an initial starting point to identify gaps and good practices in the field. Subsequently, starting from some of the shortcomings identified in this review, we will report a second study aimed at going deeper and critically analyzing the instruments employed to evaluate this kind of experiences. This second study (Section 3.2) will discuss the limits and potential of the specific methods employed in this field, in order to critically analyze their coherence with the intended learning goals and with the embodied cognition framework. This analysis will allow tracing relevant tendencies in the field and will provide guidelines to orient researchers in the definition of appropriate methodological choices to analyze meaning construction and learning in FUBILEs.

To sum up, the overall research presented in this Chapter will contribute to situate this thesis in relation to previous works. Furthermore, by systematically and critically analyzing related studies, it will allow using the experience of the other as a mirror through which we can reflect on our own practice.

3.1 Learning of Abstract Concepts through Full-Body Interaction: A Systematic Review

This Section is based on the article:

Malinverni, L., & Pares, N. (2014). Learning of Abstract Concepts through Full-Body Interaction: A Systematic Review. *Educational Technology & Society, 17 (4)*, 100-116.

http://www.ifets.info/journals/17_4/7.pdf

Over the past ten years several learning environments based on novel interaction modalities have been developed. Within this field, Full-Body Interaction Learning Environments open promising possibilities given their capacity to involve the users at different levels, such as sensorimotor experience, cognitive aspects and affective factors. However, Full-Body interaction is still a young field and research on design and assessment methods offers a fragmented panorama from which it is not possible to derive clear research solutions.

Starting from this necessity, we present a systematic review of Full-Body Interaction Learning Environments developed between 2003 and 2013 and aimed at fostering the learning of abstract concepts. A total of thirty selected papers, published during the last ten years, have been reviewed. The purpose of the review is to provide a clear systematization of theoretical approaches, design strategies, evaluation approaches and results of research in FUBILEs. It would allow delineating a general panorama of tendencies and practices in the field, hence setting guidelines for future research.

3.1.1 Method of Analysis

This study reviews studies published in the last ten years (2003-2013) related to the use of Full-Body interaction for learning of abstract concepts. The literature reviewed proceeds from peer-reviewed studies published in English in scientific journals, proceedings of international conferences, symposia and book chapters. The search was carried out through the consultation of the following online databases of academic resources: ERIC, JSTOR, PapersFirst, ACM, IEEE, WilsonWeb, Elsevier, InformaWorld, Mary Ann Liebert, SpringerLink, Wiley Interscience, MIT Press and SAGE.

The initial research was based on searching the terms “learning” and “education” combined with the keywords: embodied interaction, Full-Body interaction, Whole-Body interaction, Motion-Based interaction, gesture-based interaction, bodily interaction, and kinesthetic interaction. We then searched for articles cited in the initially found papers. The selection was based on the inclusion criteria of papers that describe learning environments designed for neurotypical populations, which address knowledge acquisition as the primary goal and that are based on Full-Body interaction. Theoretical papers and studies on other forms of embodied interaction, robotics and construction kits were excluded.

Finally, we have included a total of thirty papers published between 2003 and 2013 (see Table 1). Since research in FUBILE is an emerging field, the chronological distribution of publications is strongly skewed toward recent years, with twenty-one papers being published between 2011 and 2013 and only ten published between 2003 and 2011. Also, as a consequence of the novelty of the field, most papers proceed from international conferences mainly dedicated to HCI or Learning Science. Only five of the reviewed papers proceed from journals and three are book chapters.

We oriented the analysis toward providing an exhaustive panorama of FUBILEs to offer a clear systematization of theoretical frameworks, design strategies and experimental results. For this purpose, the review focuses on the following aspects: the underlying theoretical frameworks; the design methodologies used; the interaction design choices; the evaluation methods; and the outcomes of the empirical analysis. We used content analysis to classify the defined research topics into categories. Our coding procedure was realized through Nvivo software and comprised a blend of a priori categories with new categories emerging from a grounded analysis.

Table 1. Reviewed papers

	Project	Theoretical Framework			Design Strategy			Educational Context		Interaction Design		Evaluation		
		Dev Psych	*Em Cogn*	*Phy*	*Semant*	*Adap*	*Phy*	*Content*	*Users*	*Nº of users*	*Mapping*	*Learn*	*Comp study*	*UX*
(Adachi et al., 2013)	*Human Sugoroku*	**X**				X		Science	Children	M	Functional		X	X
(Anastopoulou et al., 2011)	*Kinematics graphic*	**X**			X			Physics	Adults	S	Identity	X	X	
(Antle et al., 2008)	*SoundMaker*	**X**	**X**		X			Music	Children	M	Metaphor		X	X
(Antle et al., 2013)	*SpringBoard*		**X**		X			Social	Adults	S	Metaphor		X	X
(Carreras & Parés, 2004)	*Connexions*				X			Science	Children	M	Metaphor	X		X
(Charoenying et al., 2012)	*Bar Graph Bouncer*	**X**	**X**	**X**	X			Math	Children	M	Identity			X
(Cress et al., 2010)	*Dance mat for numerical comparison*	**X**	**X**		X			Math	Children	S	Identity	X	X	
(Edge et al., 2013)	*SpatialEase*	**X**	**X**			X		Language	Adults	S	n.d.	X	X	
(Enyedy et al., 2012)	*Learning Physics through Play Project*	**X**	**X**		X			Physics	Children	M	Identity	X		
(Grønbæk et al., 2007)	*IGameFloor (StepStones)*	**X**				X		Various	Children	M	Functional			
(Hashagen et al., 2009)	*Der swarm*	**X**	**X**					Math	Children	S	Functional	X	X	
(Holland et al., 2009)	*Song Walker Harmony Space*	**X**	**X**			X		Music	Adults	M	Metaphor			
(Holland et al., 2011)	*Harmony Space*	**X**	**X**		X	X		Music	Adults	M	Metaphor			
(Howison et al., 2011)	*Mathematical Imagery Trainer*	**X**	**X**		X			Math	Children	S	Identity	X		
(Johnson-glenberg et al., 2012)	*Feed yer Alien*	**X**	**X**		n.d.			Science	Children	M	Functional	n.d.		
(Johnson-glenberg et al. 2011)	*Disease Outbreak*	**X**	**X**		n.d.			Science	Teens	M	Functional	X	X	
(Johnson-glenberg at al., 2011b)	*PUSH*	**X**	**X**		X			Physics	Children	M	Identity			
(Johnson-glenberg et al., 2010)	*Layer Cake Scenario*	**X**	**X**					Science	Teens	M	Functional	X	X	
(Johnson-glenberg et al., 2010)	*Physics-Spring Pendulum*	**X**	**X**					Physics	Adults	S	Identity	X	X	
(Kiili et al., 2012)	*BrainDive*			**X**			X	Various	Children	S	Functional	n.d.		
(Kynigos et al., 2010)	*Wobble board*		**X**					Physics	Children	M	Identity	X		X
(Lee et al., 2012)	*Live your life in English*	**X**	**X**		X			Language	Adults	S	Identity			X
(Lim et al., 2011)	*ORIENT*	**X**		**X**				Social	Teens	M	Functional	X		X
(Lindgren & Moshell, 2013)	*MEteor*		**X**		X			Physics	Children	S	Identity	X	X	
(Lucht & Steffi, 2013)	*HOPSCOTCH*	**X**		**X**		X		Various	Children	M	Functional	X	X	X
(Lyons et al., 2012)	*Climate change installation*			**X**	X		X	Social	Children	M	Metaphor	n.d.		
(Malinverni et al., 2012)	*Arquimedes*	**X**	**X**		X			Physics	Children	M	Identity	X	X	X

(Pares et al., 2005)	*Watergames*				X	X		Social	Children	M	Metaphor	n.d.		
(Smyrnaiou & Kynigos, 2012)	*The apples*		**X**					Physics	Teens	M	n.d.	n.d.		
(Volpe et al., 2012)	*BeSound*	n.d.			n.d.			Music	Children	S	Metaphor	n.d.		

3.1.2 The Theoretical Framework

Research in FUBILEs is mainly grounded on the benefits that physicality may provide to facilitate learning and enhance user experience. This idea is supported by different theoretical frameworks, which range from pedagogy to cognitive science and physiology. From our analysis, we identified the employment of three main approaches: (1) based on developmental psychology and pedagogical theories, (2) relying on embodied cognition and (3) based on the physiological benefits that exertion can bring to cognition. To situate the reviewed projects, we provide an overview of the main theoretical frameworks employed by the different studies. Despite these approaches are interrelated, we describe them as separate sections for the sake of clarity.

3.1.2.1 The developmental psychology framework

From a pedagogical perspective FUBILEs are mainly based on constructivist and constructionist frameworks. The central pedagogical value is posed on the idea of learning-by-doing, understood as the fundamental role of hands-on activities and active experiences in the learning process. Even if active pedagogies do not necessarily imply the involvement of the whole body, nonetheless their experience-based nature is often employed as a conceptual grounding to frame the development of FUBILEs.

In this context a particular relevance is given to the works of Jean Piaget, Seymour Papert and Jerome Bruner. Even when these authors have different perspectives on child development, they all agree that knowledge emerges as a result of people's action-in-the-world (Ackermann, 2001). Such perspective supports the action-oriented approach of Full-body interaction and suggests its potential for facilitating the construction of knowledge through the internalization of actions. Within that Piaget's notion of schemata, Papert's notion of body-syntonicity and Bruner's concept of enactive representation are often employed to inform the design rationale. Piaget suggests that the cognitive structuring of children is partially based on the extension of physical schemata, which represent internalized patterns of activity that are then used for thinking (Antle et al.,2008). Papert (1980), through the notion of body-syntonicity, describes instructional designs based on using children's knowledge about their own bodies to stress the "resonance" between abstract concepts and what people know about themselves (Watt, 1998). Finally Bruner's theory about modes of representation of knowledge suggests that providing learners with different ways of thinking (enactive, iconic, symbolic) can facilitate the learning process (Di Paolo et al., 1991). These concepts, thus, serves as conceptual anchors to justify design choices and to guide specific design decisions.

3.1.2.2 The embodied cognition framework

Twenty-one papers base their designs on the embodied cognition framework. Embodied cognition has its philosophical roots in Merleau-Ponty's philosophy. Such framework emerged in cognitive science around fifty years ago and has been incorporated in HCI during the last two decades (Antle, 2013). According to this framework, almost all cognitive processes are influenced by physical states, bodily structures (Wilson, 2002) and experiential opportunities (for a detailed analysis of the embodied cognition framework see Chapter 2).

Embodied cognition, by focusing on the fundamental role of action and perception in shaping cognitive processes, coherently relates with the pedagogical approach of learning-by-doing and provides a scientific ground for defining design strategies for FUBILEs. With this context, particular relevance is given to Barsalou's Grounded Cognition approach, Johnson and Lakoff's theory on the embodied nature of linguistic concepts, and to the studies on the relation between gesture and thought. Barsalou's Grounded Cognition suggests that mental representations are grounded in motor areas of the cortex: when knowledge is needed, the perceptual and motor states acquired during experience are reactivated through simulation (Barsalou, 2008). This concept is applied in FUBILEs through the design of rich multimodal experiences that can support diverse experiential paths to facilitate knowledge construction. On the other hand, Johnson and Lakoff's theory finds its application mainly through the notion of Embodied Metaphor, which suggests that abstract concepts and conceptual metaphors are based on image schemas that derive from physical actions (Johnson, 1987). Finally, the studies carried out by Goldin-Meadow (2011) show the intertwined relation existing between gestures, language and learning outcomes and propose instructional models capable of taking into account the role of body in thinking processes. According to her research, gestures can predict and provoke learning by displaying knowledge that cannot be expressed verbally yet and by facilitating knowledge construction. --- This hypothesis is therefore applied in the design of actions to interact with the FUBILE.

3.1.2.3 The physiological framework

The third theoretical approach is related to the impact of physical activity on cognitive functioning, memory, attention allocation and academic performance (Castelli et al., 2007; Hillman et al., 2008). Recent researches show that aerobic exercise can improve several aspects of cognition, suggesting a physiological relation between physical activity and academic success. However, despite the raising importance of studies relating physical activity with academic success (Raine et al., 2013) it is interesting to notice that only three of the reviewed papers encompass such aspect in their design framework. The limited weight of this framework can be explained in relation to the fact that physiological benefits are mainly derived from longitudinal training. Instead, almost all FUBILEs propose short time span experiences.

3.1.3 Design Strategies

The overview of the theoretical frameworks shows that research in FUBILEs is based on findings derived from research in developmental psychology, cognitive science and physiology. Developmental psychology and embodied cognition, by stressing the tight relation between body and knowledge construction, suggest the possibility of using relevant bodily actions to facilitate the grounding of abstract concepts. The studies on the physiological effects of exertion suggest that FUBILEs can be beneficial from a perspective that encompasses also the cognitive process at the very ground of learning such as memory and attention.

However, since HCI is an applied science it is necessary to analyze how these findings can be used to inform design. Such task represents a challenging requirement that implies concretizing complex theoretical frameworks into specific instances. To observe of how this challenge has been addressed, the following sections describe the most relevant design strategies and their relation with the underlying theoretical frameworks.

At a methodological level, most studies do not report a clear description of the employed design method. From the information available, it is possible to notice that most research is based on a

Designer-Driven approach, where all design decisions are grounded on exploring theoretical constructs or technology's possibilities. Only four papers use a design method that involves stakeholders or end-users in the design process (Enyedy, Danish, Delacruz, & Kumar, 2012; Grønbæk et al., 2007; Howison et al., 2011; Johnson-glenberg et al., 2010). Namely, two of them are based on the collaboration with teachers (Enyedy et al., 2012; Johnson-glenberg et al., 2010), one involves both teachers and children through the use of participatory design methods (Grønbæk et al., 2007) and one involves users following a Design-Based research approach (Howison et al., 2011). Finally, any of the analyzed papers directly addresses the body as a source of knowledge during the design process. At a general level, three main design strategies were identified: a semantic approach, an approach based on the adaptation of existing materials and a physiology-oriented approach.

3.1.3.1 The semantic approach

Most analyzed projects rely on a semantic approach. This implies a design strategy oriented toward using the actions, events and activities of FUBILE as a reference for constructing meaning. This approach is generally aimed toward facilitating an embodied experience of a certain concept or toward representing an abstract concept as a concrete instance. From a theoretical perspective it is related to projects based on the embodied cognition framework.

Within this context, different semiotic resources, understood as "resources for making meaning" (T. Van Leeuwen, 2004) have been utilized to express the target contents. The greatest relevance is given to the role of *actions* as a vehicle to transmit meaning. Examples can be found in the *Method for Meaning Generation* proposed by Carreras & Pares (Carreras & Parés, 2004) and in the *Embodied Metaphor Approach* used by Antle (2013) and Holland (2011).

The *Method for Meaning Generation* focuses on operationalizing actions in terms of *attitudes* that we want the users to adopt and concentrates the design strategy on defining how the user will physically interact with the system. Examples can be found in "Connections" (Carreras & Parés, 2004) and "WaterGames" (Pares et al., 2005) where the values related to certain behavior (e.g., users hold hands with each other) serves as a link to express a specific concept (e.g., collaboration between scientists).The *Embodied Metaphor Approach* proposes the use of Johnson's theory of conceptual metaphor (Johnson, 1987) to inform design. An example can be found in "Springboard", where the concept of "the balance of social justice" is derived from the physical experience of balancing our own bodies (Antle et al., 2013). Other examples are "Song Walker Harmony Space" and "Sound Maker" where embodied metaphors are applied to musical concepts (Holland et al., 2011).

Similarly to *actions*, another semiotic resource is *space*. An example can be found in Cress et al. (2010) where the spatial format supports children's understanding of numerical comparison through the use of spatial cues (e.g. left = smaller, right = bigger). At the same time, the three projects based on Johnson's Embodied Metaphors, use both physical and spatial metaphors as resources in their design. Interestingly, Antle et al. (2008) point out that in "Sound Maker" children tended to use more spatial elements than bodily-based elements as sources for meaning-making. Another project based on the features of space is "Arquimedes" (Malinverni et al., 2012), where the physical affordances of the interface are used to ground content learning. The project, based on the use of a large inflatable slide, employs the gravity experienced on the sliding surface to express concepts related to gravity itself.

Other projects propose the *coupling between physical movement and computational feedback* as the main semiotic resource for meaning-making (Anastopoulou et al., 2011; Charoenying et al., 2012). Both projects focus on the learning of graphical representations of mathematical and physical concepts and stress the role of mapping between changes in the user's movements and changes in graphs as the mediator of learning. For example "Bar Graph Bouncer" (Charoenying et al., 2012) couples the number of jumps performed by children with bar graph representations of quantities.

Finally, the project "PUSH" (Johnson-glenberg et al., 2011) and "Climate change" (Lyons et al., 2012) use the notion of effort as a semiotic resource. The former project uses the effort experimented by children while pushing virtual objects to address concepts of Newtonian forces. The latter uses the notion of effort to allow children understand the severity of climate change.

3.1.3.2 Adapting existing materials

Eight projects have a design strategy based on adapting existing materials to Full-body interaction. Different strategies have been identified: (1) the adaptation of already existing applications, (2) the inspiration from traditional physical games and (3) the adaptation of educational material.

The project “Human Soguroku” adapts an already existing application designed for a desktop computer to Full-Body interaction for making the experience *more immersive* (Adachi et al., 2013). The project “SpatialEase,” instead draws inspiration from an existing application and from the traditional physical game of “Simon says” (Edge et al., 2013).The use of traditional games for developing FUBILEs finds examples in the projects “IGameFloor” (Grønbæk et al., 2007), “HOPSCOTCH” (Lucht & Steffi, 2013) and “WaterGames” (Pares et al., 2005). In “IGameFloor” and “HOPSCOTCH” the mechanics of the traditional games “Twister” and “hopscotch” are used in didactic exercises. Quite differently “WaterGames”, instead of embedding novel content into already existing gameplay, looks for an existing game that shares a conceptual affinity with the addressed topic and therefore works as a semantic reference (e.g. “Ring-a-ring Roses” associated to “respect for diversity”) (Pares et al., 2005).Finally, the project proposed by Lee et al. (2012), adapts the educational material of “Live your life in English” to a FUBILE to instill the naturalistic approach of English conversations and provide a context for *authentic learning*.

No explicit relation has been identified between a specific theoretical framework and these design strategies. Adapting existing materials can have its pros and cons. On one hand, it facilitates understanding through the use of culturally established models. On the other, especially in those cases based on adapting existing desktop applications, it could run the risk of reducing the potential of Full-Body interaction to that of merely emulating mouse-based interaction paradigms with the body as a large-scale pointing device.

3.1.3.3 Physiology oriented approach

Two papers propose a design strategy based on a physiological approach and design interaction according to the relation between physical and cognitive workloads (Kiili et al., 2012; Lyons, Slattery, Jimenez, Lopez, & Moher, 2012). This approach correlates with studies on the impact of physical activity on cognitive functioning, memory and academic performance. Such strategy focuses on analyzing the tight relation between physical arousal, attention and memory formation. It therefore suggests the necessity of balancing the physical workload with the cognitive load and proposes designs aimed toward offering an amount of physical activity that is beneficial for learning processes.

3.1.4 The Educational Context

3.1.4.1 Learning goals

Eighteen projects refer to STEM topics: seven refer to mathematics, seven to physics and four to science. This predominance can be associated with the governmental efforts to foster STEM learning. Furthermore, besides the driving forces of funding policies, also some of the projects ground this content decision on the affordances provided by Full-Body interaction. Studies on mathematical cognition suggest the embodied and spatial nature of mathematical concepts (Lakoff & Núñez, 2000), and several studies suggest a correlation between spatial thinking skills and STEM academic performance (Newcombe, 2010).

Four projects focus on learning abstract musical concepts and three on learning a second language. Projects that address learning musical concepts (Antle et al., 2008; Holland et al., 2011; Volpe et al.,2012) arise from the idea of using physicality and spatiality to provide a concrete experience of abstract concepts such tonal harmony. Projects about language learning arise either from the necessity of providing *authentic learning* experiences to the users (Lee et al., 2012) or from already existing instructional methods such as the *Total Physical Response*, which addresses second language learning through the co-production of spoken commands with bodily action (Edge et al., 2013)

Five of the analyzed projects focus on social sciences and particularly on topics that require a moral engagement such as social justice (Antle et al., 2013), environmental issues (Lyons et al., 2012), cultural diversity (Lim et al., 2011; Pares et al., 2005) or respect for diversity (Pares et al., 2005). The selection of these topics find their rationale in the capacity of direct experience to foster emotional arousal, suggesting the hypothesis that FUBILE could be capable of producing a higher impact, evoking empathy and producing behavioral changes.

Finally, three projects are not designed for a specific learning goal but work as frameworks where different contents can be implemented (Grønbæk et al., 2007; Kiili et al., 2012; Lucht & Steffi, 2013). Such a general approach correlates with the adoption of the theoretical framework based on the physiological benefits of exertion.

According to the revised version of Bloom's taxonomy, learning goals can be structured into four classes of knowledge: *factual knowledge* (recall of elements), *conceptual knowledge* (knowledge of the core concepts), *procedural knowledge (*applied knowledge about "how to" do something) and *metacognitive knowledge* (knowledge about one's own cognition) (Krathwohl, 2002). Regarding these classes, projects based on frameworks where different contents can be implemented mainly address factual knowledge through didactic exercises (e.g., select the right answer). Instead, projects grounded on embodied cognition mainly address conceptual and procedural knowledge.

3.1.4.2 Target users

Out of the thirty projects, twenty are designed for children, four for teenagers and seven for adults. In projects designed for children the target age ranges from preschoolers (Cress et al., 2010) to primary school, with a high predominance of children between 10 and 12 years old. A possible explanation of this distribution can be found in children's developmental trajectory; i.e., children around 11 years old are in a stage in which they start to think abstractly, reason about hypothetical problems (Perinat & Lalueza, 2007) and have well developed motor capabilities.

3.1.4.3 Context of use

Twelve projects arise from laboratory research and are tested in experimental settings. Other twelve are designed to be embedded in a school environment. Five are for museum spaces and one for a public space. The difference between settings has a fundamental role in defining design requirements, determining the educational experience and the empirical evaluation. This is clearly seen by comparing the educational experiences in an experimental setting or in a school environment. In most projects tested in the laboratory, participants use the system once for a limited amount of time and without any other educational support. Instead, in projects such as "Learning Physics" *(*Enyedy et al., 2012) the system is embedded in a complete educational program lasting fifteen weeks.

3.1.5 Interaction Design

3.1.5.1 Physical configuration

Due to the physical and spatial nature of FUBILEs, a first aspect to consider is the configuration of the physical interface. Most projects are based on audiovisual outputs that combine visual representations and audio effects. Twenty-nine are mainly visual, while one uses only audio output (Antle et al., 2008).

In seventeen projects the physical interface is based on the use of vertical screens or wall projections, requiring users to interact in the space in front of the display. Within this configuration few differential elements are present, such as adding interactive sensors in the adjacent space (Holland et al., 2011; Lucht & Steffi, 2013; Lyons et al., 2012). On the other hand, twelve projects are based on floor projections, which allow the user to move around the periphery of or directly on the visual output (Carreras & Pares, 2009; Cress et al., 2010; Grønbæk et al., 2007; Hashagen et al., 2009; Johnson-glenberg et al., 2010; Lindgren & Moshell, 2013).

Interestingly, only two projects present a substantial difference in the physical interface: "Arquimedes" (Malinverni et al.,2012) and "WaterGames" (Pares et al., 2005). In "Arquimedes", the physical interface is a large inflatable slide, with a virtual environment projected on the sliding surface. In "WaterGames", the physical interface is a group of water fountains, where the output is constituted by water springs. The homogeneity in the physical interfaces should provoke a reflection on the affordances of displays such as vertical screens and floor projections and suggest possible paths for innovation.

3.1.5.2 Single user or multiple users

Eleven projects are designed for a single user, whereas nineteen are designed for multiple users. In the latter case, the number of users that can simultaneously use the system ranges from a minimum of two to a maximum of twelve, with most projects addressing a number between three and five. A possible reason arises from the studies on group productivity, which indicate higher benefits when working in small groups (Mc Grath, 1984) .

In multi-user systems it is relevant to look at how different patterns of group interaction are implemented since specific design choices can generate interactions that are beneficial for learning outcomes (Dillenbourg et al., 2009). Except for the "Climate change" project (Lyons et al., 2012) and "Bar Graph Bouncer" (Charoenying et al., 2012), based on the competition between two users, all other projects are oriented toward collaboration. For example, "Feed yer Alien" (Figure 3) distributes different roles among the users: one chooses the correct food and the other brings it to the alien (Johnson-glenberg et al., 2012). Such design generates interdependencies among tasks and consequently facilitates discussion and shared decision-making. Instead projects such as "Archimedes" (Malinverni et al., 2012) and "Wooble" (Kynigos et al., 2010), do not differentiate between users and assign the same role to all of them. However, relevant differences are present: in "Arquimedes" each child acts as an individual entity, whereas in "Wooble" children have to behave as a homogenous entity by coordinating their collective displacement. Although analyzing the relation between group interaction and learning is not the purpose of this paper, it is necessary to consider the definition of different patterns of collaboration as a fundamental design choice since it can be used both to express meaning and to facilitate social interactions which are beneficial for learning.

Figure 3. Feed yer Alien installation (Johnson-glenberg et al., 2012)

3.1.5.3 Input technologies and operationalization of user behavior

Social sciences suggest that the notion of *body* depends on how we look at it (Thomas, 2003). This concept, applied to HCI, requires analyzing how the system conceptualizes the user's body and his behavior. According to Fogtmann et al. (2008), interaction with a system always imposes constraints on how the body is involved in this interaction. This is due to the choice of different sensing devices which offer diverse understandings of the interacting body.

Two main approaches are used to sense the interacting body: either a "sensor-activation" approach or a "motion tracking" approach. Within the former context different commercial devices are used (e.g., DanceMat, Wiimote, smart phone's accelerometer), while motion tracking approaches are based on specifically developed artificial vision systems, Kinect devices or laser scanning. Despite differences in the sensing systems used, most projects are based on tracking body or limbs position in space, with some of them integrating also data on the quality of movements (i.e. speed, flow, time, etc.).

Other projects propose different operationalization of user behavior such as: tracking gestures, the quantity of movement or the collective behavior of multiple users. Examples of this last approach can be found in "Wobble" and "Watergames." In "Wobble" players control a virtual board through their collective displacement on the floor: the system recognizes the total weight of players and its distribution and operationalizes the interaction in terms of coordinated movement and proximity between users (Kynigos et al., 2010). In "Watergames" (Figure 4) the system reacts and activates a fountain only when a group of children creates a closed ring and spins around the fountain (Pares et al., 2005).

These examples, by showing different forms of conceptualizing users, suggest that the definition of the input represents a fundamental starting point. This is because it directly affects the mental models of users on how they can interact with the system and defines possibilities for meaning construction. The definition of the sensing technology does not only represent a technological choice but can feed knowledge construction by operationalizing user behavior in a meaningful way.

Figure 4. WaterGames Installation (Pares et al., 2005)

3.1.5.4 Mapping

The concept of mapping, defined by Norman (1988) as the relation between "*controls and their movements and results in the world*", has been present for many years in HCI. While in its general definition mapping provides a strategy to make an interface easy to use, within FUBILEs a further layer of complexity is added since users do not only have to understand how the systems works but also must understand the target learning goals (Figure 5).

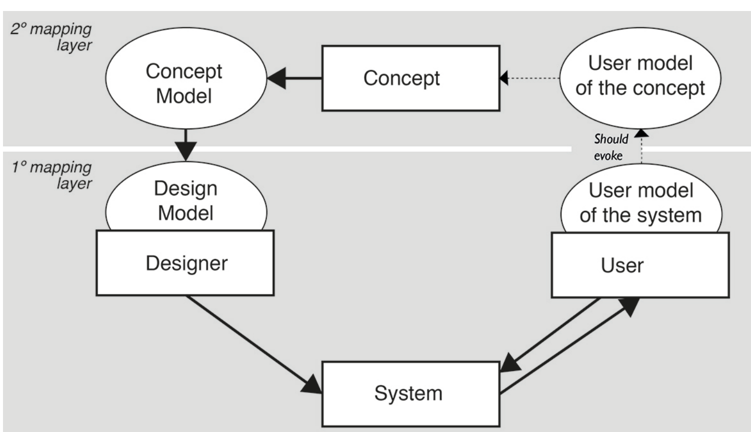


Figure 5. Multi-layered mapping. Users need to understand the system (first layer) and mapping should support the understanding of the content (second layer).

A first aspect to analyze is whether mapping and user actions are related to the defined learning goal and how they related. Three main approaches were identified: a “functional” approach, an “identity” approach and a “metaphorical” approach.

The “functional” approach represents the cases in which user actions and mapping do not relate with the content but arise from a usability perspective. Examples can be found in (Grønbæk et al., 2007; Johnson-glenberg et al., 2010; Kiili et al., 2012; Lim et al., 2011; Lucht & Steffi, 2013), which mainly rely to the application of traditional interaction paradigms of mouse-based interaction (i.e., select, drag, drop). The majority of these projects arise either from a technologically oriented framework or from approaches related to exertion and to the adaptation of existing materials.

On the other hand, both the “identity” and the “metaphorical” approaches are oriented toward establishing a relation between user actions and content. Based on the embodied cognition framework and on a semantic design, these projects focus on designing actions that allow having a physical experience of the concept taking advantage of body knowledge. The identity approach orients the mapping toward creating tight *analogies* between user action and content. For instance “Magic Angle”, which aims at the learning of methods to measure angles, requires children to physically enact angles with their arms (Liu et al.,2006). Similarly “Kinematics graphic” (Anastopoulou et al., 2011) maps the arm movement to graph of the relation between velocity, time and distance. Finally “Meteor” (Lindgren & Moshell, 2013) and “Archimedes” (Malinverni et al., 2012) require children to physically perform the behavior of specific virtual objects. From a semantic perspective the identity approach works as a denotative meaning, understood as using the literal meaning of user actions to indicate the concepts.

However, as Holland et al. (2011) pointed out, some concepts cannot be expressed through the literal meaning of body actions. To address this issue the “metaphorical” approach proposes a mapping strategy based on defining metaphors to bond users actions with the content. In these cases user action does not correspond to its literal meaning but works as a symbol for something else; e.g., (Antle et al., 2013, 2008; Carreras & Parés, 2004; Holland et al., 2011; Lyons et al., 2012; Pares et al., 2005). For instance, the project “SpringBoard” (Figure 6) uses Johnson’s Embodied Metaphor of balance to map the proprioceptive experience of balancing our own body onto the concept of social justice. The use of a metaphor offers strategies to address abstract concepts that cannot be physically enacted in a literal way; however it is necessary to reflect on whether the multiple layers of meaning of metaphors can facilitate the understanding or add an additional level of complexity in the learning process. For metaphors to be correctly understood, they need to be based on strongly shared socio-cultural references. This is often difficult to guarantee, especially in projects addressed to children.

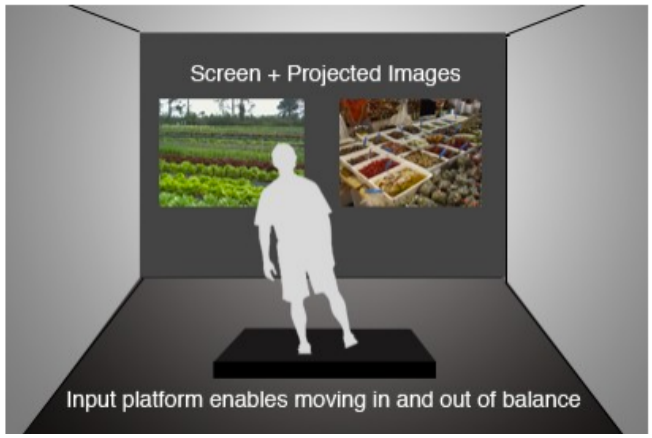


Figure 6. Springboard installation (Antle et al., 2013)

Table 2. Interaction design

	Features	Number of projects	
Physical configuration	*Vertical screen / projection*	17	
	Floor projection	12	
	Other	2	
Number of users	*Single users*	11	
	Multiple users	*Competitive*	2
		Collaborative	17
Input data	*Body/limb position*	17	
	Quality of movement	3	
	Quantity of movement	3	
	Gestures	2	
	Collective behavior of multiple users	3	
Mapping	*Functional*	8	
	Identity function	9	
	Metaphorical	6	

3.1.6 Evaluation

Twenty-one papers report empirical studies for evaluating the impact on learning and user experience. Sixteen of them focus on assessing learning outcomes, while five are oriented toward evaluating user experience. In all cases an effort is posed on evaluating the specificities of Full-Body interaction by comparing it with other instructional methods or with traditional interfaces.

3.1.6.1 Evaluating learning

Papers aimed at assessing the impact on learning are mainly based on the administration of retrospective measures, understood as evaluating learning through the administration of tests after the experience. Two main approaches are used: three studies use only post-task assessment, while eleven use an experimental design based on pre and post-test. Both single measure and repeated measures have pros and cons: the latter can increase the risk of repetition biases while the former makes it difficult to properly track learning gains.

Only Cress et al. (2010) use data logs of the performance to evaluate learning. In their study on using the DanceMat to foster numerical skills in children, they analyze data logs to assess improvements in accuracy and performance time between the first and second use of the application. Data logging can provide highly reliable quantitative data, however its application for complex learning goals can be challenging.

In terms of assessment instruments nine projects are based on multiple-choice questionnaires, three on interviews and three on mixed methods that combine interviews, questionnaires and discussion. This distribution requires a reflection on the relation between theoretical frameworks and assessment instruments. Most projects rely on constructivism but utilize instruments such as multiple-choice questionnaires. This does not seem coherent since questionnaires are often criticized by constructivism itself due to their deficiencies in properly discriminating the reasoning process behind the answers (Berg & Smith, 1994) and in evaluating understanding at a deeper level (Reeves & Okey, 1996). This contradiction requires further research on evaluation methods for FUBILEs, since only one project explicitly includes the tracking of the learning process and a deep analysis of students' understanding (Howison et al., 2011).

At the same time retrospective assessment is partially contradictory with the very nature of FUBILEs and embodied learning. Recent studies suggest that implicit bodily-based knowledge may precede the ability of children to properly articulate verbally their understanding (Broaders & Goldin-Meadow, 2010). Such aspect suggests the necessity of considering the role of bodily-based knowledge and overcoming the limits of verbal expression in the assessment of FUBILE.

3.1.6.1.1 The assessment of Full-Body interaction: comparing interfaces

Ten out of fifteen papers aimed at assessing learning report studies that evaluate the specific potential of Full-Body interaction by comparing it with other interfaces or instructional methods. Such studies are based on experimental designs where users are assigned either to a Full-Body interaction condition or to a control condition.

Relevant differences are present in the control condition. Four studies compare the use of the same application with two different interfaces; e.g., in "Archimedes", the same application is used either on a large inflatable slide or on a desktop computer (Malinverni et al.,2012). Two papers compare their system with a different desktop application, i.e. "SpatialEase" compare a FUBILE for learning second language with an already existing desktop application that has the same learning goals (Edge et al., 2013). Finally four papers compare the interactive experience with other instructional methods, such as traditional classroom instructions.

Despite the diversity in their research question, all comparative studies evaluate whether there is a significant difference between two conditions (i.e. whether an interaction modality is more effective than another) but none of them consider the qualitative aspects related to how users can learn differently depending on the interface. Such limitation has been already discussed by Kozma (1994) who suggested deepening the research on the effects of media on learning through the use of more qualitative approaches.

3.1.6.1.2 Results

Results of learning outcomes and comparative studies report a heterogeneous panorama. Despite fifteen papers evaluate learning, only fourteen clearly report their results: nine report significant improvements in learning, while five did not find any significant learning gains.

Comparative studies between Full-Body interaction and traditional instructional methods report significant differences in learning gains for the users assigned to the FUBILE condition. Comparative studies between FUBILE and desktop interfaces show no significant difference in five out of six projects. Only Cress et al. (2010) who compared a numerical task on DanceMat and on a tablet computer reported a significant difference in favor of users of the FUBILE.

The broad diversity in learning goals, design strategies and assessment methods makes it difficult to extrapolate consistent conclusions about these findings, however some aspects can be considered to provide guidelines for research and design. The projects that reported significant learning gains addressed learning goals that are clearly operationalized, while most studies that did not report significant gains deal with much more diffuse topics. For instance "Archimedes", which reported significant learning gains, focused its learning goal on Archimedes principle (Malinverni et al., 2012); conversely "Wooble", which did not report any learning gain, addresses goals related to "force, balance, weight, location, direction" (Kynigos et al., 2010). Despite several factors could contribute to the effectiveness of a FUBILE, it could be beneficial to clearly delimitate learning goals to circumscribe the amount of information that we want to communicate to the user. The results of "Wobble" are particularly indicative. After using the system, users were asked to define its educational content and none of them related it with physics. This misunderstanding suggests the necessity of carefully evaluating the communicative and interpretative aspects of design.

Studies on the comparison with traditional methods confirm the literature on the benefits of learning by doing and the role of active experience in grounding concepts. On the other hand, studies on the effect of the interactional difference posit much more challenging questions. As mentioned before, the study proposed by Cress et al. (2010) has two differential elements: (1) it is the only one that uses an evaluation method based on analyzing user performance and (2) it addresses the topic of numerical magnitude, which is deeply related to spatial and bodily cognition.

Even if it is not possible to disentangle these factors, novel research lines for FUBILEs could address the definition of proper learning goals and adequate assessment methods. Relevant shortcomings can found in a dichotomist approach (i.e., "is A more effective than B?"), which does not allow understanding in which aspects Full-Body interaction really differs from other kinds of interaction modalities.

Table 3. Summary of results

Evaluation		Significant difference	Non significant difference
Learning gains		(Cress et al., 2010; Edge et al., 2013; Enyedy et al. 2012; Howison et al., 2011; Johnson-glenberg et al., 2010, 2011b; Lucht & Steffi, 2013; Malinverni et al.,2012)	(Carreras & Parés, 2004; Hashagen et al., 2009; Kynigos et al., 2010; Lim et al., 2011)
Difference between conditions	Different interfaces	(Cress et al., 2010)	(Edge et al., 2013; Johnson-glenberg et al., 2010; Lindgren & Moshell, 2013; Malinverni et al., 2012)
	Different Instructions	(Anastopoulou et al., 2011; Johnson-glenberg et al., 2010, 2011a; Lucht & Steffi, 2013)	

3.1.6.2 Evaluating user experience

Seven papers focus on evaluating user experience, while the others combine this evaluation with the assessment of learning. Different aspects are analyzed: the enjoyment of the experience, its impact on the user, the level of motivation, and changes in the attitude toward the learning goals. Methods include interviews, questionnaires and observations. Contrary to assessment of learning, results are highly homogeneous, reporting significant differences in engagement, immersion and motivation in all of the studies aimed at comparing user experience in Full-Body interaction with a traditional interface.

Such findings suggest that FUBILEs can be highly effective in emotionally involving the users and motivating them. Antle et al. (2013) and Lucht et al. (2013) report particularly relevant results. Antle reports a significant difference in awareness, impact and willingness to get involved with social justice between the users assigned to the FUBILE and those assigned to the control condition. Lucht shows that children trained with FUBILE report a significantly higher positive attitude toward English, when compared to those assigned to the traditional classroom condition.

Such findings are consistent with the research on physical activity and user's attitude (Bianchi-berthouze, 2013) and suggest considering the pedagogical potential of FUBILEs from a perspective that includes the affective aspects of learning. However, longitudinal studies become extremely necessary at this point to be able to compensate for the novelty factor.

3.1.7 Discussion

This review reported a panorama of the theoretical frameworks, design approaches and empirical evaluations of FUBILEs, identifying tendencies and shortcomings useful for future research. At the same time, the analysis allowed identifying some initial starting points to guide reflection and research on FUBILEs. In particular, we consider that further discussion should address three main aspects: 1) the definition of the addressed learning goals; 2) the definition of the employed semiotic resources and the identification of the kinds of users' experiences that these resources can afford; 3) the employed design and evaluation methods.

3.1.7.1 The definition of the addressed learning goals

The overview of the addressed learning goals pointed out of the need of analyzing the consistency between the defined contents and embodiment. As suggested in Section 2.2, embodied experience may offer affordances that can be particularly suitable to address specific areas of knowledge. Starting from this perspective, some of the reviewed projects explicitly look for contents that meaningfully relate to embodiment, either by selecting concepts whose meanings may be grounded on bodily experiences (e.g. mathematical ideas) or by using existing bodily-based instructional methods. Instead, other projects do not propose a clear rationale behind the selected learning goals and employ embodied interaction mainly for its engaging qualities.

Both strategies may represent legitimate approaches. Nonetheless, we suggest that, to take full advantage of the specificities of Full-Body interaction, we should pay a close attention to analyzing what concepts and experiences can be easily expressed through this medium and what are less straightforward or inadequate. Starting from this perspective, we propose the notion of "expressiveness", understood as *"the definition of what is understood through the embodied experience and that which can be expressed through the available resources*". This notion implies to consider the interplay between the definition of the learning goals and the way in which physicality and space can be employed to facilitate this communicational effort. This knowledge can be derived from a careful understanding of the underlying theoretical framework, from the overview of how the body as being traditionally employed in educational contexts. Nonetheless, in order to properly take advantage of this knowledge, we cannot limit ourselves to a Theory-Driven approach (i.e. defining the learning goal only on the basis of related research). Instead, we need to carefully evaluate our proposals by confronting them with users' interpretations. From a design and evaluation perspective, this need implies to define methods and strategies to evaluate the communication of flow of the experience. Or, in other words, to understand the communicational ground that can be established between the researchers and the users, through the analysis of their representations, previous knowledge and interpretations.

3.1.7.2 The available semiotic resources and their role in affording learning processes.

The design of a FUBILE implies taking several decisions on the way in which we orchestrate the multiple aspects of our design proposal. The analysis of the employed design choices allowed spotting out some of the available semiotic resources. Within them, we identified: the design of users' actions and activities, the configuration of the physical/digital environment, the mapping between users' actions and computational feedbacks, the way in which the body of the user is conceptualized, the relation between multiple users, etc. Each one of these resources might be characterized through a variety of specific features (e.g. the quality of the sensorimotor experience, its rhythm, the material and layout of the space, etc.). These features, in turns, shape their potential to express meaning or to support certain kinds of experiences. Furthermore, their overall configuration determines an experience that is greater than the sum of its parts.

As a consequence, when defining the specific features of the available semiotic resources, designers should go beyond the considerations about its technological easiness and convenience. Instead, we should carefully embrace the analysis of their specific cultural and physical affordances. This need implies evaluating the way in which different features shape understanding, meaning construction and behavior. As a consequence, defining the design specifications of a FUBILE requires a two-sided process. On the one hand, we should motivate our design decisions according to a carefully understanding of their affordances. On the other hand, we should analyze how these potential unfold in their current context of usage. This means to the meanings that users construct and the way in which our choices determine specific forms of interacting with the environment.

Furthermore, additional research may address the effort of analyzing how specific features may more easily support processes that are beneficial for learning (e.g. attention, strategy formation, engagement, etc.).

To sum up, this review pointed out relevant aspects to be considered when designing a FUBILE. In order to briefly summarizing them, we propose an initial checklist of questions about critical aspects that need to be considered in the design process (see Table 4). Even if these questions represent just a preliminary structure to think about design, we consider that they might be helpful to foster reflexive design practices.

Table 4. Design Checklist

Educational context	- Definition of learning goals and learning process: *How are the learning goals selected? Is there any theoretical support for their relation with physicality? Do they address needs expressed by stakeholders? How are users supposed to learn?* - Definition of target users - Context: *How is the educational experience framed? Why? Is technology a stand-alone device or it is accompanied by a specific pedagogical intervention?*
Interaction design	- Physical interface: *Which physical interface will be used? Why? How digital technology relate to the physical interface? Why? Which affordances can it support? What behaviors and understandings does it actually support?* - Number of users: *How many users will be able to use simultaneously the system? Which patterns of group interaction are implemented? Why? Which emergent social interactions can be afforded?* - Operationalization of user behavior: *which aspects of user behavior are used as inputs by the system? Why? Do these aspects allow mapping with learning goals?* - Mapping: *Do the mapping of user activities relate with learning goals? How?*

3.1.7.3 Design and evaluation methods in FUBILEs.

Alongside with the aspects related to concrete design decisions, the current review also allowed spotting out some relevant methodological gaps in the employed design and research approaches. On the one hand, the review showed a tendency toward poorly reporting the design process. Furthermore, it highlighted that most studies are based on a Designer-Driven approach, with only few examples including either users or stakeholders in the design process. This tendency is partially unaligned with the emergent claim of HCI community about involving users at a deeper level. It, therefore, suggests the need of researching on design methods capable of blending complex theoretical models with a user-centered approach. At the same time, the review also pointed out the lack of explicit efforts to use bodily knowledge within the design process. Starting from this perspective, further research should address the effort of defining possible methodological approaches to properly integrate users' contributions and embodiment in the design process.

On the other hand, the overview of the employed evaluation approaches showed how this research often ends up offering a scattered panorama from which only poor conclusions can be derived. This shortcoming may be a consequence of the use of assessment instruments (e.g. multiple choice questionnaires) that offer limited affordances for understanding embodiment. This weakness may undermine the effort of moving this research field forward. As a consequence, researchers should pay a close attention to analyze and reflect on appropriate methods for evaluating FUBILEs.

3.1.8 Considerations for this Thesis

In relation to the global goals of the thesis, the present review provided an exhaustive panorama on related research, hence allowing identifying tendencies, good practices and gaps. In particular, in relation to the employed design methods, we detected a tendency toward grounding design decisions mainly on the exploration of technological possibilities and theoretical constructs. This trend provokes a shortage of approaches capable of taking into account users' contributions and bodily knowledge in the design process, hence running the risk of undermining the educational effectiveness of the design proposal. To address this issue, in the next sections, we will explore methodological approaches aimed at considering users' previous knowledge and their embodiment as sources to inform design (Chapter 5 and 6).

On the other hand, from the perspective of the employed evaluation methods, the review questioned the effectiveness of standard approaches (e.g. multiple-choice questionnaires) in producing knowledge to inform research on learning and meaning construction in FUBILEs. In order to delve into this finding, in the next section (Section 3.2), we will systematically analyze the limits and potential of the employed evaluation approaches. Subsequently, we will explore novel methodological solution (Chapter 5, 6 and 7). Finally, from the perspective of delineating qualities to support experiential learning, the review offered a first glance on the relation between embodied experience and learning goals. Furthermore, it allowed defining the different semiotic resources employed in the design of FUBILEs. This analysis, offer an applied counterpart to its theoretical exploration described in Section 2.2. Furthermore, it will be used as a conceptual tool to guide the design of FUBILEs in the subsequent research.

3.2 Toward Coherent Approaches for Researching and Evaluating Learning Experiences Based on Full-Body Interaction: a Systematic Critical Review

In the previous sections, we provided a general overview of research in FUBILEs and stressed the need for further research on adequate design and evaluation methods. In particularly, we questioned the *methodological appropriateness* (Patton, 1990) of the techniques and methods employed to research learning in environments based on embodied interaction (Malinverni & Pares, 2014; Price & Jewitt, 2013a, 2013b). In this context, specific criticisms addressed the lack of sensitivity of certain approaches to properly understand and be responsive to embodied learning (Malinverni & Pares, 2014) and the risks of applying conflicting criteria for validity (Harrison et al., 2011). Furthermore, additional reflections pointed out the need to go beyond the evaluation of only cognitive aspects and encompass the wider range of human resources included in meaning-making processes (Jewitt, 2013).

Starting from this viewpoint, the present study specifically addresses and reviews the methodological approaches and data gathering instruments that are currently employed to research, understand and evaluate learning in FUBILEs. In particular, the review will address the limits, potential and assumptions of the currently employed approaches, in order to delineate the affordances that they offer to understand embodied learning and critically analyzing their coherence with the intended learning goals and with the embodied cognition framework.

In order to better situate this research, we will first summarize the epistemological and philosophical roots of embodiment (for a detailed analysis see Section 2.1). Second, we will overview the relationship between values, assumptions and methods. Subsequently, we will use this theoretical background as bedrock to structure a systematic critical analysis of research approaches employed to evaluate learning in FUBILEs. This review will point out the strengths, potential and limits of the different instruments and methodological approaches, hence opening the path to discuss shortcomings and good practices in the field. Through this analysis, thus we do not aim at providing a prescriptive account on methodological choices or at establishing a "correct and univocal method". Instead, by reviewing current practices, we aim at exploring methodological approaches that allow for a deeper and fuller understanding of embodied learning (Polkinghorne, 1983). This approach will, therefore, allow guiding practitioners in the definition of appropriate research methods and foster reflection on one's own practice.

3.2.1 Situating Embodiment

As mentioned in Section 2.1, in western culture, the notion of embodiment finds its roots in the phenomenological tradition settle down by Heidegger and Merleau-Ponty, who emphasized the embodied, spatial and temporal nature of human experience (Polkinghorne, 1983). This standpoint questioned the discourse and research around how knowledge can be built both at the individual level of human experience as well as at the macroscopic level of epistemology (Garcia Canclini, 1973; Varela et al., 1991).

Even if the legacy of Merleau-Ponty started to receive more attention only from the '70 (Garcia Canclini, 1973), his thoughts deeply influenced the development of a relevant paradigm shift across several disciplines. In this broad panorama, the claims for embodiment have moved research on knowledge construction from the Cartesian focus on symbolic and abstract processing, toward conceptualizations deeply grounded on situated experience and contextual opportunities.

At the level of individual experience, the embodiment hypothesis claims that to study cognition and development we cannot restrict research only to the mind but we need to consider the relation between the mind, the body and the world (Wilson, 2002). Research carried out under this framework showed that not only the cognitive processes linked to mastering sensorimotor contingencies meet their origin in embodied experiences but also higher-level cognitive skills may arise from sensorimotor functions (Gallese & Lakoff, 2005; Johnson, 1987; Wilson, 2002). At the same time, research on learning showed how children performing specific gestures or manipulations can contribute to the understanding of specific concepts (Goldin-Meadow, 2011). These findings fostered an increased attention toward the potential of embodied learning (Freiler, 2008), understood as learning processes that are supported by the lived experience of being in our bodies and in the world. In this context, a particular attention has been given to experiential learning approaches, which suggest that learning is more fruitful when it arises from concrete embodied experiences and is then elaborated through reflection-on-action (Kolb et al., 2001).

This shift toward and embodied and situated standpoint acknowledged sources and forms of knowledge that were often neglected in traditional pedagogical approaches. Nonetheless, this recognition did not only affect the conception of how the human beings construct their understandings but instead it also questioned the way in which knowledge may be constructed at a social and scientific level. At a macroscopic epistemological level, the claims for embodiment addressed the need for a situated perspective in knowledge construction and questioned the criteria for legitimating the sources employed to construct knowledge in scientific practice (Esteban, 2001). According to this perspective, knowledge about the world cannot be separated from our standpoint in the world (Varela et al., 1991). Thus, both the disembodied observer that analyzes the world from a "god's eye view" (Haraway, 1988) as well as the decontextualized mind that constructs reality "ex-nihil", should be considered as inadequate perspectives to understand the world and the human being (Varela et al., 1991). Instead, research should situate itself in a "middle ground" between these two extremes (Garcia Canclini, 1973) and acknowledge its situated standpoint in specific socio-historical and material circumstances. As a consequence, the addressed unit of analysis should be capable of encompassing all the implied agents and their relation with the environment (Clark, 1998).

At a transversal level, the concept of embodiment represents both an essential structure of human condition as well as a specific standpoint in research. The implications of this paradigm shift have been deeply explored in fields such as philosophy of science and epistemology. However, their legacy was often only superficially considered in research carried out in Human-Computer Interaction. In this context, research on embodied interaction, despite its theoretical grounding on phenomenology and embodiment (Dourish, 2004), often embraces this paradigm only from a functional and simplified perspective (i.e. move your body to interact with digital technology). Even if also this approach can contribute to innovative design practices, we suggest that to move forward research in embodied interaction, practitioners should not only stick to the surface aspects of this theoretical framework but should commit to a broader paradigm shift (Harrison et al., 2011).This claim can be applied to a wide variety of aspects of the design practice (i.e. the definition of design choices, the employed design methods, the relation with the context of usage of a technology, etc.). However, for the purpose of this review, we will focus on tracing the relation between the implications of this theoretical framework and the methods used for research, understand and evaluate learning in FUBILEs. This perspective, thus, requires a reflective stance on the role that methods cover in shaping knowledge by guiding, enabling and constraining the way in which information is framed, collected and interpreted (Harding, 1989).

3.2.2 Methods and Knowledge Construction

During the last decades, research has repetitively pointed out how artifacts, computational practices and design choices can carry specific epistemological and political qualities (Chun, 2004; Penny, 2013; Turkle, 2012; Winner, 1980) that mirror certain arrangements of power, ideological discourses and conceptions about the human being and social practices. A relevant example of these influences can be found in the field of learning technologies.

The development of learning technologies has always been shaped by theoretical frameworks that define what “learning” and “knowledge” mean and how they are constructed. For instance, the influence of behaviorist assumptions on learning led to the development of software that use reward systems to make children repeat again and again specific exercises (Bers, 2012). Subsequently, the rise of the cognitivist paradigm and the tendency toward shaping all practices around computational metaphors (Agre, 1997) led to conceptualizing learning as an amodal symbolic computational process and to the proposal of learning experiences mainly based on symbol-processing (Bers, 2012).

This parallelism between influential epistemological discourses (*zeitgeist*) and the genealogy of learning technologies points out the importance of the underlying theoretical framework in guiding, enabling and constraining design and research practices. As Agre (1997) highlighted, the design field tends to be shaped around epistemological frameworks which (implicitly or explicitly) suggest the questions that need to be asked and how, methodologically, we can answer them. As a consequence, these underlying assumptions determine what “we care about”, what we measure and how we measure it. From this perspective, design and assessment methods cannot be considered as neutral techniques, but as mirrors of specific values, assumptions and discourses.

In the context of HCI, the role of values and assumptions has been widely discussed by critical and reflective design approaches such as Reflective Design (Sengers et al., 2005), Value Sensitive Design (Friedman et al., 2013) and Critical Technical Practice (Agre, 1997). At the same time, approaches such as Design-Based Research (Barab & Squire, 2004), Cooperative Inquiry (Guha, Druin, & Fails, 2013) and Participatory Design (Muller & Druin, 2003), highlighted how the choice of a design method may also entail a political or ethical positioning (e.g. the willingness to empowering users through PD).

On the other hand, from the perspective of evaluation methods, researchers have long debated around the assumptions underlying the employed approaches (Hoepfl, 1997; Kozma, 1994; Reeves & Okey, 1996). In particular, research pointed out how the influence of positivist epistemologies often led to consider learning as a stimuli-response mechanism or as a retrieval of information. This set of assumptions shaped several research approaches and evaluation methods around models derived from natural science, which tried to strictly quantify learning outcomes and to carefully isolate specific variables (Reeves, Herrington, & Oliver, 2005). This kind of approaches, in some cases, can lead to more rigorous results (Waetjen, 1992). However, they have often been criticized for their poor sensitivity to properly understand and be responsive to phenomena such as complex learning processes (Reeves & Okey, 1996) or the media effect on learning (Kozma, 1994). Furthermore, additional criticisms addressed the lack of congruence between the assumptions of positivist methods and the tenants of learning theories such as constructivism (Reeves & Okey, 1996).

Even if these considerations are crucial to the overall field of Technology-Mediated Education, they might be particularly relevant in the context of FUBILEs. This latter context proposes novel ways of learning (i.e. embodied learning), which consequently need to be properly evaluated and understood. As mentioned in Section 3.2.1, embodiment stands on a specific set of assumptions related to how knowledge can be constructed. As a consequence, when choosing the paradigm of inquiry for learning in FUBILEs, a careful reflection should address the limits, opportunities and appropriateness of the employed techniques. This aspect can be particularly relevant to extend the understanding of embodied learning, guiding design and avoiding eventual troubles that may arise from applying criteria that conflict with the core concepts on which embodiment is grounded (Harrison et al., 2011). Building on this viewpoint, in the next sections, we will overview the methods employed to gather data for evaluating learning in FUBILEs.

3.2.3 The Analysis

To carry out the critical analysis of currently employed methods for researching and evaluating learning in FUBILEs, we reviewed the studies published in the last 14 years (2002-2016) related to the evaluation of learning experiences based on Full-Body interaction. The literature reviewed proceeds from peer-reviewed studies published in English in scientific journals, proceedings of international conferences, symposia and book chapters. The search was carried out through the consultation of the following online databases of academic resources: ERIC, JSTOR, ACM, IEEE, Elsevier, ScienceDirect, SpringerLink, Wiley Interscience and SAGE. The initial research was based on searching the terms "*learning*", "*education*", *"evaluation"* and *"assessment"* combined with the keywords: *embodied interaction, full-body interaction, whole-body interaction, motion-based interaction, gesture-based interaction, bodily interaction, and kinesthetic interaction*. We then searched for articles cited in the initially found papers.

The selection was based on the inclusion criteria of papers that report evaluation procedure for learning environments designed for neurotypical populations, which address learning as the primary goal and that are based on Full-Body interaction. Theoretical papers and studies on other forms of embodied interaction (i.e. Tangible User Interfaces), robotics and construction kits were excluded. At the same time, papers that do not assess aspects related to learning (i.e. usability, system's accuracy, etc.) were excluded. Finally, we have included a total of 23 papers in the review (see Table 5). Most papers proceed from international conferences mainly dedicated to HCI or Learning Science. Eight of the reviewed papers proceed from journals and one is a book chapter. Within them, a wide variety of addressed learning goals are proposed such as physics, musical concepts, science, storytelling, maths, vocabulary learning, history and social aspects.

This review constitutes a continuation of the research described in Section 3.1, where a general overview of FUBILEs was reported. However, in the current study, we especially focused towards providing a critical and reflexive analysis of the employed evaluation methods. In particular, the review focuses on spotting out current approaches, identifying their limits and potential, and analyzing their consistency with the intended learning goals and with the embodied cognition framework. This standpoint aims at tracing relevant tendencies in the field and, at the same time, guiding practitioners in the effort of defining appropriate methodological choices.

Table 5. Reviewed papers: evaluation approaches

	Topic	**Research Method**		**Instruments**			
		Quantitative Approach	*Qualitative Approac*	*Questionnaires*	*Interviews*	*In Situ Interaction*	*Children's production*

			h				
(Ahmet, Jonsson, Sumon, & Holmquist, 2011)	physics		x		x	x	
(Anastopoulou et al., 2011)	physics	x		x			
(Antle et al., 2008)	musical concepts		x			x	
(Carreras & Parés, 2004)	science	x		x			
(Chu & Quek, 2015)	story telling	x	x		x	x	x
(Cress et al., 2010)	maths	x				x	
(Decortis & Rizzo, 2002)	story telling		x		x	x	
(Edge et al., 2013)	vocabulary learning	x		x			
(Hashagen et al., 2009)	maths		x		x	x	
(Howison et al., 2011)	maths		x		x	x	
(Johnson-glenberg et al., 2010)	science	x		x			
(Johnson-glenberg et al., 2011b)	science	x		x			
(Kourakis, Aker, & Parés, 2012)	history	x		x			
(Kynigos et al., 2010)	physics	x		x			
(Lim et al., 2011)	social	x		x			
(Lindgren & Moshell, 2013).	physics	x			x		x
(Lucht & Steffi, 2013)	vocabulary learning	**x**		**x**			
(Malinverni , Lopez Silva, & Pares, 2012)	physics	x		x			
(Malinverni, Ackermann, & Pares, 2016)	physics		x		x	x	

(Nemirovsky, Kelton, & Rhodehamel, 2012)	maths		x		x		
(Price, Sakr, & Jewitt, 2015)	history		x		x	x	
(Smyrnaiou & Kynigos, 2012)	physics		x		x	x	
(Watson, Mandryk, & Stanley, 2013)	various	x		x			

3.2.4 Results

Research on learning in FUBILEs presents a heterogeneous panorama of research standpoints and employed methods, techniques and instruments. From a methodological perspective, thirteen of the analyzed papers employ quantitative nomothetic research approaches. Ten, instead, are oriented toward idiographic and qualitative approaches.

Within the studies that employ quantitative research methods, five of them use a within-subjects experimental design to assess learning through pre and post task measurements (Kourakis et al., 2012; Kynigos et al., 2010; Lim et al., 2011; Lindgren & Moshell, 2013; Watson et al., 2013). The rest, instead, combines the within-subjects design with a between-subjects design where different methods or interfaces are compared (Anastopoulou et al., 2011; Carreras & Parés, 2004; Cress et al., 2010; Edge et al., 2013; Johnson-glenberg et al., 2010, 2011a; Lucht & Steffi, 2013; Malinverni et al., 2012). Twelve studies focus only retrospective measures employing multiple choices questionnaires (Anastopoulou et al., 2011; Carreras & Parés, 2004; Edge et al., 2013; Johnson-glenberg et al., 2010, 2011a; Kourakis et al., 2012; Kynigos et al., 2010; Lim et al., 2011; Lucht & Steffi, 2013; Malinverni et al., 2012; Watson et al., 2013) or structured interviews (Lindgren & Moshell, 2011). Instead, only Cress et al. (2010) propose a quantitative approach to analyze improvements in users' performance during the interaction with the system.

On the other hand, the ten studies framed around a qualitative paradigm, adopt approaches derived from ethnographic research and Design-Based research (Ahmet, Jonsson, Sumon, & Holmquist, 2011; Antle, Droumeva, & Corness, 2008; Chu & Quek, 2015; Decortis & Rizzo, 2002; Hashagen, Büching, & Schelhowe, 2009; Howison, Trninic, Reinholz, & Abrahamson, 2011; Malinverni, Ackermann & Pares, 2016; Nemirovsky, Kelton, & Rhodehamel, 2012; S. Price, Sakr, & Jewitt, 2015; Smyrnaiou & Kynigos, 2012). Employed methods focus mainly on semi-structured interviews, video analysis of in situ interaction (i.e. how children interact with the system) and analysis of children production (i.e. drawings). Interestingly, the 80% of them employ a methodological triangulation that combines retrospective measures (e.g. interviews) with the analysis of in situ interaction. Instead, Nemirovsky et al. (2012) focus mainly on post-task measurements through in-depth interviews and Antle et al. (2008) frame the research mainly around the observation of in situ interaction. Within qualitative studies, two of them propose a comparative approach where either different interfaces (Hashagen et al., 2009) or different design approaches (Antle et al., 2008) are compared.

The broad diversity of employed approaches is indicative of the existence of different epistemological standpoints and goals in the research related to FUBILEs. While this diversity may be a source of richness for research, we nonetheless suggest that a critical reflection on the employed instruments and methodological approaches may be beneficial to properly frame the design and research agenda in this area. To guide practitioners in the definition of appropriate assessment methods for FUBILEs we, therefore, choose to structure the review accordingly to the most common employed data gathering instruments, namely: *multiple choices questionnaires, interviews, analysis of in situ interaction and analysis of children production.* The choice of adopting this structure is motivated by the willingness of providing a "ready-at-hand" tool to reflect upon one's own methodological choices.

3.2.4.1 Multiple-Choice Questionnaires

Questionnaires represent a widespread instrument in the evaluation of FUBILEs (48% of the reviewed papers). Even if questionnaires can be administered both in an open-ended or a closed format, most studies employ them according to a multiple-choices format. Generally, their administration follow a within-subject experimental design aimed at tracking the learning gains through the comparison of pre and post-test scores (Carreras & Parés, 2004; Edge et al., 2013;

Johnson-glenberg et al., 2010, 2011a; Kourakis et al., 2012; Kynigos et al., 2010; Lim et al., 2011; Lucht & Steffi, 2013; Malinverni et al., 2012). Eventually, also several studies complement this research with comparative studies where the effectiveness of the FUBILE is contrasted either with another instructional method (Anastopoulou et al., 2011; Johnson-glenberg et al., 2010, 2011a; Lucht & Steffi, 2013) or with an analogous desktop application (Edge et al., 2013; Malinverni et al., 2012).

From a pragmatic perspective, the use of multiple-choice questionnaires allows gaining precision in the analysis by providing numerical data that can be easily treated through statistical analysis. At the same time, its widespread employment makes it a sort of "standard" and accepted approach. Nonetheless, going beyond its standardization, further reflections should address its limits, potential, implications and methodological appropriateness to evaluate learning in FUBILEs.

3.2.4.1.1 Multiple choices questionnaires and learning goals

Evaluation methods based on multiple-choice questionnaires operationalize learning as a change that occurs through experience and that can be measured by calculating the number of correct answers. Learning is, therefore, mainly conceptualized as a form of knowledge acquisition produced by specific stimuli. As a consequence, its processual nature and other aspects of the learning experience (i.e. motivation and emotional factors) are not taken into account (Berg & Smith, 1994). This conception finds its roots in neo-behaviorist epistemologies, according to which cognitive processes should be studied as "black boxes", where it is possible to analyze just the input and the output but not the mediating process. As a consequence, it builds a discourse around knowledge as an asset that can be easily "delivered" in a sort of unmediated way (Ackermann, 2007) and conceptualize learning experiences mainly in terms of quantifiable learning gains. These implications should be carefully scrutinized in relation to our research purpose.

Educational approaches and assessment methods derived from behaviorism have often been criticized for their insufficiencies in supporting and evaluating learning processes that go beyond the acquisition of factual knowledge, i.e. conceptual learning or strategic reasoning. From an evaluation perspective, specific criticisms addressed their lack of sensitivity to observe fundamental indicators of constructive learning, i.e.: the unfolding reasoning processes, the ability of the learners to attribute meaning and to interpret the experience in their own words and to connect novel knowledge with their already existing structures of meaning (Reeves & Okey, 1996). As a consequence, multiple-choice questionnaires can be sensitive enough to evaluate learning outcomes related to the acquisition of factual knowledge (i.e. acquisition and recall of verbal information). However, they offer poor affordances to address learning goals related to conceptual knowledge or strategic reasoning.

Starting from this distinction, it is relevant to notice that, within the studies that use multiple-choice questionnaires, only three of them (Edge et al., 2013; Lucht & Steffi, 2013; Watson et al., 2013) aim at fostering factual learning (i.e. learning of specific words in a foreign language), while the rest aims at fostering conceptual learning (i.e. physics). This incongruence between the defined goals and the sensitivity of the employed instrument may provoke important shortcomings. Is indeed noteworthy that, within the studies that evaluate learning gains through pre and post questionnaires, the 55.5 % of them report significant improvements (Edge et al., 2013; Johnson-glenberg et al., 2010, 2011a; Lucht & Steffi, 2013; Malinverni et al., 2012) while the 44.5% do not report any significant difference (Carreras & Parés, 2004; Kourakis et al., 2012; Kynigos et al., 2010; Lim et al., 2011). These findings offer opposing viewpoints from which it is not possible to derive any consistent conclusion on the potential of FUBILEs. At the same time, by considering that each FUBILE is composed by a plethora of stimuli, it becomes even harder to extrapolate some robust design guidelines.

Even if these outcomes may represent a faithful radiography of the learning impact of FUBILEs, it is also legitimate to consider them as eventual artifacts produced by the employment of poorly sensitive data gathering instruments. These shortcomings require a careful reflection on the extent to which these instruments can produce valuable knowledge to understand embodied learning.

3.2.4.1.2 Multiple choices questionnaires and embodiment

According to the embodied cognition framework, cognition and meaning emerge in the interaction between the embodied agent and its social and physical environment (di Paolo, Rohde, & Jaegher, 1991). Embodiment, therefore, represents a relational (Overton, 2004) and situated construct. As a consequence, as Clark (1998) suggested, in order to understand embodiment, it is advisable to define a unit of analysis capable of assuming a holistic perspective on the agent in relation to the environment.

Instruments such as multiple-choice questionnaires frame the unit of analysis only on a limited portion of cognitive outcomes (i.e. ability to recall and give the expected answer), hence excluding the embodied, contextual and emotional aspects. Through this standpoint, they may run the risk of mirroring the dualistic bias of western culture, according to which formal and symbolic knowledge is privileged over the practical and physical one (Nathan, 2012). As a consequence, they may end up choosing a unit of analysis that is too narrow and inconsistent to properly offer a deep and full understanding of the phenomena (Harrison et al., 2011), hence reducing the knowledge that can be derived from this research approach.

To sum up, even if multiple-choice questionnaires can be employed within different research paradigms and may constitute useful instruments to build one's argument, nonetheless, they present relevant limitations to research learning in FUBILEs. Specifically, the most relevant limits address the defined unit of analysis and its lack of sensitivity to include embodiment as a source to construct knowledge in research.

3.2.4.2 Interviews

Ten of the analyzed papers employ interviews to assess learning in FUBILEs (Ahmet et al., 2011; Chu & Quek, 2015; Decortis & Rizzo, 2002; Hashagen et al., 2009; Howison et al., 2011; Lindgren & Moshell, 2013; Malinverni et al., 2016; Nemirovsky et al., 2012; Price et al., 2015; Smyrnaiou & Kynigos, 2012). Within them, a wide variety of methodological approaches is proposed. Adopted approaches vary according to their level of structuring, the extent to which they employ either closed or open-ended questions, the adopted interpretative stances, the proposed scheduling of the interview and the combination of this method with other sources of information. This heterogeneity requires paying attention to their methodological differences instead of considering it as a unique method that builds a specific discourse around learning experience. For this purpose, we will review some of the different methodological choices that have been employed to conduct interviews to evaluate learning in FUBILEs.

3.2.4.2.1 The level of structuring

At a structural level, nine out of ten papers use a semi-structured approach for interviewing users. Their goals are generally oriented towards analyzing users' understandings and subjective interpretations of the experience and gathering impressions and criticisms for design refinements. On the other hand, instead, just Lindgren & Moshell (2013) use a structured format based on three pre-defined questions to evaluate specific learning goals.

Within the studies that employ semi-structured interviews, only two (Nemirovsky et al., 2012; Price et al., 2015) clearly report some examples of the used questions. The rest, instead, just briefly summarize them. From these general descriptions, it emerges that questions are generally oriented toward asking users to recall what they did, to explain the employed strategies, to clarify how they interpreted specific aspects of the experience and to give their opinions. This research's focus offers a certain sensitivity to observe the reasoning process used by children, their interpretative stances and the qualitative shades of their understandings (Ginsburg, 1981). Furthermore, if confronted with multiple-choice questionnaires, it allows tracking some fundamental indicators of constructive learning (i.e. the ability to "translate" a concept with our own words and to connect it with previous knowledge and related concepts). As a consequence, interviews offer affordances that make them a suitable approach to evaluate learning processes related to conceptual learning and strategic reasoning. This feature is consistent with the learning goals proposed by the FUBILEs that employ interviews for evaluation.

Besides its consistency with the specific learning goals, further considerations should address its relation to the embodiment experience. According to experiential learning theories, reflection-on-action constitutes a fundamental step to learn from concrete experience (Kolb et al., 2001). As a consequence, analyzing the subjective meanings that users attribute to actions, events and system's features may allow for a deeper understanding of the process of learning from experience. Nonetheless, even if semi-structured interviews may allow grasping some of the features of embodied learning, additional reflections should address their specific limits. On the one hand, researchers should pay close attention to the kind of questions that are asked. For this purpose, we suggest that a higher consideration for including more procedural details about the interviews in the reports (e.g. examples of the used questions) could be highly beneficial for the whole community. On the other hand, as mentioned in Section 3.2.4.1, research approaches that focus only on post task measurements may run the risk of falling in the dualistic trap of being oblivious to embodied meaning making. To tackle this potential shortcoming, specific methodological considerations should address the scheduling of the interview and the eventual methodological triangulation with other data gathering instruments.

3.2.4.2.2 The scheduling of the interview

At a procedural level, two different scheduling approaches are used by the reviewed studies to perform interviews. Nine studies carry out the interviews after the task. Instead, Howison et al. (2011) follow a clinical interview approach and perform the interview while the user is interacting with the system.

The studies that report the employment of post-task interviews show that this approach can allow gathering data on users' reflections on the experience, on what they recall of it, on how they interpreted it and on the aspects that were more salient and "worth to be remembered". Instead, the use of concurrent interviews showed to offer affordances to track reasoning processes as it is unfolding during the task or, in other words, to grasp reflection-in-action (Schon, 1983).

Even if these two approaches offer affordances to track different aspects of meaning construction, their possible limitations should be considered. On the one hand, the demand of answering questions during the interaction has been reported for its risk of being disruptive for the overall experience (Chu & Quek, 2015) and poorly suitable for young age users (Markopoulos, Read, MacFarlane, & Höysniemi, 2008). On the other hand, specific concerns highlighted the limits of post-task approaches to obtain information on specific behavioral aspects displayed during the interaction (Price & Jewitt, 2013b). To tackle this latter issue, an interesting methodological solution is proposed by Nemiroski et al. (2012). In their study, during the post-task interview, users are showed with a video playback of their own interactions with the system. They are, therefore, asked to explain and reflect on their own behaviors, choices and understanding of the interaction. In this case, the use of video elicitation during the interview facilitated the process of recalling and gaining a deeper level of details on specific aspects of the interaction without disrupting the experience. Furthermore, comparative studies on the use of this approach to research learning in Tangible User Interfaces, showed its benefits to address the embodied, situated and signified nature of concrete experience (Price & Jewitt, 2013b).

To sum up, when planning an interview for researching on embodied learning, researchers should pay a close attention to how its scheduling may shape the data that we can collect. In particular, a careful consideration should address the relation between our research goals and the tradeoff between the specific sensitivity and weaknesses of different scheduling solutions.

3.2.4.2.3 Analyzing interviews and methodological triangulation

The reviewed papers proposed variations in the approaches employed to analyze the interviews. Especially, the most relevant methodological differences were related to how the data were analyzed and to whether interviews are combined with other sources through a methodological triangulation.

The nine studies that employ semi-structured interviews analyze data through grounded content analysis. This means that interviews are analyzed inductively by defining codes and categories from the observation of the collected data. Instead, Lindgren & Moshell (2013), which employ a structured interview, base their analysis on a priori coding scheme and plot and rate the answers according to predefined categories.

The selection between a bottom-up and a top-down analytical approach tend to be motivated by the specific research questions and features of the interview. Nonetheless, it also entails some specific implications on the kind of knowledge that we can construct. Top-down approaches based on predefined coding schemes allow to quantitatively analyzing data. They, thus, provide materials upon which statistical inferences on learning gains may be built. On the other hand, bottom-up approaches allow taking into account emerging concepts and representations that were not predefined by the researcher. They, thus, allow gathering information on aspects that may not have been foreseen and observing what aspects users considered as particularly salient or relevant. As a consequence, they may offer deeper insights on the way in which users engage with the experience.

These features may be especially relevant to guide design's refinements and to understand the paths through which users signify concrete experiences. This sensitivity can be particularly accentuated when data proceeding from interviews are combined with other sources. In this context, two fundamental approaches are proposed.

On the one hand, eight papers (Ahmet et al., 2011; Chu & Quek, 2015; Decortis & Rizzo, 2002; Hashagen et al., 2009; Howison et al., 2011; Malinverni et al., 2016; Price et al., 2015; Smyrnaiou & Kynigos, 2012) employ a methodological triangulation to merge the analysis of the interviews with data gathered from the observation of users' in situ interaction (for a detailed analysis of in situ interaction see Section 3.2.4.3). On the other hand, Nemirowski et al. (2012) propose a micro-ethnographic approach to analyze the multiple resources employed by the users while explaining their experience during the interview (e.g. talk, gestures, facial expression, body posture, inscription, tool use, pace, gaze). In both cases the proposed approaches go beyond the limits of observing only cognitive and verbal aspects, hence offering relevant affordances for the understanding of embodied learning. Research approaches that merge the analysis of the interviews and of in situ interaction allow observing how meaning is constructed in the relation between the features of the experience and the characteristics of the experiencer. They can, therefore, tap into a fundamental aspect of research in embodied learning. Namely, the cycle between experimentation and reflection which allows transforming concrete experience into an object of knowledge (di Stefano, Gino, Pisano, & Staats, 2014; Kolb et al., 2001).

On the other hand, the analysis of the non-verbal behaviors displayed during the interview, can provide several benefits for the understanding of embodied learning. First, by explicitly recognizing the multiple resources that humans employ to construct and communicate meaning (Streeck, Goodwin, & LeBaron, 2011), it can offer a strong degree of consistency with the embodiment framework. Second, it can allow tapping into knowledge that is not verbally expressed. As several studies pointed out, gestures can offer a display of knowledge that is not yet explicit (Goldin-Meadow, 2011; Roth, 2002), hence constituting a reliable index of transitional knowledge. As a consequence, this approach may allow tracking the way in which embodied knowledge is transformed to become explicit (Karmiloff-Smith, 1995).

To sum up, interviews may offer affordances that make them more suitable to research on constructivist learning processes such as conceptual learning and strategic reasoning. Furthermore, they can allow gathering users' interpretations, hence offering cues to guide design iterations and improvements. Nonetheless, researchers should pay a close attention to the way in which this approach can be framed to fit with an embodied standpoint.

3.2.4.3 Analysis of in situ interaction

Ten papers propose the analysis of in situ interaction (understood as the study of how users interact with the system) to research on meaning construction and learning in FUBILEs. Within that, two studies focus only on in situ interaction (Antle et al., 2008; Cress et al., 2010), while eight papers combine this analysis with other sources (e.g. interviews) through a methodological triangulation (Ahmet et al., 2011; Chu & Quek, 2015; Decortis & Rizzo, 2002; Hashagen et al., 2009; Howison et al., 2011; Malinverni et al., 2016; Price et al., 2015; Smyrnaiou & Kynigos, 2012).

3.2.4.3.1 In situ interaction and learning goals

Antle et al. (2008) and Cress et al. (2010) mainly employ the analysis of in situ interaction to assess learning goals related to procedural knowledge (i.e. learn to perform numerical comparison in math, learn to recognize musical notation, etc.). The evaluation focuses on comparing users' performance between different trials. For this purpose, different techniques are employed. Antle et al. (2008) analyze users' performance through video and field observation. Cress et al. (2010) instead, employ a data log system to track children's performance.

Independently from the employed technique, the chosen assessment method allows to properly observe the procedural learning goals pursued by the designed experience. At the same time, both studies analyze in situ interaction to compare either two interfaces (Cress et al., 2010) or two different mapping strategies (Antle et al., 2008). In both cases, the results of comparative studies are far more conclusive than results proceeding from studies based on questionnaires. For instance, Cress et al. (2010) compare the use of a similar application either with a tablet or with a dance-mat interface. In their study, they show a significant difference in learning gains for children assigned to the FUBILE condition. Similarly, Antle et al. (2008) show that grounding mapping on embodied metaphors improves learning benefits with respect to other mapping strategies. These outcomes, faced with the results of comparative studies reported in Section 3.2.4.1, suggest that the analysis of in situ interaction could be a more sensitive instrument to inform on the specificity of a given design solution and media. At the same time, it can provide an adequate approach to observe learning processes related to procedural knowledge.

On the other hand, the other eight studies address learning goals that include both conceptual and procedural knowledge. Their evaluation approach is based on combining the analysis of in situ interaction with users' self-reports of the experience through concurrent or post-task interviews. In particular, in these studies, the analysis of in situ interaction focuses on observing how users construct meaning through their embodiment and through the interaction with the environment. This approach showed to be effective in properly identifying relevant indicators of conceptual learning (Price et al., 2015; Malinverni et al., 2016) and strategic reasoning (Smyrnaiou & Kynigos, 2012) such as the ability to connect experience with previous knowledge or to metacognitively reflect on the employed strategies.

To sum up, therefore, the analysis of in situ interaction, especially when combined with other sources, may offer features that support the evaluation of procedural, conceptual knowledge and of strategic reasoning. Furthermore, its situated nature can provide an adequate sensitivity to observe and understand embodied learning.

3.2.4.3.2 In situ interaction and embodiment

Research that focuses on in situ interaction tends to propose idiographic and qualitative studies. At methodological level, the employed approaches generally derive from phenomenology, ethnography and conversation analysis (Heath & Hindmarsh, 2002.; Hindmarsh & Pilnick, 2002) . The epistemological substrate of these approaches coherently fits with the philosophical roots of embodiment.

At a procedural level, the analysis of in situ interaction is generally carried out through video observation and analysis of users' behaviors. These data are generally analyzed according to a grounded approach, understood as inductively deriving codes and categories from data, instead than framing the observations around a system of predefined categories. This methodological choice is generally motivated by the complexity and emergent nature of the behaviors under analysis and by the exploratory goals pursued by several of these studies.

When choosing a grounded approach, different techniques and level of granularity are proposed. Ahmet et al. (2011), Decortis & Rizzo (2002), Hashagen et al. (2009), and Smyrnaiou & Kynigos (2012) focus their analysis on global aspects such as the employed strategies and the performed actions. Instead Chu & Quek (2015), Malinverni et al. (2016), Price et al. (2015) propose a fine-grain analytic approach derived from micro-ethnography and multimodal analysis to track the multiple resources employed in embodied interaction. Specifically, Chu & Quek (2015) design a system to support creative storytelling and propose a method to assess imagination in action (MAIA) based on two analytical levels. First, they describe the micro-actions performed by the users (i.e. gestures, body postures, facial expressions, gaze, pace, etc.). Subsequently, they derive their semantic interpretation by identifying sets of micro-actions (vignettes) that depict a part of the story that the child is trying to tell. Similarly, Price et al. (2015) and Malinverni et al. (2016) use an analytical approach derived from multimodal analysis (Jewitt, 2013; Kress, 2010) to observe in situ interaction. This analysis is carried out through a frame-by-frame visualization of the videographic materials and through the multimodal transcriptions of the multiple resources employed to construct meaning (e.g. child's position, gaze, gesture, speech, etc.). These resources are later combined for the analysis and interpretation.

The definition of the level of granularity depends both on the addressed research questions as well as on the human and temporal resources available to carry out the study. However, it is relevant to notice that, independently from the chosen level of granularity, the proposed units of analysis tend to concentrate on the following aspects: bodily enactments, verbal commentaries, use of the physical/digital environment, focus of attention and collaboration between peers. The selection of these aspects coherently fits with the embodied cognition framework. First, it manages to take into account the embodied, spatial and social nature of experience. Second, it acknowledges the role of salience and selective engagement as the foreground to construct multimodal representations from embodied experience (Barsalou, 2008).

Results proceeding from these studies provide relevant information to widen knowledge available on embodied learning both at a theoretical and at an applied level. For instance, Hashagen et al. (2009) report how children continuous immersion in the FUBILE may hinder the process of constructing abstract knowledge. They, thus, suggest the need for providing moments to allow children to "step-out" and to observe the experience from an external perspective (Ackermann, 2004). Smyrnaiou & Kynigos (2012), instead, focus on the temporal dimension of knowledge construction. They, therefore, show that the longer users play with the FUBILE the more their verbal interactions move from action-centered to concept-centered dialogues. At the same time, the fine-grain analysis performed by Price et al. (2015) allows identifying indicators of constructive learning that are displayed in the relation between actions and verbal explanations. Furthermore, it permits to spot out specific usability issues and derive relevant implications for the design of FUBILEs for public spaces. Finally, Malinverni et al. (2016), by analyzing the different paths that children may employ to construct meaning from an embodied experience, derive design guidelines to facilitate reflection-in-action (Schon, 1983), the social construction of knowledge and focusing "on what matter" of the experience.

To sum up, the analysis of in situ interaction offers affordances that allow: 1) observing how users construct meaning through multiple embodied and material resources, 2) evaluating aspects related to conceptual and procedural knowledge and 3) spotting out eventual usability issues. Furthermore, when combined with the subjective meanings of the experiencer, it allows extending research by incorporating the meaning that users attribute to their actions.

This analytical approach, thus, may result particularly consistent with the claims related to embodiment since it focuses and acknowledges the situated, relational and embodied qualities of meaning construction. At the same time, when combined with methods such as interviews, it allows tapping into a fundamental aspect of embodied cognition: the way in which embodied experience is transformed into forms of explicit knowledge. Both studies on gestures (Goldin-Meadow, 2011) as well as research in developmental psychology (Karmiloff-Smith, 1995) suggest that constructing knowledge from experience is not necessarily a direct and unmediated process. Instead, often, embodied knowledge needs to be transformed before becoming explicit. As a consequence, approaches based on a methodological triangulation can offer relevant insights to support the understanding of how children may bridge between concrete and conceptual knowledge.

3.2.4.4 Children's productions

Two of the analyzed papers propose the use of the drawings produced by the children as a post-task assessment instrument (Chu & Quek, 2015; Lindgren & Moshell, 2013). In particular, Chu & Quek (2015) analyze the drawing produced by the children in terms of the depicted scene and of their consistency with the enactment performed by the child during the interaction. They, thus, integrate this analysis within their proposed methodological triangulation. Lindgren & Moshell (2013) instead analyze drawings in terms of the aspects of the interactive experience that are depicted in the drawings. They, thus, show how children assigned to the desktop condition tended to focus more on irrelevant surface details than children assigned to the FUBILEs condition.

The limited amount of studies employing this assessment method for FUBILEs does not allow deriving strong conclusions about the suitability of this approach in the context of embodied learning. Nonetheless, research in this field showed how drawings and related narratives represent a valid research method to access young children's views and experiences (Clark, 2005; Cox, 2005). We, thus, suggest that this approach may offer relevant contributions to research oriented toward exploring subjective interpretations and meaning construction. As Kress (2010) pointed out "*the inner constitution of a sign reveals the interests of the sign maker*". Thus, the agentive nature of creative activities may be particularly effective for gathering data about children's interpretations since it affords children to project and materialize their own interests and representations in the production of an artifact (Kress, 2010). Furthermore, the multimodal nature of activities such as drawings may allow tapping into representation and concepts that cannot be expressed verbally.

3.2.5 Discussion

As Sale et al. (2002) indicate, methodological choices should be selected according to our specific research goals. Nonetheless, this decision does not only imply to consider what aspects are relevant for the final research objectives. Instead, it also entails the need for carefully scrutinizing the suitability of the specific approaches, their underlying assumptions, their coherence with the adopted theoretical framework and their usefulness to generate knowledge upon which novel basis for action and reflection may be build.

The review of the data gathering instruments employed to research learning in FUBILEs deepens on how different approaches can offer distinctive strengths, limitations and affordances that make them more or less appropriate for this specific research field. In this context, we paid a close attention to critically observe how certain methodological choices may entail specific assumptions on learning and knowledge construction that can be either consistent or in conflict with the intended learning goals and with the theoretical background on which we ground our design and research. This critical analysis, thus, allowed identifying relevant shortcomings and good practices from which it is possible to derive some methodological guidelines.

3.2.5.1 Methodological shortcomings and reflective practices

In some of the analyzed studies, the employed data gathering instruments just offered a limited sensitivity to deepen the understanding of embodied learning and guiding the design process (e.g. multiple-choice questionnaires). The diversity of the employed instruments can enrich the research field by offering different viewpoints to look at learning in FUBILEs. However, as Polkinghorne, (1983) pointed out, the quest for methodological appropriateness "becomes the creative search to understand better" and to use approaches that are responsive to the particular questions and objects of knowledge that we are addressing. This standpoint, thus, requires a careful reflection on the affordances, limits and potential of the instruments that we are employing.

In the context of HCI, several authors criticized the lack of rigor in properly evaluating experiences and the tendency to reduce assessment to a procedure that barely goes beyond the mere formality (Reeves, 2000). Even if, in the last years, an increased attention addressed the need for taking research methods more seriously, in some cases this evaluation effort may run the risk of falling into the trap of a "cargo cult science" (Yarosh et al., 2011). Or, in other words, it may tend to mirror "*the rituals of rigorous work without an understanding of the underlying reasons or assumptions*" (Yarosh et al., 2011). As a consequence, researchers may end up repeating established approaches, in a somehow "automatic pilot mode", without critically analyzing neither neither the specificities of the instruments nor the features of the phenomena that they want to study. Thus, for instance, they may apply instruments and criteria that do not fit with the intended epistemological framework or that do not properly address the defined object of study. This flaw may have a negative impact on the content validity of the employed instruments (i.e. are the employed instruments really measuring what we want to observe?) and on the effectiveness of the research for producing valuable knowledge. To minimize these risks, researchers should therefore carefully scrutinize their own practice critically reflect on the specificities of each methodological choice. In this context, reflective approaches derived from qualitative research methods (Mauthner & Doucet, 2003), critical theory (Harding, 1989) and reflexive design practices (Friedman et al., 2013; Sengers et al., 2005) may constitute valuable tools to guide practitioners.

Alongside with this self-reflection on methodology, research in embodied interaction should also carefully consider the implications entailed by this framework. As Antle (2013) pointed out, this research often arises from a Technology-Driven approach where the underlying theoretical framework is poorly understood. The consequences of this standpoint are visible both in the employed design practices and evaluation procedures, where just the surface features of embodiment are considered (i.e. use the body to interact with technology). This simplified viewpoint on embodiment may act as an epistemological obstacle in the process of understanding technology-mediated embodied learning experiences. We, therefore, suggest that researchers should carefully scrutinize the way in which they define embodied learning experiences and the way in which specific methodological choices may shape this construct.

This reflection should motivate researchers to go beyond the idea that design for embodiment only means to develop "movement based experiences" or that embodied learning corresponds to a sort of "I do, therefore I know" assumption. It, instead, requires a broader paradigm shift capable of considering the relation between embodiment and knowledge construction both at an individual level and at an epistemological level (Harrison et al., 2011). Embracing this shift would not only allow thinking at design from a broader perspective but would also provide critical instruments to reflect on one's own practice. In particular, we suggest that this shift would contribute to critically analyzing the coherence and consistency of the employed research approach, hence contributing to rigorous research practices (Frauenberger, Good, Fitzpatrick, & Iversen, 2014).

3.2.5.2 Implications for the assessment of embodied learning

Alongside with the reported shortcomings, the review also allowed identifying cases where the employed methods offered affordances to deepen the understanding of embodied learning. Since the goal of this review was not to define a correct and univocal method but to contribute to the reflection on methodological appropriateness, we will summarize some of the features of the methodological approaches that showed to be particularly responsive to investigate embodied learning.

In the review, we suggested that the methodological appropriateness for evaluating learning in FUBILEs deeply depends on the coherence of the employed approach with the underlying theoretical framework and with the intended learning goals. In this context, we, thus, highlighted the need for data gathering instruments capable of being sensitive to observe, analyze and interpret how learning is embodied in the situated lived experience. From this definition, we derived two main requirements that should be taken into account to reflect on appropriate evaluation methods for FUBILEs.

On the one hand, we suggested the need of methodological approaches that are responsive to the relational nature of embodiment (Overton, 2004). Or, in other words, capable of acknowledging embodied learning as a process that arises in the relation between the mind, the body and the world. This need requires of instruments that can address the way in which the features of the experience, our senses, our actions and our previous structures of knowledge contribute to construct meaning. In this context, valuable approaches can be found in methodological triangulations that analyze and combine the affordances of the system, the different semiotic resources employed during in situ interaction and the users' interpretations that are displayed through different sources (e.g. verbal, gestures, drawings, etc.). Alongside with this need, research methods for FUBILEs should also be capable of properly tracking the processes of experiential learning (Kolb et al., 2001). This means that they should allow observing the paths through which users get engaged with the experience, experiment with it and transform it into an object of knowledge.

The combination of these requirements suggests the need for research standpoints capable of encompassing both the relational and the temporal dimensions of embodied experience. Further research should, therefore, deepen on the methodological possibilities to address these aspects. At the same time, possible research paths could explore the legitimation of poorly considered (but maybe relevant) sources of knowledge, such as the embodiment of the researcher (e.g. why we claim for embodied knowledge in design but we don't employ it as a source to build scientific understanding?).

To sum up, we, therefore, suggest that, in the quest for methodological appropriateness, researchers should adopt a standpoint capable of questioning their own practice and pursue consistent research approaches. This implies a careful reflection of the way in which they define and deal with embodied experiences. At the same time, it requires a certain degree of commitment toward deepening the understanding of embodied learning, instead of just focusing the research toward evaluating the effectiveness of one's own system. Finally, this quest requires the creative skill of defining "ad hoc" instruments, tailored to fit with the specific features of each experience and research question.

3.2.6 Considerations for this Thesis

In relation to the global goals of the thesis, this review offered a critical analysis of the instruments that are employed to research learning and meaning construction in FUBILEs. Through this standpoint, we managed to spot out relevant tendencies, good practices and shortcomings in the field. Furthermore, the adopted critical viewpoint allowed situating and defining the notion of methodological appropriateness in relation to the addressed research field. In particular, we pointed out relevant criteria to evaluate methodological appropriateness, namely: 1) the responsiveness and sensitivity of the employed instruments to analyze learning as embodied in the situated lived experience; 2) their suitability to grasp how embodied experience may be transformed into an object of knowledge; 3) the coherence between the assumptions of the employed instrument and the theoretical framework of embodiment; 4) the consistency between the employed instruments and the addressed learning goals. These criteria allowed framing the discourse of the thesis and provided lenses for self-reflection on our own practice.

Nonetheless, in order to properly frame this analysis in the overall context of the thesis, it is important to highlight that the reflections reported in this review did not predate chronologically the empirical research reported in Chapter 4, 5, 6 and 7. Instead, they were strongly informed by the experience gained through our "hands-on" methodological exploration.

4 LEARNING FROM EXPERIENCE: METHODOLOGICAL APPROXIMATIONS TO THE DESIGN AND EVALUATION OF FUBILEs.

Writing a thesis that focuses on experiential learning inevitably ends up being a path of self-reflection on one's own practice and learning process. Building on this perspective, in the next chapters, we will describe a series of studies carried out during this thesis and oriented toward exploring appropriate methodological approaches to design and evaluate FUBILEs. The studies will be described according to their chronological order to highlight how the experience and insights gained from each one of them informed the following developments. This structure will make visible the iterative process of methodological approximations through which we improved our way of designing and evaluating FUBILEs.

To start with this path in Section 4.1, we will present two FUBILEs that we developed at the beginning of this thesis. The analysis of their methodological weaknesses will provide a first-person understanding of the shortcomings identified in Chapter 3. Hence, starting from the reflection on this failed experience, in the following chapters will present research oriented toward tackling some of the identified flaws. Specifically, the following aspects will be addressed: 1) the importance of incorporating users' previous knowledge, interests and embodiment in the design process, 2) the need for a broader unit of analysis and more adequate data gathering instruments; 3) the relevance of properly addressing embodiment and experiential learning in the evaluation.

In Chapter 5 we will present a first approximation toward methodologically improving our research by including children in the design of FUBILEs. As outlined in Section 2.3 and in Section 3.1.3, design methods for educational technologies need to be informed by a careful understanding of users' worldview. Nonetheless, potential challenges may lie in combining users participation with complex theoretical frameworks such as embodied learning. To address this issue, in Section 5.1, we will present a study that addresses methodological approaches aimed at integrating and merging the contributions of different stakeholders during the design process. In particular, it will propose a model oriented toward including children with autism and mental health experts in the ideation stage of the design of a FUBILE aimed at supporting social initiation. The second study (Section 5.2), instead, describes the development of a FUBILE aimed at supporting learning of ecosystem relationships. Building on the knowledge gained from the previous research, this study will aim at combining the proposed inclusive model with an iterative design process inspired in Design-Based Research (Barab & Squire, 2004). This approach will offer a first approximation to start to address embodiment in the design process. Furthermore, it will propose an iterative design structure to include children and experts' contributions in different stages of the design process. These studies will contribute to define techniques and models to understand and integrate children's contributions in different stages of the design process of a FUBILE.

Chapter 6 will be dedicated to describing research oriented toward defining methodological approach to better understand embodiment meaning making and integrate this understanding in PD processes. As pointed out in the previous chapters, to properly take advantage of embodiment we need to incorporate its analysis both in the design and in the evaluation processes. To address this issue, two case studies will be presented. The first study (Section 6.1) will describe the employment of a multimodal analytical approach to analyze children's contributions during a PD workshop aimed at designing a FUBILE for and with children with Autism Spectrum Disorder. The second study (Section 6.2) will further elaborate the proposed multimodal analytical approach in order to employ it to guide the iterative design process of a FUBILE aimed at supporting children's reflection of group dynamic. Both studies will, therefore, contribute to investigating methodological approaches to understand the meanings that users create during in situ interaction and integrate them in the definition of design refinements. Finally, in Chapter 7, we will go back to the first FUBILEs that we developed (see Section 4.1) and employ the lessons learned during this research process to deepen in its evaluation and research on indicators of learning displayed during in situ interaction.

This overall path will allow constructing knowledge on methodological approaches for FUBILEs. Furthermore, this research will also explore relevant design qualities to support embodied learning. Hence, the knowledge gained through this path – combined with the knowledge derived from the theoretical analysis (Chapter 2 and 3) – will be summarized in Chapter 8.

4.1 Learning from failures in designing and evaluating FUBILEs: two case studies

4.1.1 Research Context

In this study, we present the design and evaluation of two multiusers FUBILEs that were developed at the beginning of this thesis. The two FUBILEs, Archimedes (Malinverni et al., 2012) and PhyGame, were designed for the same platform, the Interactive Slide, a large inflatable slide augmented with interactive technology (Soler-adillon et al., 2009). Both games were targeted to the same child population (11-12 years old) and addressed physics-related contents. Specifically, Archimedes addressed learning goals related to buoyancy and Archimedes' principle. PhyGame, instead, focused on the physics of motion and Newton's Laws.

Their design derived from a Theory-Oriented approach aimed at exploring user actions and sensorimotor experiences as mediators in the learning experience. Within that, we focused on physics, based on our hypothesis that bodily experience of forces and gravity could help in grounding the understanding of these concepts. In the design and evaluation process, users were involved only in the last stage as testers. For both games, the evaluation focused on assessing the impact of Full-Body interaction on learning gains. For this purpose, assessment was based on the standard procedure of comparing learning outcomes between a Full-Body interaction interface (the Interactive Slide) and a traditional interface (a desktop computer) through the use of pre- and post-test multiple-choice questionnaires.

In the next sections, we will present their design strategies, evaluation and results. This structure will allow setting the basis for structuring a critical reflection on our methodological pitfalls and on the weaknesses of the proposed approach. Grounding on this analysis, we will discuss the gaps in the reported studies, in order to delineate possible design guidelines and paths for future research. Furthermore, we will stress out how the lessons learned from this failed experience allowed informing our research and framing its main goals.

Figure 6. Archimedes

4.1.2 Archimedes

The first game, "Archimedes" (Figure 6), focused on supporting the learning of buoyancy and Archimedes principles in 11 years old children. Its design strategy was based on using the physical affordances and sensorimotor experience suggested by Interactive Slide to contextualize the educational content. By considering that the most significant experience with the Slide is related with "sliding down", we concentrated our interest around phenomena linked with gravity. Buoyancy was therefore chosen as the main learning goal.

After proceeding with the operationalization of learning goals we developed a simple problem-solving game. To solve the game children have to help a fish and a cat to reach their goals. For the fish, by raising the level of one water ponds, and, for the cat, by building a bridge over a second pond. For this purpose, a set of virtual objects are available: balls, rocks and wood logs. The virtual objects scroll in the upper part of the scenario according to a random order. Children have to select objects with adequate properties and throw them into one of the two ponds of water of the virtual environment. They can do this by either sliding over the object in the Interactive Slide or by double-clicking over it in the desktop computer interface. The design of the gameplay implies that children had to understand the physical behavior of the objects within the context of Archimedes' principle and make a strategic use of them in order to successfully solve the game's challenge.

4.1.2.1 Archimedes: Evaluation

The game was tested with a population of 331 children (mean age: 11 years old ±1). Participants were recruited from 5th and 6th grade of primary schools proceeding from different neighborhoods of the city. When we contacted the schools we ensured that children did not have any formal prior knowledge on the topic.

During the experiment, participants were randomly assigned to the Interactive Slide condition or to the Desktop computer condition. The administration of pre- and post-test questionnaires was used to assess learning gains. Questionnaires, based on multiple-choice questions, were developed through the consultation of curricular evaluation material for primary and secondary schools. Tests were administered in a dedicated room and supervised by a researcher and a teacher. Pre-tests were administered 40 minutes before the experience, while post-test were administered 10 minutes after children finished the game. In both cases, children were allowed to play until they reached the end of the game to avoid abrupt interruptions.

4.1.2.2 Archimedes: Results

Since data were not normally distributed, we used a Wilcoxon Signed test to compare pre- and post-test scores for Slide and Computer conditions. Results showed a statistically significant difference between pre-test and post-test for the Slide Condition (Z = -1, 983; p = 0,047) with an improvement in post-test scores (positive rank = 40,09; negative rank = 37,30). Instead in the computer condition, no significant difference was found between pre- and post-test. However a modest improvement was also reported (Z= -1,621, sig = 0,105; positive rank = 37,79; negative rank = 31,37). Even if significant learning gains were reported only in the Slide condition, Mann-Whitney U test showed no significance in the comparison of post-test scores between the two conditions (Z = -1,056, p = 0,291). For a summary of the results see Table 6.

Table 6. Summary of results of Archimedes

	Int. Slide (pre-post) (Wilcoxon Signed test)	**Computer (pre-post)** (Wilcoxon Signed test)	**Int. Slide-Computer comparison (Mann-Whitney U test)**
Archimedes	**p= 0,047 (post)** Z = -1, 983	p= 0,105 (post) Z= -1,621	p= 0,291(IS) Z = -1,056

4.1.2.3 From shortcomings to requirements

Results from Archimedes' evaluation suggested the possibility that the Interactive Slide could be more effective than the desktop computer in facilitating the learning of physics-related concepts. However, the lack of significant differences between the two interfaces motivated further exploration on how Full-Body interaction can be designed for learning processes. Starting from the analysis of Archimedes' shortcomings, we defined novel requirements for the design of the second game, Phygame. Specifically, the following issues were considered:

<u>a) The weakness of mapping between learning goals and user's physical activity.</u>

A possible explanation of the results of Archimedes was that the specific affordances of the embodied experience were only partially suitable to support the learning goals. This consideration implies that maybe the defined content (Archimedes' principle) was not particularly adequate to be communicated through the physical interaction provided by the Interactive Slide. The main shortcomings could have been related to the weakness of the mapping between user's actions and content and with the lack of an appropriate kinesthetic feedback (e.g. buoyancy). A possible path to explore this hypothesis was formalized in the following requirements:

a) The necessity of identifying a topic that better fits with the specificities of the embodied experience that users can have on the Interactive Slide.

b) The necessity of designing sensorimotor experiences capable of offering a stronger consistency between the addressed learning goals and the actions performed by the users. This requirement was supported by the embodied cognition framework, which suggests that a tight mapping between physical actions and abstract concepts could be useful to support learning (Kontra et al. 2012). At a design level, this requirement was formalized in two main design decisions:

- The design of a tight mapping between learning goals, user actions and kinesthetic feedback: *body mapping*.

- The definition of a wider range of possible actions in order to make the users have a strategic use of their body by choosing the most appropriate action according to certain goals: *body strategy*.

<u>b) Evaluating the Assessment Instrument</u>

Another issue that raised from the results of Archimedes was related to the effectiveness of the employed assessment instruments. During the administration of the questionnaires, we faced some issues related to the willingness of children to complete the post-test. Specifically, the researcher who administered the tests reported several complaints from children about having to do the test "again". This discontent may have biased the results by reducing children's attention and motivation in the task. Other issues were raised around the possible impact that pre-test administration could have in making children "test-wise".

To address this issue, we decided to include a meta-assessment instrument in the evaluation of the second game, PhyGame. For this purpose, a cluster of questions unrelated to the learning goals was inserted both in the pre-test and post-test questionnaires. The purpose of those questions (*meta-assessment instrument*) was to evaluate children's commitment to completing the post-test. Our hypothesis was that an improvement in those unrelated questions could indicate a "test-wise" bias, whereas a downgrade could indicate a bias related to a decrease in attention when fulfilling the test.

4.1.3 PhyGame

From the previously defined requirements, PhyGame (Figure 7) was developed with the main objective of providing a coherent mapping between performed action, learning goals and kinesthetic feedback. To define the mapping strategy we analyzed the possible actions that can be performed on the Interactive Slide (Landry et al., 2013) and we defined a content that could coherently accommodate them. Through this analysis, we decided to work on the physics of motion and chose Newton's laws of motion as the main learning goals.

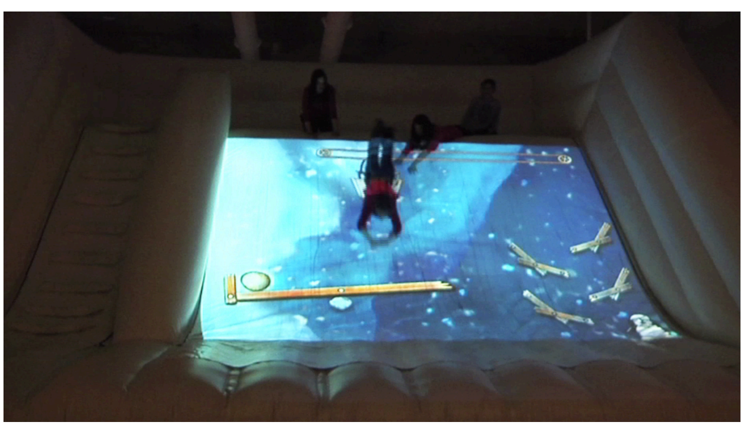


Figure 7. Phygame

Subsequently, from the set of available actions described in (Landry et al., 2013) we selected the ones that may offer a greater consistency with the defined learning goals. After that, we focused toward strengthening the relation between actions and learning goals by generating specific game mechanics. For a detailed description of this mapping see Table 7. Finally, the defined physical actions and game mechanics were integrated into a game based on a puzzle-like problem. Children have to guide a penguin's egg through a set of difficulties until it reaches its parents. To do so, children have to build a path for the egg by activating, pushing or stopping elements (e.g. pulleys, levers or inclined planes). Children must achieve this by using their own bodies on the Interactive Slide, or by manipulating virtual avatars in the desktop computer, depending on the experimental condition they were assigned to.

Table 7. Mapping between learning goals, actions, kinesthetic experiences and game mechanics in the PhyGame.

LEARNING GOALS	PHYSICAL ACTIONS	KINESTHETIC EXPERIENCES	GAME MECHANICS
- An object at rest stays at rest until an outside force affects it.	- Generate a force to put an object in motion	- Experience how forces change your state of motion	- Put an object in motion
- An object in motion stays in motion until an outside force affects it.	- Generate a force that stops an object - Try to stop your motion	- Experience the effort in trying to stop and the tendency to continue being in motion	- Make an object stop - Stop your own motion
- The greater a force exerted on an object, the more it accelerates.	- Coordinate between two children to slide down	- Experience the effect of different forces	- Depending on the acceleration required by the egg, one or more children have to slide down
- The greater the mass of an object, the more it resists acceleration.	- Use different forces to move objects with different masses.	- Experience the need of greater effort to move objects with greater mass	- Move objects with different masses

4.1.3.1 PhyGame: Evaluation

The game was tested with a population of 209 children. Participants were recruited from 6th grade of primary schools (mean age = 11 years old) from different neighborhoods of the city. When we contacted the schools we ensured that children did not have any prior formal knowledge of Newton's Laws of motion.

The procedure of the experiment was similar to the previous study. Children were assigned to two conditions (the Interactive Slide condition and the Desktop computer condition) and pre- and post-test multiple-choice questionnaires were used to assess learning gains. As in the previous experiment, the tests were administered in a dedicated space and the same time interval was used between pre-test, game and post-test. Questionnaires were developed following curricular material for schools and structured into three main clusters:

- Conceptual knowledge: to assess the learning goals stated in Table 1.
- Procedural knowledge: to assess the transfer of knowledge in other contexts.
- Meta-assessment instrument: unrelated questions to evaluate the reliability of the assessment procedure.

Additionally, to reduce children's complaints about having to do the same test twice, we introduced some changes in the formulation and order of the questions of the post-test.

4.1.3.2 PhyGame: Results

Since data were not normally distributed we employed a Mann-Whitney U test to compare posttest between the Interactive Slide and Desktop Computer conditions. Results showed an overall significant difference in all question clusters (including the meta-assessment instrument) between the two conditions, in favor of the Interactive Slide condition.

Subsequently, we employed a Wilcoxon Signed to compare pre-and post-test scores for the different clusters for each condition. A significant difference between pre- and post-test scores was present only in the cluster of conceptual knowledge questions for the Interactive Slide condition ($p = 0{,}036$, $Z = -2{,}098$), while no significant learning gain was reported in procedural knowledge in any condition, with actually a downgrading for the Desktop Computer condition (for a summary see Table 8).

Interestingly, results from the meta-assessment instrument showed a significant downgrading in both conditions. This decrease may confirm the hypothesis of bias due to the effect of administration of pre- and post-test on children's attitude in filling out the questionnaires. Furthermore, the difference in the downgrading between the Interactive Slide and the Desktop

Computer points out relevant issues related to the content validity of the questionnaires.

Table 8. Summary of Results of PhyGame

Question Cluster	**Int. Slide (pre-post)** (Wilcoxon Signed test)	**Computer (pre-post)** (Wilcoxon Signed test)	**Int. Slide-Computer comparison (Mann-Whitney U test)**
Conceptual knowledge	**p = 0,036 (post)** Z= -2,098	p = 0,334 (post) Z= -,967	**p = 0,001 (IS)** Z = -3,215
Procedural knowledge	p= 0,473 (post) Z= -,718	p = 0,004 (pre) Z = -2,847	**p= 0,001 (IS)** Z= -3,996
Baseline	**p= 0,001 (pre)** Z = -3,576	**p= 0,001 (pre)** Z = -3,919	**p= 0,007 (IS)** Z = -2,688

4.1.4 Discussion

In both Archimedes and PhyGame, we focused on the learning of physics-related concepts, starting from the assumptions of embodied cognition theory; e.g. the understanding of concepts of dynamic forces can be grounded in the physical enactment of them. In both cases, our instructional method was a game-based simulation of the defined physics' properties.

The results showed that Archimedes favored a significant learning gain in the Slide condition. However, no significant difference was found between playing on the Interactive Slide with respect to using the application on the Desktop computer. On the other hand, PhyGame produced an overall significant difference between the two conditions. Nonetheless, learning gains were present only in the Interactive Slide condition and were restricted to only one cluster of questions. The differences in these results should open a reflection on the differences in their design strategies and especially on the relation existing between game design, interaction design and learning goals. Furthermore, additional reflections should be oriented toward critically examining the methodological issues related to the employed assessment instruments.

4.1.4.1 Game design, learning goals and children's knowledge

Archimedes was designed by first defining buoyancy as the main learning goal, and then by designing a game based on existing curriculum material to address this content. The game was designed to create conditions for which children need to grasp some concepts related to buoyancy in order to solve it. However, limited research was oriented toward designing the users' actions. This approach implies that our design strategy was mainly game-oriented and less attention was posed in the design of the physical interaction. Conversely, in Phygame, the design mainly focused on improving the Full-Body interaction experience and designing adequate users' actions (*body mapping, body strategy*). However, in the effort of properly mapping learning goals, physical actions and kinesthetic feedback, we lacked the awareness and the reflexivity necessary to design an effective game.

In other words, the two different strategies, one game-oriented (Archimedes) and the other interaction-oriented (Phygame) produced different results. The game proposed in Archimedes showed to be educationally effective independently on the interface. Instead, Phygame did not achieve these standards but managed to produce a difference related with the interaction modality. These outcomes suggest that the interaction design adopted in Phygame could be partially effective to support constructing meaning from sensorimotor experience. However, specific weaknesses in game design undermined its educational effectiveness.

In Archimedes, it was necessary to understand the learning concepts to figure out an effective strategy to solve the game. Instead, if we critically examine PhyGame, we can see that being able of solving the game does not necessarily implies the understanding of the learning goals (i.e. the behavior of the game can be explained even when relying on a naive physics conception). This shortcoming failed in making children question their own misconceptions, since the experience can be easily assimilated into their already existing structures of meanings. Hence, this design failure may weaken the educational usefulness of the game. This drawback points out the need of deepening the knowledge about children's previous knowledge and misconceptions while designing and developing educational technologies.

To tackle this issue, a possible strategy should address the inclusion of children's contributions in an earlier stage of the design process. This approach can allow informing the designer about children mental models, representations, misconceptions and previous knowledge. Consequently, it can guide the design of an experience that can fit with children's structure of knowledge. Despite inclusive methods, such as Participatory Design (PD), gained considerable importance in HCI during the last years (Druin, 2002b) however, up to our knowledge, only Grønbæk et al. (2007) employed PD in the design of a FUBILEs for children. Possible reasons behind this research gap may derive from the challenge of combing children's contributions with the complexity of the theoretical background and design constraints. Relevant research possibilities can address the effort of defining appropriate methods to integrate Participatory Design and Full Body Interaction in order to define techniques to design for and with the body.

4.1.4.2 Interaction design, mapping and learning

From the perspective of interaction design, PhyGame partially compensated its poor game design in the Interactive Slide condition. The use of meaningful bodily activity can offer a possible explanation. As the results suggested, PhyGame may have supported conditions for which the use of Full-Body interaction generated a significant difference in terms of learning. This result is particularly evident in the questions related to conceptual knowledge, which were those aspects that served as building blocks for the design of the interaction (see Table 7). These results are only preliminary and their validity may be undermined by the biases produced by the employed assessment instrument. However, an analysis of the different mapping strategies used in Phygame and Archimedes can provide initial guidelines for future works.

Within the context of interactive environments, actions can be interpreted at least on two levels:

(1) the *simulated action*, which is the action signified through changes in the game (Meneghelli, 2009), and

(2) the *performed action*, which is the action that is physically enacted by the user.

The mapping between these two levels has been widely analyzed in HCI. However, generally, studies focus on enhancing usability and facilitating understanding of the interface (Norman, 1988).Nonetheless, in the context of FUBILEs, it is necessary to go beyond usability and conceive mapping as a holistic strategy. This means that the interface should not only correspond to the mental models of the user on how to use it but also that the interaction should evoke the ideas that the experience wants to communicate. This means that, when we deal with the understanding of abstract concepts such as in the case of Archimedes and Phygame, users interaction should be able to provide conditions for evoking the content.

In Archimedes, the learning content was mainly embedded in the *simulated action*. For example, throwing a virtual rock in the water pond makes the water level rising more than throwing a beach ball. Even if the different effects of user's actions were clearly visible in the simulation, at a practical level no differentiation was present in the user's performed actions. Instead, PhyGame focused on embedding the content into the *performed action*. For example, two children have to slide together over one end of a catapult in order to exert sufficient force to send the egg high enough to enter a hanging bucket. This mapping strategy, based on creating tight analogies between the learning goals and the bodily activity may have been partially effective in fostering embodied learning. Thus, the use of analogy and consistency between experience and content may represent a partial design contribution to the research related with FUBILEs. However, when considering design strategies aimed at communicating a specific content, further reflections should address the potential for expressing meaning of the employed resources and the role of users' interpretations.

4.1.4.3 Defining learning goals: semiotic resources and interpretation

In all cultural products, meaning is constructed twice: once in their creation and once in their usage. As pointed out in Section 2.3, the two-sided nature of meaning construction requires paying a close attention to two main aspects. On the one hand, we should carefully scrutinize the relation between what we want to communicate and the resources available. On the other hand, we should properly understand the way in which the users interpret our communicative effort.

As suggested in Section 3.1.3, in the context of FUBILEs, the former requirements implies a careful analysis of the features of the resources available (i.e. physicality, spatial configuration, digital outputs, etc.) and of what it is possible to express and communicate easily with them. In our case, we choose to employ Full-Body interaction to express concepts related to very specific concepts (e.g. Archimedes' principle and Newton's Law of motion). This idea was grounded on the theoretically informed hypothesis of building a close analogy between embodied experience and content (Kontra et al., 2012). Nonetheless, we poorly took into account the specificities of spatiality and physicality as resources to express meaning. Physicality and spatiality express meaning in a way that is fundamentally different from language. While in the linguistic context there are a series of culturally shared codes that define meaning relations, physicality and spatiality are intrinsically *polysemic*. That means that more than one meaning can be associated with the same action or spatial configuration (Beattie, 2013). These resources, therefore, tend to be particularly ambiguous, i.e. producing multiple possible interpretations. It is, therefore, necessary to ask ourselves some questions about the consistency of the learning goals that we had defined. Even if, for instance in the Phygame case, the learning goals coherently bond with sensorimotor experience, up to which point is it effective to try to communicate a univocal concept (Newton's Laws of motion) through a polysemic resource? And, consequently, which are the meanings that can best fit this kind of experiences?

Dealing with these questions can be crucial for the proper development of FUBILEs since they can provide guidelines for understanding what concepts, contents and experiences can be particularly suitable to be addressed through this specific medium. Complementarily, in the process of defining learning content, researchers should pay a careful attention to how users construct meaning out of embodied experience. In both studies, we focused our design strategy toward defining a set of actions to which we attributed a pre-given meaning, without properly considering how users could have interpreted them. According to semiotics, communication occurs only when there is interpretation (Eco, 1975). This idea, applied to the educational context, is consistent with the constructive approach according to which knowledge construction cannot be considered as a mere transmission of knowledge but represents an active process in which the learner manage available resources to create new knowledge. It implies that, in order to validate our designs, it should be advisable to consider them in relation with the interpretations made by the users. Relevant research possibilities can be found in the analysis of the relation between embodied experience and elicited mental models. This implies a careful evaluation of how the users construct meaning during the interaction with the system and how they subsequently interpret it.

4.1.4.4 Game structure, physical activity and learning process

A common shortcoming of both Archimedes and PhyGame may lie in the design of the relation between the game structure and the physical activity. Both games were highly immersive and required children to maintain a constant attention on the events occurring on the projected surface. At the same time, both games fostered fast paced physical actions, which probably did not allow sufficient time for reflection and strategy formation. This drawback should make us reflect on the necessity of aligning the game structure, the learning process and the physical activity to facilitate different phases of knowledge construction.

As pointed out in Section 2.3 knowledge construction derives from the dynamic processes that occur between concrete experience, reflection-in-action and reflection-on-action. This perspective shows the necessity of designing learning environments capable of supporting the learner going through different phases of knowledge construction. Relevant possibilities can address the design of the game pace in order to balance the physical workload with the cognitive load (Kiili & Perttula, 2012) and modulate the level of immersion for providing conditions for engagement, reflection and strategy formation.

4.1.4.5 Research methods and assessment instruments

The evaluation used in the presented studies was focused on two main objectives: (1) the assessment of the learning gains of children, and (2) the comparison between a Full-Body interface and a desktop computer interface. The experimental procedure was based on a between subjects comparison with assessment through pre- and post multiple-choice questionnaires. We choose to use this approach mainly because its widespread employment in the evaluation of FUBILEs (Malinverni & Pares, 2014). However, by assuming a critical perspective on our experience, in our case, this method offered some important limitations in terms of providing information to move research forward. The main shortcomings were related to the poor reliability of the employed assessment instrument, its lack of sensitivity to properly grasp phenomena related to embodiment and its inadequacy to inform future design iterations.

4.1.4.5.1 Reliability issues

The results from the evaluation of PhyGame require reflecting on the effects produced by the administration of pre- and post-test questionnaires. In PhyGame, a cluster of unrelated questions (meta-assessment instrument) was used to evaluate the reliability of the procedure. The significant downgrading for both conditions in these questions can indicate a possible bias related to children's attention when filling out the questionnaires. These considerations should open questions about how much pre- and post-test questionnaires are effective instruments to assess learning gains and how much their reliability is affected by children's attitude toward them. This issue mainly addresses the content validity of the proposed instruments. In other words, a careful reflection should address whether with pre and posttest questionnaires we were actually assessing learning gains or we ended up evaluating children's willingness to answer the questions. Often, instruments such as multiple-choice questionnaires are suggested for its suitability to offer quantitative data upon which statistical inferences can be easily made. However, as our study suggests, their reliability cannot be taken for granted but should be carefully scrutinized.

4.1.4.5.2 Sensitivity issues

As mentioned in Section 2.3, embodied learning processes ground themselves in salient concrete experiences, which are transformed according to the pre-existing structures of meaning and worldviews of the learner. This process indicates that, in order to properly understand this phenomenon, we need of methodological approaches capable of encompassing both the way in which meaning is constructed during in situ experiences as well as the process through which the salient features of these experiences are interpreted.

These needs stand in a strong contrast with the affordances offered by multiple-choice questionnaires. On the one hand, these instruments have been widely criticized due to its lack of sensitivity to grasp the reasoning processes behind the answers (Reeves & Okey, 1996). As a consequence, they offer inadequate affordances to take into account interpretive processes. On the other hand, their strictly retrospective nature, which focuses only on cognitive skills, automatically excluded from the analysis all the aspects related to constructing meaning during in situ interaction.

Despite more than 20 years ago Kozma already pointed out the limits of applying only retrospective approaches to evaluate media effects on learning (Kozma, 1994), still nowadays most research in this field tends to be shaped around this paradigm (see Section 3.2). This gap is particularly relevant in Full Body Interaction due its specific features. Full-Body interaction relies on physicality and spatiality, hence appropriate research approaches should include these aspects in the research and consider them in relation to the learning processes. It is, therefore, necessary to define adequate research methods capable of going beyond the current limitations and providing a deeper understanding of how meaning and learning are constructed in these environments.

4.1.4.5.3 Issues in informing future design iterations

The contrasting results obtained from the two studies offered weak contributions for guide eventual design iterations and improvements. Even if we extrapolated some potential design suggestions, these insights were many based on a theoretical perspective informed by related literature. This weakness was provoked by the fact that the employed instruments did not allow observing empirical data upon which design's improvements can be justified.

This issue is particularly challenging in the context of FUBILEs. These environments are characterized by a plethora of stimuli and variables (e.g. game design, embodied experiences, interaction design, spatial configuration, digital feedback, etc.). Therefore, trying to extrapolate which aspects may have been effective and which are not, ends up being an activity that is not so far from a speculative guessing game.

As a consequence, as pointed out in Section 2.3, employing instruments that are sensitive enough to offer a better understanding of the phenomenon can also contribute informing design refinements. This perspective would allow considering design and evaluation as components of a feedback loop system, in which the learning environment is continually modified based on participant interactions, learning outcomes and assessment findings (Robinson et al., 2001). Such perspective shares some commonalities with Participatory Design approaches and Design-Based Research. It, therefore, suggests defining methods oriented at evaluating users' interpretations in different stages of the design process and consequently adopting research approaches capable of dealing with the multimodal nature of these environments.

4.1.5 Learning from Failures in Designing and Evaluating FUBILEs: Lessons Learned

The presented case studies and the post-mortem reflection the adopted methodological approach allowed delineating relevant considerations to structure guidelines for future research. To summarize these insights, we will structure them accordingly to the main research questions of the thesis.

4.1.5.1 Design Methods

From the perspective of guiding research on design methods, this critical analysis pointed out several issues to be considered in future research. First, it showed the need for investigating children's previous knowledge, representations and misconceptions in order to properly inform the design of the content. Second, it requires researching on how users construct meaning during and through in situ interaction in order to properly understand the role of their embodiment and of the system's affordances in shaping their understandings. Third, the current study suggests the need of more deeply investigating the communicative potential of FUBILEs in order to spot out what contents and experiences can be particularly suitable to be addressed through this medium. This means to understand it meaning potentials, or, in other words, what can be expressed through Full-Body interaction. Fourth, the ambiguous findings obtained in this research suggest the possible benefits of iterative design approaches aimed at considering design and evaluation as complementary aspects of a feedback loop system. To sum up, from a design method perspective, the current research suggests adopting methodological approach akin to PD and Design-Based Research and evaluate their feasibility for Full-Body interaction.

4.1.5.2 Evaluation Methods

The strong methodological weaknesses of the employed data gathering instruments require researching on appropriate research approaches in order to better understand embodied learning and guiding the design process. This requirement implies to focus on a broader unit of analysis and adopting instruments capable of adequately taking into account the interpretative and embodied aspects, instead of focusing only on the assessment of post-task cognitive outcomes. For this purpose, relevant contributions can be found in ethnographic approaches and in multimodal interaction analysis (Jewitt, 2013). Finally, from a broad perspective, the employed methodological approach highlighted the limits of considering empirical research only as an instrument to demonstrated theory instead of legitimating it as another source to produce knowledge. To sum up, the presented case studies offered a first-person perspective to the understanding of the limits identified in Section 3.2. They, therefore, suggest that our future research should embrace a radical epistemological shift in order to consider embodiment not just as a design concept but also as a methodological standpoint.

4.1.5.3 Design Qualities

This research allowed us to identify some initial considerations to inform the definition of design qualities that may support learning in FUBILEs. First, the evaluation of Phygame, suggested the potential benefits of designing a consistent relation between the embodied experience and the meanings that we want to express. These findings partially confirmed related research in cognitive science (Kontra et al., 2012) and suggest *embodied consistency* as a useful resource in the design of FUBILEs. Nonetheless, when addressing the *embodied consistency* of the proposed interaction, we should not fall into the naïve trap of considering that “the action X means Y”. Instead, the polysemic nature of the employed resources should be carefully considered. On the other hand, possible shortcomings have been identified in the pace and intensity of the physical activity proposed by the two games. Hence, further design considerations should address the research on conditions to support users to go through different stages of learning process (e.g. immersion, reflection, etc.).

To sum up, even if these case studies presented a wide number of methodological weaknesses, the lessons learned through these experiences allowed us to frame future design directions by providing a critical lens for reflecting on our own practice. Additionally, by stressing pitfalls and reflecting on our previous experience, we pointed out how "opening the source code" of one's own failures can constitute a relevant practice in the research community, allowing the reflection on aspects that are often under-represented.

Chapter 5

5 UNDERSTANDING AND INTEGRATING CHILDREN'S PREVIOUS KNOWLEDGE, INTERESTS AND MOTIVIATIONS IN THE DESIGN OF FUBILES: TWO CASE STUDIES

As discussed in Chapter 2, the design of Interactive Learning Environments can be considered as a communicational effort to express certain concepts or facilitate certain experiences. Thus, on the one hand, the designers define the features and qualities that may signal certain concepts or forms of usage (Norman, 1988). On the other hand, the users create their meanings by merging their own experiences with the affordances offered by the object (Jewitt, 2013). As a consequence, the relationship between the affordances of the environment and people's interpretations constitutes the foreground of the success or failure of our communicational attempt (Eco, 1975) and, hence, of the learning experiences. However, as showed in Section 3.1, the design of FUBILEs has been shaped under a Designer-Driven approach focused only on the task of defining the design qualities and features. Hence, design rationales have often neglected the role of people's interpretations or relegated them to the last stage of the design process (Reeves et al., 2005).

Although this tendency has been widely criticized by inclusive and iterative approaches such as Design-Based Research (Barab & Squire, 2004) or Participatory Design (Iversen & Dindler, 2013), it still persists as a widespread practice. In particular, as highlighted in Section 3.1, research approaches such as Design-Based Research and Participatory Design have been primarily integrated in desktop computer applications (Wang & Hannafin, 2005), but are still underestimated in research related to the design of educational technologies based on novel interaction modalities.

This situation may be particularly risky. On the one hand, novel interaction modalities propose different ways of interacting with technology (e.g. embodied interaction) and offer affordances and experiences that are essentially different from traditional interfaces (e.g. desktop computers). As a consequence, users may build meanings using resources that are fundamentally different from the ones offered by traditional interfaces (e.g. physicality, space, material artifacts, etc.). On the other hand, traditional interfaces can easily rely on the legacy of established codes and conventions. Instead, experiences based on embodied interaction need to ground their communicational attempts on resources that are intrinsically polysemic (e.g. physicality) and that are not established as conventional codes.

As previously suggested, these differences with respect to traditional interfaces require designers to frame their communicational attempts in the intersection between the available resources and the analysis of how users engage with these experiences, how they make sense of them and how they build meaning out of them. As mentioned in Section 2.3, this need requires to take into account users' interests, previous knowledge, values, cultural references, etc. in order to design experiences that are worth their attention and that are familiar enough to support the construction of novel knowledge. At the same time, we pointed out that this analytical approach could be particularly fruitful in iterative design processes that allow designers to carefully observe not only how users cognitively engage with the experience but also how they physically approach it. In other words, designers should pay a close attention to what users consider relevant to be physically explored and to how their engagement is displayed through multiple embodied resources. Starting from this viewpoint, we, thus, suggest that designers should assume a "listener/observer" role to get closer to users and to understand their embodied interaction.

In order to explore this idea, in this Chapter, we will describe our initial research efforts toward exploring methods and strategies to promote a more direct involvement of children in the design process. Following the tradition of Participatory Design, we explored possible methodological approaches to understand children's interests, previous knowledge and embodied engagement and use them to guide design.

In the next sections, we will present two case studies where we employed different Participatory Design techniques to ground design on children's universes of meaning. The first study is contextualized within a research project aimed at developing a Full-Body interaction game for children with Autism Spectrum Disorder (ASD). In this context, the presented study aimed at combining children's interests with specific learning goals set by experts in the design of an overall playful experience. The second study (Section 5.2) addresses the iterative development of FUBILE oriented at supporting learning of Ecosystem relations in neurotypical primary school children. Its research goals especially tackle the effort of understanding and employing children's contributions to guide design.

In order to illustrate these two case studies, the report will be organized as follow. First, we will present the specific context of each research and identified methodological issues. Subsequently, we will report the employed methodological approach and its outcomes. Finally, we will discuss the strengths and weaknesses of the proposed approaches in order to delineate relevant contributions.

5.1 An inclusive design approach for developing video games for children with Autism Spectrum Disorder

This Section is based on the following articles:

- Malinverni, L., Mora-Guiard, J., Padillo, V., Valero, L., Hervás, A., & Pares, N. (2016, in press). An inclusive design approach for developing video games for children with Autism Spectrum Disorder. *Computers in Human Behavior*. http://www.sciencedirect.com/science/article/pii/S0747563216300188

- Malinverni, L., Mora, J., Padillo, V., Mairena, M. A., Hervas, A., & Pares, N. (2014). Participatory Design Strategies to Enhance the Creative Contribution of Children with Special Needs. In *IDC '14 Proceedings of the 2014 conference on Interaction design and children* (pp. 85–94). New York, NY, USA: ACM. http://dl.acm.org/citation.cfm?id=2593981 -

- Malinverni, L., Mora-Guiard, J., Padillo, V., Hervas, A., & Pares, N. (2014). Pico's Adventure: A Kinect Game to Promote Social Initiation in Children with Autism Spectrum Disorder. In *ITASD 2nd International Conference on Innovative Technologies for Autism, Paris, France*.

- Mora, J., Malinverni, L., & Pares, N. (2014). Narrative-Based Elicitation: Orchestrating Contributions from Experts and Children. In *CHI '14 Extended Abstracts: ACM SIGCHI Conference on Human Factors in Computing Systems*. http://dl.acm.org/citation.cfm?id=2581292

This research is situated in the context of the development of a FUBILE for ASD children.

Specifically, the project arose in the context of the European Project M4all, which aimed at developing a set of playful learning experiences based on the use of the Kinect device for children with cognitive and/or motor disabilities. Within this framework, we developed a Full-Body interaction videogame, called "Pico's Adventure" aimed at promoting social initiation skills. The game was developed through a close collaboration with the experts of the "Specialized Unit on Developmental Disorders" (UETD) of Hospital Sant Joan de Déu2 (HSJD) and with a group of ASD children. To guide its design process we defined an inclusive design approach to develop therapeutic games. The method presents strategies to integrate the expertise of clinicians, contributions of children and experience of designers through a set of elicitation and merging techniques. The goal of this method is to design games that are effective in terms of therapeutic objectives and that are enjoyable for children. In the next sections, we will firstly contextualize the design rationale behind the research. Subsequently, we will formalize the inclusive model that we propose and describe how we applied the model to the design of a fully developed videogame. Finally, initial outcomes and results will be discussed and its methodological contributions will be analyzed.

5.1.1 The Research Framework

Autism Spectrum Disorders are neurodevelopmental disorders characterized by impairments in verbal and non-verbal social communication and by restrictive interests and sensory abnormalities (according to the Diagnostic and Statistical Manual of Mental Disorders, DSM-5, by the American Psychiatric Association, 2013). In this context, social communication impairment has been considered as one of the most important difficulties to support a good quality of life (Roeyers, 1995) and improved social functioning is considered one of the most important intervention outcomes (Rogers, 2000).

For this purpose, a wide range of treatments have been designed, evaluated and published in autism literature. Traditional approaches are related to cognitive-behavioral therapies, social stories, programs for learning social skills, play based interventions and relation development interventions (Fuentes-biggi et al., 2006). However, the effectiveness of the treatments is mainly associated with

[2] HSJD is a renowned hospital specialized on child care that combines clinical activity and research.

their continuity and intensity in terms of weekly hours (Boyd et al., 2014). Requirements related to the intensive nature of treatments led mental health professionals to explore the use of digital games and gamified therapeutic interventions to complement traditional treatment methods (Goh, Ang, & Tan, 2008). Within this context a wide variety of game-based approaches have been developed. Examples of these can be found in projects such as: "A SUNNY DAY: Ann and Ron's World" (Yan, 2011), "TeachTown: Basics" (Whalen et al.,, 2010) "LIFEisGAME" (Abirached et al., 2011), "Invasion of the Wrong Planet" (Marwecki, Rädle, & Reiterer, 2013), "Collaborative Puzzle Game" (Ben-Sasson, Lamash, & Gal, 2013) and "SIDES" (Piper, Brien, Morris, & Winograd, 2006).

Game-based approaches are thus grounded on the interest that children show in digital games and the capacity of games to foster motivation and engagement (Prensky, 2003), and produce behavioral changes (Deterding & Dixon, 2011). Moreover, game-based interventions with children within the Autistic Spectrum Disorder have been proven to accelerate learning processes (Charlton, Williams, & McLaughlin, 2005) by reducing the need for supplementary rewards and by increasing the willingness to complete the required tasks (Hoque et al, 2009).

Grounding on this previous research, we choose to frame our design approach around the development of a game-based system capable of supporting co-located collaborative gameplay. At the same time, we choose to employ Full-Body interaction as a design paradigm to develop the experience. This choice was motivated by findings proceeding from the embodied cognition framework.

As outlined in Section 2.2, research on embodiment showed the fundamental importance of physicality in social cognition, social information processing (Niedenthal et al., 2005) and empathy (Freedberg & Gallese, 2007). Such results suggest that the understanding of the other and social perception may involve embodiment (Di Paolo et al., 2010). Furthermore, as De Jaegher (2013) points out, autism may be strongly embodied in its nature since the difference in processing of sensory input may lead to different sense-making which influences meaning construction processes.

From this perspective, we concluded that, since our goal addresses social interaction, the use of an embodied experience could bring clear benefits. Moreover, the use of Full-Body interaction can be particularly relevant when we design for children with ASD. Recent studies suggest a possible association between motor development and social communication skills, proposing the potential of interventions that make use of motor related activities, such as imitation or play-based treatment

(McCleery, Elliott, Sampanis, & Stefanidou, 2013).

5.1.2 Methodological Issues in Developing Games for Children with Special Needs

The potential of employing games as complementary strategies to support social skills acquisition has lead to a widespread proliferation of digital games for children with ASD. Within this context, different approaches have been employed. These range from gamifying therapeutic interventions to fully developed games. This tendency toward applying games elements is consistent with the increased use of gamification in different fields, such as healthcare, business or education (Burke, 2012). However, as Burke (2012) highlights, this surge of gamified applications has lead to a peak of inflated expectations. According to the author about 80% of gamified solutions will fail in reaching their objectives due to a lack of understanding of game design and inefficient player engagement strategies.

Although this analysis is mainly oriented toward business strategies, a similar concern on the fundamental role of appropriate design methods has also been expressed in research concerning the development of psychotherapeutic gaming interventions (Goh et al., 2008). In this latter context, the main design pitfalls are related to shortcomings in reaching the therapeutic goals and to difficulties in designing an experience that can be truly engaging and motivating for children. Possible reasons behind these pitfalls can be found in the oversimplification of game design principles and in the lack of inclusive approaches capable of integrating the knowledge of mental health experts with the interests of children and the experience of designers.

On the one hand, often, game design is reduced to juxtapose reward system to already existing therapeutic techniques. As a consequence, some gamified therapeutic interventions may run the risk of having a reduced appeal for children, especially when compared with games available in the market. This risk is particularly relevant since, according to a recent study, children with ASD tend to spend nearly twice the amount of time playing video games than typically developing children do (Mazurek & Engelhardt, 2013). This habit suggests that many children with ASD have a richly developed gaming culture.

On the other hand, despite an increasing effort to define multidisciplinary teams for designing therapeutic gaming interventions, often children’s contributions, interests and motivations are poorly taken into account during the design process. Most projects in this area are based on design methods that are mainly designer-driven, in which little space is given for end-users.

This tendency is a product of what Rogers & Marsden (2013) define as "the rhetoric of compassion" when designing technology for people with special needs. As the author points out, often research in HCI focuses the attempts to help people with special needs from a third person perspective. This implies that the proposed technological solutions are based on our understanding of what they need, instead of giving them the voice to express their views (Rogers & Marsden, 2013). Such tendency reflects a power dynamic where clinicians and designers are considered to have "enough knowledge," so it is considered unnecessary to listen to children and hear them express their own motivations.

This tendency goes against the emergent recommendation from the Human-Computer Interaction community to involve end-users at a deeper level in the design process. In this context, several participatory techniques have been proposed to include neurotypical children in game design processes (Dindler et al., 2005; Moser, Chisik, & Tscheligi, 2014). However, although it is understood that children with special needs are often the population that can benefit the most from inclusive design processes (Frauenberger, Good, & Keay-Bright, 2011) and an increased attention has been focused on including their voices in the design (Guha, Druin, & Fails, 2008), the use of Participatory Design (PD) with children with ASD still presents some limitations.

Examples of using PD with children with ASD can be found in the project "ECHOES" (Frauenberger et al., 2011), "COSPATIAL" (Millen, Cobb, & Patel, 2010) and "SIDES" (Piper et al., 2006). In these projects, a number of PD techniques have been used, such as getting feedback from children on design choices (Frauenberger et al., 2011; Millen et al., 2010), analyzing their preferences (Frauenberger et al., 2011), and creating scenarios (Millen et al., 2010). The incorporation of these methods permits integrating children's contributions directly into the initial design stages, allowing a deeper influence on the definition of the final product. However in several cases, children's contributions are limited to accessory aspects (e.g. asking if they prefer the visual aspect of the option A or B) or are only inserted as aesthetic features to embellish an existing design. This tendency not only reflects the practical challenge of involving children with ASD in PD activities, but also implies an ethical reflection on the amount of space that is provided for their contributions.

This latter aspect is particularly delicate in a multidisciplinary context such as technology for autism, where several perspectives need to be merged. As Scaife and Rogers (1999) point out it is often difficult to combine the perspectives of children and experts since some proposals can be unworkable in computational terms or the preferences of children could actually come into conflict with the therapeutic goals. It becomes, therefore, necessary to identify methods capable of distributing power and orchestrating various contributions (experts, designer, and children) within a coherent holistic design. This implies the necessity of defining strategies to combine the need to fulfill therapeutic goals, while at the same time allowing sufficient space for children's contributions. However, to our knowledge, none of the projects aimed at including children with ASD in the design process propose a clear methodology on how to properly integrate children's voices in the design of the final product, nor do they provide a clear explanation on how they carried out the "translation" from children's contributions to an interactive experience. In addition, none of them includes information about how children's contributions were combined with therapeutic requirements and game design. This situation leaves unanswered several relevant questions about methodological tools (i.e. how have children's contributions been selected and integrated in the design process? How have they been combined with experts' and designers' knowledge? How have all these aspects been framed and integrated in an overall coherent experience?).

To address these questions we propose an inclusive approach to game design. The method is based on defining a model to integrate the expertise of clinicians, contributions of children and experience of designers through a set of elicitation and merging techniques. The goal of this method is to design playful experiences that are effective in terms of therapeutic objectives and are enjoyable and engaging for children. At the same time, the proposed method addresses the ethical concern related to designing for and with a population with special needs by including them in the design process. In the following sections, we will introduce the structure and goals of our proposed approach and later describe how it has been applied in the development of the game Pico's Adventure, which aims to foster social initiation in children with ASD.

5.1.3 An Inclusive Model for Game Design

Starting from the necessity of merging different perspectives (therapeutic techniques, game design and children's interests) and from the need to clearly define methods for framing, selecting and orchestrating the different contributions, we propose an inclusive design model for developing games for children with special needs. The model presents strategies to orchestrate different perspectives, as well as a set of elicitation and merging techniques to integrate the different contributions into a coherent whole. The goal of this approach is to design a game that is effective in terms of therapeutic objectives, while being enjoyable and engaging for children. For this purpose different stakeholders are involved in different stages of the design process.

The model has been structured in a four steps procedure and has been applied to the development of the game Pico's Adventure, which has the goal of promoting social interaction in ASD children. Specifically the four phases are the following:

- The elicitation of requirements from experts aimed toward properly defining the therapeutic goals, the structure of the experience and the therapeutic techniques.
- The elicitation of contributions from children with ASD aimed toward identifying their interests, motivations and preferences.
- The integration of contributions from experts and children in order to define the mechanics of the game, its elements and the experience as a whole.
- The exploratory evaluation of game suitability with children with ASD.

The elicitation of requirements from experts and contributions by children were carried out through a series of meetings with experts and through participatory design (PD) sessions with children with ASD. In both the meeting with experts and PD sessions we used a set of narrative resources to facilitate elicitation of requirements and to provide a common direction to the different contributions (Mora, Malinverni, & Pares, 2014).

Subsequently, to integrate contributions from experts and children, a continuous "translation" between different languages and disciplines is required. For this purpose we used the game design praxis proposed by Fullerton (2008), who describes the elements that constitute a game, i.e. players, objectives, conflicts, resources, rewards, etc. The rationale behind the procedure was based on a "building construction" metaphor. The elements which constitute the laying foundations of the game - the deepest part of the construction which supports and structures all other building blocks -

were defined in collaboration with experts in order to guarantee the therapeutic effectiveness of the game. Conversely those elements that characterize and specify the game experience were defined in collaboration with children in order to ensure the pleasurability and enjoyment of the game. Furthermore, those elements that combine both structural and experiential aspects were defined by merging experts' and children's perspectives.

Finally we carried out an initial exploratory study with 10 children with ASD who did not participate in the PD in order to evaluate the effectiveness of the game in terms of therapeutic goals and its likeability for children. In the following sections we will describe the application of this model to the development of the game Pico's Adventure.

5.1.4 Applying the Inclusive Design Model for the Development of the Game Pico's Adventure

5.1.4.1 Eliciting requirements from experts

The first step of the proposed design method was concerned with eliciting requirements from the mental health's experts that were collaborating in the project. Collaborating experts proceed from the Specialized Unit on Developmental Disorders (UETD) of Hospital Sant Joan de Deu (Barcelona). This unit is mainly dedicated to the diagnostic and treatment of autism in young population, according to a cognitive-behavioral approach.

Requirements from experts of the UETD were aimed at defining the target demography, the structure of the game, the objectives, the roles of players, and the patterns of social relations. To define these aspects, a total of five meetings with the UETD experts were arranged during the initial stage of the design process. Each meeting lasted for almost two hours and involved between 4 and 8 experts from the UETD.

The first meeting aimed at reciprocally introducing the two teams (designers and experts) and situating the project. Furthermore, since the project starts from the requirement of using a predefined hardware (the Kinect device), we showed the specificities of this technology and examples of its usage. Starting from this introduction, the subsequent meetings took the form of group interviews and brainstorming sessions aimed at establishing the conditions for co-creation through dialogue. For this purpose, after each meeting, the designer team produced a document summarizing the main decisions taken and sketching some initial proposals to be discussed in the following meeting. The outcomes of the meetings were collected through note-taking.

Besides these initial meetings, during the unfolding of the overall process, additional meetings were organized to evaluate our progress. The following sections provide a detailed description of how the main goals, treatment plan and specific therapeutic objectives were translated into game design elements.

5.1.4.1.1 Framing the game: technology as a mediator of social interaction

During the first meeting with mental health experts, they reported the need of addressing learning goals related to social initiation. Social impairment is possibly the most important deficit in children with ASD (Roeyers, 1995) and social initiation represents a pivotal aspect for the proper development of social skills. Even if children with ASD can learn to respond to social initiations started by others, they may have major difficulties in initiating this social interaction by themselves.

Starting from this definition of the needs of the addressed population, we focused our project on designing a game that address skills related to social initiation, i.e. looking for and approaching others, making eye contact, showing joint attention, starting social communication and producing any verbal or gestural behavior for communicative goals.

The highly interpersonal nature of these skills implies to conceptualize interaction with technology not as a dialog between a child and a virtual or robotic agent, but as an instrument to scaffold social interaction with somebody else (e.g. a parent, caregiver or another child). From a therapeutic perspective, this notion can be related to the concept of "*therapeutic triangle*", understood as the relation that is established between the patient and the therapist through the use of a mediating object (e.g. a musical instrument, artworks, etc.). Applying this notion to game design requires conceptualizing the game as a mediator to facilitate interpersonal relationships. Consequently, the designed experiences must foster the establishment of social interactions during play between the child and the accompanying person. This implies designing game experiences that are either sufficiently valuable for the child to feel the need to communicate them or that require the child to look for external collaboration. These requirements strengthen the need for design approaches capable of getting close to the interests of the end-users in order to properly understand what they consider "worth to be communicated and shared".

5.1.4.1.2 Defining our target demography

Once defined the main goal of the experience, together with the experts we specified the target users as 4 to 6 years old children with high-functioning autism (HFA). This population was selected by taking into account two main aspects. On the one hand, from a treatment perspective, high-functional ASD children are those who have more chances of having an autonomous life if adequately assisted through their childhood. Furthermore, early intervention is seen as crucial in raising the benefits of any sort of assistance (Warren et al., 2011). On the other hand, the specific configuration of the employed technology (Kinect device) requires a minimum motor control and understanding of videogame-like structure that could be difficult for younger populations.

5.1.4.1.3 From treatment plan to game structure

Based on the defined goal and target users, the mental health experts defined a treatment plan. The treatment plan was structured into four sessions, organized in the following manner:

1. First session: the child plays in single-user mode.
2. Second session: the child starts playing alone but at some point requires help from someone else; e.g. an adult such as a parent.
3. Third session: the child plays with an adult from the beginning of the session, namely, one of his/her parents.
4. Fourth session: The child plays together with another unknown ASD child included also in the treatment program.

This sequence was chosen to provide a progressive scaffolding of social interaction by firstly allowing children to familiarize themselves with the play environment, then introduce the co-located play modality through the presence of a familiar adult, and finally to share the play experience with another child.

Since this structure is reminiscent of the idea of “a journey” toward social initiation skills, we chose to use the narrative structure of Campbell’s monomyth as the underlying framework (Campbell, 1949) to define the game structure (Table 9) and its back-story. Specifically the game back-story was defined around the “journey” of a virtual character, a friendly alien, who arrives on the Earth due to a mistake and needs to go back to its planet. At the same time this structure was used to guide children in the PD activities (see section 5.1.4.2).

Table 9. Pico's Adventure game structure

SESSION	NARRATIVE ELEMENTS (Campbell’s monomyth)	DESIGN REQUIREMENTS
1st session	- Presenting the character and the environment - Call to adventure: presenting the goals - Meeting the mentor	- Introduction to the virtual environment - Start interaction - Develop a relation with the virtual agent
2nd / 3rd sessions	Escalation (tests, challenges and alliances)	- Start to play collaboratively with a familiar adult - Increased difficulty of challenges
4th session	- Resolution (final challenge) - Return with the elixir	- Playing with an unfamiliar child - Social initiation skills work as an elixir after having successfully achieved goals together with another child

5.1.4.1.4 From requirements to player’s interaction patterns

One of the leading concepts of the project was to help children with ASD in understanding the importance and benefits of starting social interaction. To this end, we revised players cooperation patterns commonly used in game design (i.e. player vs. player, cooperative play, team competition, etc.) and chose to focus toward a cooperative model. From the literature review of cooperative game design patterns, we defined a set of patterns to be implemented in the game experience, namely: synergies between different user abilities, shared goals, and complementarities of player actions (Seif El-Nasr et al., 2010). These cooperative patterns were therefore embedded in and structured according to the treatment plan proposed by the experts.

5.1.4.1.5 From therapeutic goals to game mechanics structure

Together with the definition of the treatment plan, the psychologists defined a set of behavioral skills that are usually addressed within cognitive-behavioral treatments for fostering social initiation. These skills, therefore, represented the subgoals of the project and were defined as follows:

- *Use of instrumental and conventional gestures*
- *Stimuli discrimination*
- *Turn-taking*
- *Imitation*
- *Joint attention*
- *Vocalization*
- *Recognition of basic emotions*
- *Cooperation*

These subgoals were divided into two main categories:

- Transversal subgoals: those which are applied in all sessions of the treatment plan (i.e. look for collaboration, imitation and recognition of basic emotion)

- Session-specific subgoals: those that are implemented in a progressive order in the different sessions.

Starting from the defined goals and subgoals, we reviewed (designers and experts) the techniques and exercises that are traditionally employed to address these aspects. The aim of this review was twofold. On the one hand, it aims at extrapolating the core essence of traditionally used exercises in order to apply them in a playful way within a digital game. On the other hand, it focuses toward confronting the employed exercise with the specificities of our technological configuration in order to define the approaches that could be more appropriate for this medium. This analysis allowed us to design a basic structure of possible game mechanics as reported in Tables 10 and 11. In this initial stage game mechanics were defined only at a structural level, as “empty boxes”, in order to allow space for subsequent contributions from the children.

Table 10. Pico's Adventure: transversal goals

MAIN GOAL	RELATED OBJECTIVES	MECHANICS
Social Initiation Skills	Look for collaboration	Cooperative activities that require more than one player to solve the tasks
	Imitation	The virtual agent shows the game mechanics through its behavior, the child has to imitate it
	Recognition of basic emotions	The virtual agent will behave according to four basic emotions (happy, afraid, sad, eager) and the child has to respond accordingly

Table 11. Session specific sub-goals and game mechanics structures

LEVEL	MAIN GOAL	RELATED OBJECTIVES	MECHANICS
1	Basic social initiation skills	Instrumental gestures	The child has to do gestures to obtain a target object
		Stimuli discrimination	The virtual agent indicates some target object, and the child has to retrieve it
		Vocalizations	The child has to use vocalizations to ward off an antagonist in the game
2	Basic social initiation skills + cooperation	Instrumental gestures	The child has to do gestures to obtain a target object
		Cooperation	The child has to cooperate with the adult in order to catch objects in the game
		Stimuli discrimination	The child has to discriminate between useful and non-useful objects
3	Basic social initiation skills + joint attention +	Joint attention	The child has to call the attention of the adult toward target objects through a pointing gesture
		Cooperation	The child has to cooperate with the adult to coordinate

	cooperation		their pointing gestures toward target objects
		Stimuli discrimination	The child has to discriminate between target objects and non-target objects
4	Basic social initiation skills + turn-taking + cooperation	Turn-Taking	The two children have to coordinate in order to simultaneously find and catch target objects
		Cooperation	The two children have to cooperate in order to solve a task
		Stimuli discrimination	The children have to discriminate between a target object and non-target objects

5.1.4.2 Participatory design with children

In order to integrate children understandings and interests in the design, we carried out five participatory design sessions with children with ASD. Starting from the specificities of the system and from the structure defined with the experts, the workshop aimed toward analyzing how children may interpret the proposed experience and figuring out what can be relevant and interesting for them.

The sessions of the workshop took place in a dedicated room of the Sant Joan de Deu Children's Hospital on a weekly basis. The participants were selected by the UETD professionals and consisted of four children diagnosed within the Autistic Spectrum Disorder, all males between 9 and 10 years of chronological age. All four children presented typical cognitive capabilities (i.e. an IQ level consistent with the average typical population), functional language and had been enrolled together in a previous social skill training group at the UETD. Although their age did not fit with that of the target users (4-6 years old), the UETD professionals considered that at this age, their developmental level was more suitable for participatory design activities. Moreover, the UETD professionals considered that informing these children about the fact that they would be participating in the design of a game for younger children would have a beneficial effect in two main aspects: a) motivating them through the attribution of responsibility and b) by fostering the perspective-taking exercise of figuring out preferences of younger children.

During each session three researchers and a psychologist were present. Each session lasted for one hour and was designed to address specific aspects of the game design. In order to structure the workshop we employed the narrative structure of the game to conceptualize each session as a chapter of the story (see table 4). This methodological choice was oriented toward generating continuity between the activities, hence grounding children's contributions on a common terrain and to foster their involvement. For this purpose we employed a set of "scene cards" which depict the different chapters of the story. Each card was used to frame the proposed activities and describes the location of the scene, the child's targeted behavior and a series of possible conflicts. At the same time, we employed personalized storage boxes to facilitate children to keep track of their progress.

During the workshop, two researchers were taking field-notes. Furthermore, each session was video recorded and analyzed through a narrative approach. This analysis was oriented toward collecting children's contribution and toward evaluating the effectiveness of the proposed activities in order to improve them through progressive approximations, adjustments and iterations (Vanden, Gravemeijer, McKenney, & Nieveen, 2006). For this evaluation three main dimensions were taken into account:

- *Suitability*, defined as the extent to which the proposed activities are capable of engaging, involving and inspiring children as active participants in the process (Mazzone, Tikkanen, Read, Iivari, & Beale, 2012) .
- *Capability*, understood as the extent to which the activities can produce useful results for the design (Mazzone et al., 2012).
- *Empowerment*, understood as the extent to which children care about what they are doing (meaningfulness) and their perception about the relevance and importance of their contributions (feeling of competence) (Malinverni et al., 2014).

This approach allowed taking into account the potential benefits for the children themselves and not just for the design outcomes (Benton, Johnson, Ashwin, Brosnan, & Grawemeyer, 2012). Furthermore, it permitted to embed a certain degree of flexibility in the design of the structure of the activities, hence reducing the eventual difficulties that autistic children may encounter in PD activities (Frauenberger, Good, Alcorn, & Pain, 2013).

Table 12. Workshop Sessions and Chapters

SESSIONS	SCENE CARD	CHAPTER (Workshop activities)
1	*Location*: wood (Planet Earth), day / *Targeted Behavior:* start interaction	Introducing the main character
2	*Location:* wood (Planet Earth), day / *Targeted Behavior*: start interaction / *Conflict:* antagonist	Build a relation with the main character, help it
3	*Location:* wood (Planet Earth), night / *Targeted Behavior*: start a cooperative activity with a familiar adult	Help the character to build and fuel the spaceship, travel back to its planet
4	*Location:* alien's planet / *Targeted Behavior*: joint attention / *Conflict:* antagonist	Help the character to find its friends
5	*Location:* alien's planet / *Targeted Behavior*: turn taking/ *Conflict:* antagonist	Meeting the friends, celebration

5.1.4.2.1 The workshop

Following the structure provided by the scene cards, we organized the activities of the workshop.

The first session

During the first session, we presented ourselves, introduced the main character of the game (the alien) and set-up a series of activities aimed at defining the alien's features. In particular, we asked children to propose possible transformations of the character depending on the ingestion of different kinds of food. These activities have the goals of investigating the possibility of including customization of the alien as a part of the game and facilitating the involvement of the children in the workshop by establishing a relationship with the main character.

Observations carried out during this session showed that the children were much more motivated, participative and creative than what we had been warned about and, hence, expected. This observation allowed us to define the activities of the following sessions from a broader and more creative perspective. At the same time, from a design perspective, the session allowed us to get a better understanding of two main aspects: (1) the fundamental role of the previous knowledge that children had on the language of cartoons and videogames as effective mediators of interaction metaphors (e.g. Children were especially motivated by transformations related with super-powers derived from their audiovisual culture such as "super armor", "ice breath", etc.) and (2) the definition of the logic behind the transformation and customization of the character. The analysis of their proposals showed that character transformations should be highly discrete, self-evident and meaningful. Furthermore, the relation between food eating and transformation should be mainly based either on visual or on functional properties of the food (e.g. obtaining a "fire outfit" if the alien eats chili, turning its skin green if it eats lettuce, etc.).

The second session

During the second session, we focused toward observing the intuitiveness of the interaction with the Kinect device, define the character's behavior and design its spaceship. Its goals were, therefore, to evaluate the affordances of the proposed hardware and define a believable and likeable character with which children may develop an emotional attachment.

The session was divided into two main parts: a first part dedicated to motor activity and a second part dedicated to drawing. In the first part, children were introduced to the game through the use of a Wizard-of-oz system that allowed starting a basic interaction with the game (Figure 8). The set up of the Wizard of Oz was based on a Kinect camera and a standard television screen in order to emulate the final configuration of the game set-up. The child could see himself inserted into the virtual environment and a researcher remotely controlled the interaction with the environment. Children were invited to play in a single user mode while the others were involved in a drawing activity. Subsequently, children were asked to start a short role-play activity in which, by turns, one child had to interpret the player and the other the alien. To guide this activity we used a step outline structure based on asking behavior related questions: e.g. "What would happen if the child did not pay attention to the character?" Meanwhile, the children that were not role-playing were asked to make a drawing of what they thought the spaceship of the character would look like.

From a design perspective, the observation of children interaction with the virtual environments allowed us to find more intuitive ways to design the interaction. The use of role-play allowed us to

Figure 8. Child playing with the Wizard-of-oz

define certain behaviors of the character and its expected reaction to the input of children. Children showed strong preference for highly expressive reactions in character behavior. Another important observed aspect was that one child felt uncomfortable seeing his own image represented on the screen. This finding suggested the possibility of adding a customization parameter to the application that would allow changing the visual representation of the player; e.g. from a fully detailed camera image to a plain simple silhouette.

The third session

In the third session, the absence of two of the participants partially disrupted the dynamics of the workshop, thus impeding to properly carry out the session since the two remaining participants were poorly motivated to pay attention to the instructions.

The fourth session

The fourth session was introduced by explaining that the alien finally managed to get back to its planet. Its design goals were to explore the visual aspects of the alien's planet and the game mechanics related to helping the character to find its friends. Children were therefore asked to draw the planet (Figure 9) and later present their works to their peers. Subsequently, we introduced a turning point in the story: "a mysterious accident happened in the planet and all the spaceships of its inhabitants are now trapped". Through the use of directed design technique children were asked to suggest what is trapping the spaceships and how we can free them by collaborating between two children. A researcher drew their suggestions on a blackboard (Figure 10).

This session showed to be particularly productive and engaging for children. Several creative solutions were proposed and children gave detailed explanations of their drawings, showing a certain level of excitement in explaining their ideas (e.g. asking us "Would you put this in the game?"). This activity however, in terms of its capability to provide concrete design solutions, caused some difficulties when integrating the highly different proposals. To overcome this issue we focused on extrapolating common features from children's proposals and give the planet an anachronistic appeal. On the other hand, the directed design activity was highly effective in stimulating children collaboration. Several design ideas were proposed and children were highly motivated in building on each other's ideas and specifying them to allow the researchers to draw them properly.

Figure 9. The drawing of the planet produced by one child

Figure 10. Blackboard during directed design

The fifth session

The fifth session had the objective of analyzing which elements of the whole gameplay received the biggest attention from children and defining idea for the resolution chapter. Children were asked to draw the story of the game in a storyboard format (Figure 11), according to what they remembered of each chapter. After that, each scene was summarized and drawn on the blackboard by a researcher through the directed design method. Finally, we explained to them that the character had finally found its friend and was now going to celebrate the reunion. Children were asked to draw this last scene and directed design was used to visualize their proposals. In this context, the researcher also suggested some ideas to evaluate our initial proposal about how to design the final level.

The technique of the "recalling storyboard" was particularly effective in terms of its capability to quickly figure out, according to the children, which are the most relevant aspects of the game and therefore focus our design choices. At the same time, the use of directed design, allowed modifying our proposals. Our initial idea was to set the final level in a "jelly world". However, children were not motivated by this idea and, instead, proposed urban environments. Therefore, we decide to discard our proposal to include their interests and contributions in the design of the final level.

Figure 11. Recalling Storyboard produced by one child

To sum up, through participatory design we therefore defined specifications of narrative elements and game mechanics, validated some initial design proposals and evaluated which aspects elicited a higher level of interest, motivation and engagement. Within that, particularly useful insights came from the fundamental role of the audiovisual culture of children as a mediator for the interaction metaphors. Furthermore, the workshop allowed the identification of children's ideas and preferences, which could be used as rewards and resources in the game. Examples of these can be found in their interest toward super-powers, high-tech devices and outer-space related elements (e.g. spaceships and rockets).

5.1.4.3 Merging Perspectives

Once both experts and children's contributions were collected we proceed toward the task of merging their perspective in the design of an overall experience. The process of merging perspectives was carried out by using the structure defined with the experts as a sort of "empty boxes" that were instantiated as specific elements through the inclusion of children contributions. Examples of these are: the definition of the character, the design of the game mechanics and the definition of the reward system. An overall model of this integration is described in Figure 12.

To define game mechanics, the basic structure defined in the collaboration between experts and designers (Table 11) was filled in and instantiated with the specifications proposed by the children. A clear example of this can be found in the third level. The initial guidelines of this level were defined as: "*The child has to call the attention of the adult toward the target objects through a pointing gesture; the child has to cooperate with the adult to coordinate their pointing gestures toward the target objects*". This requirement was framed by proposing the following scene card "*You are in the planet of the character; some spaceship are trapped; you need to help the character to free them*". From the different children's proposals about how to free the spaceship, those that fit with the pointing gesture and collaboration were selected. The final mechanic was therefore instantiated as follows: "*Children have a "super-power" laser that originates from their hand. They have to point it towards a spaceship that is trapped by a cloud and coordinate with the laser of the adult in order to liberate the spaceship*". At the same time, consistent with the usual learning curve of video games, similar mechanics were repeated and combined following an increasing level of complexity.

A similar procedure was carried out to define the behavior and appearance of the character. According to Fullerton, video game characters cover two main functions: agency and empathy. Agency refers to the practical function of the character, while empathy is the potential for players to develop an emotional attachment to the character (Fullerton, 2008). The agency of the character was established from the requirements of the UETD experts: it would cover the function of accompanying the child by providing aid and asking for their help to solve problems.

Within traditional therapeutic techniques, different kinds of aid are provided to the children to facilitate the performance of the target behavior. These aids include visual and verbal cues and modeling techniques (e.g. seeing someone perform the target behavior); they are generally administered according to an increasing order, aimed at giving the minimum amount of help needed to perform the behavior. This progressive scaffolding of aid types was implemented in the behavior of the character. On the other hand, we framed children's contributions around the definition of a believable and likable character in order to foster empathy. Children, therefore, helped define the character in terms of identity, preferences, aesthetic aspects and expressive features.

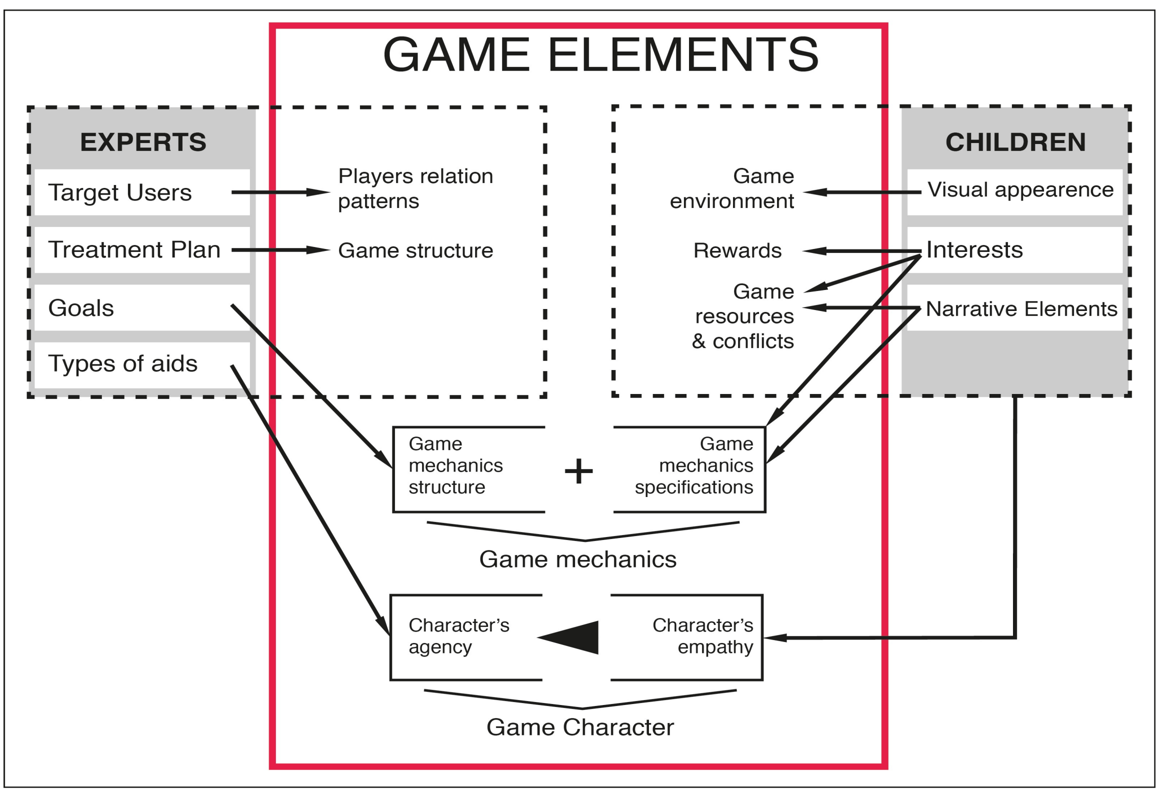


Figure 12. Schema of the inclusive model employed to design the game. The figure describes the aspects that were defined with mental health experts (left box), the aspects that were defined with children (right box) and the aspects that were defined by combining contributions from experts and children (bottom area).

Finally, both cognitive-behavioral therapeutic techniques and video games use positive reinforcements as stimuli to strengthen the desired behaviors. Therefore, a system of rewards based on visual and sound effects was designed with the children in order to reward their performance in the game. At the same time, aesthetic features of the environment and game elements were defined by combining the contributions of different children.

The use of this structural and inclusive approach to game design allowed us to develop a mid-fidelity early prototype of the game Pico's Adventures. It was initially evaluated with the children who participated in the participatory design workshop through Wizard of Oz techniques. The aim of this first evaluation was not to assess its effectiveness in terms of therapeutic goals but rather to estimate whether our final proposal met the expectations of the children who contributed in the design process.

5.1.4.3.1 The game: Pico's Adventure

The game Pico's Adventures is a Kinect-based game aimed at promoting social initiation in children with ASD. The experience is guided through the story of Pico, a friendly alien that arrived to the Earth by mistake. Pico lands in the woods because its spaceship breaks down. At the beginning of the adventure, Pico is somewhat shy, finding himself in an unknown world and a novel environment. The child has to show Pico that they can be friends by helping it in some tasks, such as providing it with food or helping it repair its spaceship. To reward the child for his cooperation, Pico gives him different "super-power" gifts that will serve as tools to fulfill certain tasks. Also, as a sign of gratitude Pico invites the players to travel together to its planet. During the game, children - either alone or in collaboration with adults or peers - must help the character to overcome different missions. Each mission is designed to address a targeted behavior related to social initiation according to increasing complexity levels. A description of each level (corresponding to the treatment plan sessions described in Table 9) is provided in Table 13.

5.1.4.3.2 Meeting children's expectations and Usability testing

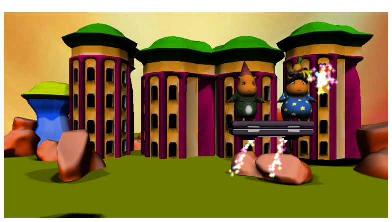
An initial evaluation was carried out with the children who participated in the PD workshop through two additional sessions after the end of the workshop. It was mainly oriented toward evaluating whether our product met the children's expectations and also for identifying possible usability issues. We used different methods to gather information about how enjoyable the game was, user understanding and user experience. Formally four main methods were used:

- An adapted version of the affective grid (Russell, Weiss, & Mendelsohn, 1989) in which children were asked to rate different game aspects according to two scales, “funny-boring” and “cool-ugly”, by sticking the image of each game element on the appropriate place on the scale.
- The Smileyometer (Read, 2007) in which children were asked to rate the overall game experience for each level in a five-point Likert scale, where the values were represented by faces.
- Short structured interviews aimed toward understanding comprehension of the game.
- Field observations and note taking of interactions, for the purpose of identifying possible usability issues.

Results from rating showed an overall appreciation of the game with three children giving the maximum points and only one reporting that he did not like to see himself on the screen. The interviews and observations of the four PD participants showed that these children were satisfied with our implementation and gave good evaluations for ease of use and comprehension. At the same time, they were proud of seeing their ideas being implemented in a video game and asked their parents to come to see “their game”.

This initial assessment allowed us to improve some minor aspects of the game, mainly related to the visual aspects of certain elements and the refinement of the behavior of the character. Main insights were derived from the affective grid and from field notes. Especially the affective grid allowed spotting out the elements that were not visually appealing for children and improving them. Field notes permitted to address usability issues and aspects of the character interaction. For instance, we noticed that many children tend to virtually touch the character through their on-screen representation. Therefore, we included special behaviors for those cases in which the child tried to touch or caress the on-screen character. Furthermore, in our initial proposal children had to use verbal expressions to drive away a bird in the first level. However, since we noticed that many children naturally waved their arms to scare the bird, we decided to also implement this option in the game.

Table13. Pico's Adventure: game sessions description

Session	Description
1st Session 	The child meets Pico in a forest. The child can offer food to Pico to overcome Pico's shyness and become friends. Pico changes its appearance according to the ingested food type. This session of the game is divided into four parts, each one changing a different aspect of Pico's body: 1) skin color, 2) outfit, 3) hat and 4) complexion. In parts three and four, a bird appears every time the child makes a food item fall to the floor. The child must then scare the bird away through vocalization or by waving his arms in front of it.
2nd Session 	This session of the game is structured in two main parts. In the first, the child must help the character to fix its spaceship by finding the parts of the spaceship that are scattered in the treetops. The action occurs at nighttime so the child can barely see the pieces. Pico gives him a point of light that can be controlled with his hand to illuminate the trees in the forest. This allows the child to find and collect the pieces. However, some pieces are too high for the child to reach. He must then ask for the adult to help, thereby giving the adult instructions on how to collect the parts of the spaceship. In the second part, the child must coordinate with the adult to catch falling stars needed to fuel the spaceship. This action may only be completed by the child and the parent holding hands and making the stars fall between their arms.
3rd Session 	In this session the child and the adult travel to Pico's planet. The goal of this session is to liberate Pico's friends' spaceships, which are trapped in colored clouds. To perform this action the child and the adult must collaborate, using laser rays that come out of their right hands and pointing together to the cloud covering the spaceship. The child must give instructions to the adult on where to point and how. Furthermore, they need to match the color of their laser with the color of the cloud.
4th Session 	In this session two children with ASD that have never met before play together. The goal of the session is to get presents that the inhabitants of Pico's planet offer them. The two children again must use a laser. They must also collaborate by pointing their lasers toward the present boxes that appear in the buildings. If the two children jointly point at a present with their lasers, they correctly signal a flying platform which their Picos fly on towards the present. Once the platform reaches the present, the two Picos take the present to the children. The two children must then touch the present with their right hand at the same time to open it. They then receive a copy each of the surprise present from inside the box.

5.1.5 Exploratory Study

5.1.5.1 Participants and method

To evaluate the developed game with target users we carried out a preliminary observational study involving ten boys with ASD (mean age: 5.3; SD: 0.94). The study was approved by the ethics committee of the hospital. The goals of the study were: 1) to evaluate the acceptance and enjoyment of the game, 2) to analyze whether it offers affordances to support the targeted behaviors, 3) to gather insights to guide new design iterations. Mental health professionals selected the participants according to the following inclusion criteria:

1. Age: between 4 and 6 years old
2. ASD diagnosis using standard instruments form the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria
3. A cognitive capacity over 70 as measured by the standard Wechsler Intelligence Scale for Children (WISC); mean IQ: 95.9; SD: 15.51.
4. Exclusivity of the treatment (no other psychological treatment would be administered to the children during the study.)
5. Absence of changes in pharmacological treatment during the experimental treatment.

The study was carried out at the UETD premises during one month. Each child participated in four sessions, scheduled on a weekly basis. During each session, children were accompanied by parents, and the sessions took place in a large dedicated playroom of the hospital where a psychologist and a researcher were also present. Other researchers observed the session from an adjacent room through a one-way mirror window. According to the defined treatment plan the child played independently in the first session, with one of his parents in the second and third sessions, and with another previously unknown ASD child participating in the study for the fourth and final joint play session.

Each session lasted for 45 minutes during which children were first introduced to the game by the psychologist. The psychologist gave them a pre-scripted explanation of the basic facts, tasks and challenges they would find in that session. After that, children had approximately 30 minutes to play with the game.

In order to gather data, the two psychologists and one researcher took field notes during the play sessions. Notes were taken according to a coding scheme checklist aimed at identifying the presence of target behaviors (see Table 14) and rating children's attitude toward the experience. After the end of each session, notes were discussed to reach a common agreement. Furthermore, all sessions were video recorded and analyzed. This analysis was performed by a researcher, who transcribed the video according to a narrative approach to contextualize the observed target behaviors within their contexts of occurrence. Both field and video analysis were oriented toward: 1) identifying target behaviors and situate then within the context of occurrence; 2) rating children's attitude and 3) identifying possibilities for future design improvements.

Table 14. Coding Scheme Checklist

CODING SCHEME CHECKLIST
Social initiation (asking for an object or help, showing something, giving something, gestures, imitation, visual contact, social smiling, pointing, social expressions, giving help)
Social responses
Joint attention
Maladaptive behaviors (echolalia, ritual, stereotypes, repetitive actions, sensorial stimulations, hypersensitivity)

5.1.5.2 Observations

5.1.5.2.1 First session

The first session has the goal of introducing the child to the virtual world and fostering his interaction with the environment and the character (Figure 13). A detailed description of the gameplay is provided in Table 13.

During the first session children showed several behaviors associated with social skills such as commentaries, responses to the conventional and instrumental gestures of the character and use of conventional gestures (e.g. using the hand to say "bye-bye"). Social initiation, in the form of commentaries, was especially triggered by changes in the character's outfit or by the appearance of unexpected foods (e.g. a donut on a tree). These surprising elements motivated children to either call the attention of the parent to the element or comment on it to share their experience. In this context it is relevant to note that the character's outfit, accessories and food items were derived from children's proposals in the PD. This outcome, thus, suggests the importance of carefully embed in the design children's contributions and aspects that they consider relevant

The principal shortcomings were found in the low rate of exploration of some children who tended to perform repetitive behaviors; e.g. remaining always on the center of the screen or repetitively selecting the same food element. This embodied pattern requires reflecting on design solutions capable of fostering exploration and variations of bodily movements.

Figure 13. Child playing in session 1

5.1.5.2.2 Second session

The second session has the goal of facilitating the incorporation of the parent in the interaction of the game. This is done by creating situations where the child asks for help to solve a task. A detailed description is provided in Table 13.

In this session children showed a higher level of exploration in comparison with the previous session. The use of the light effect promoted behavior related to experimentation. In relation with social initiation almost half of the children spontaneously asked for help from their parents to catch the spaceship's pieces that they could not reach. Instead the other half did it only after a verbal indication of the psychologist. The amount of commentaries aimed at sharing the experience were reduced in comparison with the previous session and were mainly related to major events (e.g. when the lighting effect appeared or when the character finished fixing the spaceship). However, all children performed a vast amount of social requests related to giving instructions to the parents to gather the unreachable pieces of the spaceship. This amount of instruction was mainly present in the first part of the game. During the second part, when the children held hands with their parent (Figure 14), verbal instructions were reduced and children tended to simply push or pull the parent in the desired direction. Such observations can indicate that game mechanics for eliciting social initiation should avoid situations in which the need for communicating can be easily substituted by an instrumental use of the other player (e.g. pulling or pushing the other player in the intended direction).

Figure 14. Child playing with adult in session 2

5.1.5.2.3 Third session

In the third session, children travel to the character's planet and must collaborate with their parents to liberate spaceships trapped in clouds (Figure 4), as described in Table 13.In this level, children showed a good level of social initiation related to giving instruction to their parents or making commentaries about the visual effects and elements. However, some children showed an increased amount of stereotypies (undesired repetitive or ritualistic movements for their own self-stimulation or to allow them to better cope with over-excitement, e.g. hand flapping, jumping) with respect to the previous levels, probably due to the faster pace of gameplay in this level.

Figure 15. Child playing with the mother in session 3

5.1.5.2.4 Fourth session

In the fourth session two children with ASD, who have not previously met, are set to play together. The character of each child appears, and the four of them share the experience (Figure 16). The goal of the session is to obtain presents offered by the inhabitants of the planet. For a detailed description see Table 13.

Figure 9. Two children playing together in session 4

During this session, several behaviors related to social initiation and social interaction were observed: children gave instructions to each other to coordinate their lasers for getting the presents. At the same time, since the presents were not as visible as the spaceships of the third level, the increased level of difficulty helped in eliciting communication. At the same time, the action of opening the presents generated a huge amount of commentaries related to expectations about the content, and also with sharing their surprise for the object inside. These commentaries were particularly abundant when the object violates children's expectations (e.g. a pineapple). Finally, social behaviors, such as reciprocal imitation, were observed especially in the moment related to the celebration of obtaining a new present.

5.1.5.2.5 Outcomes

Results proceeding from field observations and video analysis showed several behaviors associated with social interaction, such as: social smiling, visual contact, vocalization directed toward the other child, the adults or the game character, descriptive gestures, imitation, social expressions, pointing, sharing of emotions, initiation of social interaction (i.e. calling the attention of the parents when something interesting happened), response to social interaction and collaboration through regulatory and illustrative social interactions (i.e. explaining or indicating to their parents or to the other ASD child how to do something). At a functional level, the observed social interactions were mainly related to two goals:

- Directive acts, such as requests and instructions, aimed toward calling attention or causing the listener to perform a particular action (Searle, 1969).
- Expressive acts, such as commentaries on game elements, aimed at expressing interest toward a particular object or event (Searle, 1969).

Directive acts were mainly triggered by cooperative situations based on shared goals and synergies between abilities. In these situations, children tended to initiate the communication to indicate an action to be performed by the other player. On the other hand, expressive acts were particularly elicited by surprising elements such as the change in the appearance of the character and the content of presents. Among them, the highest rates of commentaries were derived from elements that violated expectations, e.g. a donut on a tree or receiving a pineapple as a present. Such findings suggest that surprise and violation of expectations can constitute powerful design concepts in eliciting social initiation. This finding could be considered consistent with the results reported by Alcorn et al. (2013), who suggest that discrepancies and events that violate the rules of the virtual environment motivated a wide range of social initiation in children with ASD interacting with the digital game ECHOES. However, such approach partially contradicts the supposed benefits of the high level of predictability offered by technological solutions. Further research is therefore necessary to validate the effectiveness of this design concept. Nonetheless, potential paths for future work can be derived from the use of surprising elements in the elicitation of social initiation behaviors.

Another relevant finding of the study was related to the enhancement of exploratory behaviors. The first and second sessions were based on similar game mechanics: children have to pick an object (either food or parts of the spaceship) for the character. However, in the first session a tendency toward repetitive behavior was noticed. Instead, in the second, the exploration was improved thanks to the use of the light effect to illuminate the scene. This idea arises by combining the previous mechanic with children's contributions from the PD workshop, where a child mentioned how he likes the classic search game "cold-warm". Therefore, in this case we avoided repetitive attitudes by using an effect that allows children to illuminate only a reduced area of the environment. This design concept brings to mind the idea of “peepholes”, understood as artifacts that provide a limited view into a larger space (Dalsgaard & Dindler, 2014). These “peepholes” proved to be an effective resource for promoting exploration. To sum up, the contextual analysis of children in situ interaction offered relevant insights on the relation between the affordances of the digital experience and the elicited behaviors, hence facilitating insights to guide future research and design.

Finally, children reported a good acceptance of the game. Direct observation allowed us to identify a positive attitude toward the game. Reports from parents confirmed children’s willingness and expectations to come back to the session every week. Furthermore, clinicians working with some of the participant children reported that they asked to play with Pico even months after the intervention.

5.1.6 Discussion

In this study we presented an inclusive design model and its application to the design of the game Pico’s Adventure. The model stems from the need to integrate knowledge proceeding from different perspectives (i.e. mental health experts, designers and children) in the design of an effective and enjoyable therapeutic game.

To our knowledge, so far, most papers using PD for designing games for children with special needs only describe this research as a juxtaposed activity, without properly clarifying how diverse contributions have been articulated among them. To address this neglect, the proposed model acknowledges design as a relational product and recognizes that knowledge and competences are distributed among a wide number of stakeholders, who are all in charge of defining certain aspects of the final design. Within this context, the proposed design model allows to properly track the contributions of the network of agents involved in the design process. This structure allows making visible the situated nature of design choices and considering the weight that different stakeholders may have in the decision-making process. This approach does not only have practical consequences in terms of design praxis. It, also, entails ethical implications related to the definition of who is given the possibility of speaking, on behalf of whom they are speaking, and which are the voices that matter in a design process. Within this network, we, thus, propose the role of the designers as facilitators in charge of enabling conditions for expressing requirements and as *bricoleurs* (Strauss, 1962), who have to structure, articulate and translate theories, ideas and proposals into concrete design choices. On the other hand, the proposed approach offered some concrete guidelines to deal with the task of eliciting and merging different contributions in a cohesive playful experience. Formally, the following techniques were proposed:

- The use of narrative resources (i.e. narrative structure, game back-story, scene cards) to facilitate requirement elicitation and to allow framing contributions by children and experts around common goals and imaginaries.
- The use of game design praxis (Fullerton, 2008) to select, orchestrate and merge contributions in a coherent overall playful experience. Such praxis was based on a "building construction" metaphor, in which requirements defined by experts were used to define the goals and the structure of the game, while children's contributions allowed for instantiating structural guidelines in specific playful experiences.

The combination of these techniques facilitated the progressive design of game mechanics and game elements according to requirements from experts' and children's interests. At the same time they allow defining a common vocabulary, thus facilitating the work dynamics in an interdisciplinary and intergenerational team.

The aim of the proposed design model was to develop a game that was effective in terms of therapeutic goals and that was enjoyable and appealing for children. Although it is not possible to directly derive a causal relation between the design method and the outcomes of the study, results proceeding from our study suggest the potential of our approach to fulfill these goals. Through the inclusion of experts' knowledge and therapeutic techniques, we achieved positive results related to social interaction. At the same time, by incorporating contributions from children we managed to design experiences that can provide reasons and motivations for children to begin social interactions.

However, our proposal should not be understood as a prescriptive procedure and represents only one of the possible paths to achieve these goals, so further research should be carried out to compare the limits and benefits of applying different design methods. For this purpose, we believe that a careful description of the design procedure, methods and practice can represent a valuable practice in HCI research. While in experimental research it is crucially important to clearly report methods, such precision is often overlooked in design research. Consequentially, knowledge about how and why certain design decisions were made is often inaccessible. We propose therefore that the careful description that we provided could represent a valuable contribution toward promoting good practices oriented toward widening the knowledge about available and effective design methods.

5.1.6.1 Limitations

The presented approach proposes a contribution to design methods for games for children with special needs by offering a model and a set of techniques to facilitate framing, selecting and orchestrating different contributions in an overall playful experience. However, some limitations are still present.

Firstly by addressing the PD to children with ASD of ages 10-11 years, we did not include the actual target users in the design process. Even if the children in the PD and the end-users were high functioning children with ASD, the difference in their developmental level could affect their preferences and interests, as happens with neurotypical children. Thus, further research is necessary to properly understand how this decision could have affected the design and how to include younger children in PD activities.

Second, the inclusion of the analysis of embodiment in the development of the system just represents an initial approximation. Even if we made an initial effort in this direction (e.g. including role play in the PD, analyzing in situ interaction), this kind of approach was not sufficient to properly extrapolate meaningful conclusions about embodied engagement and embodied meaning making. As a consequence, further research should address methodological solutions to address more strongly the role of embodiment.

5.1.7 Considerations for this Thesis

In relation to the global goals of the thesis, this study offered an initial approximation to devising strategies to include multiple stakeholders in the design of a FUBILE. Specifically, the proposed approach allowed tracking the influence and weight of the different contributions on specific design choices. Moreover, specific PD techniques were explored. On the other hand, this study offered a first approach to include embodiment in the design and evaluation process (e.g. use of role-play in PD, contextual analysis of in situ interaction). Nonetheless, this analysis should be further refined. Additionally, since this study addressed learning goals related to the acquisition of specific skills, further research should explore strategies to include children in the design of FUBILEs aimed at supporting the learning of content knowledge. These aspects will be addressed in the following Sections. Finally, the proposed approach allowed reformulating the role of the designer. In the study described in Section 4.1, we conceptualized the designer as somebody that is in charge of all decision-making process. In this study, instead, we acknowledged the relational nature of the design process and we situated the designer as a listener / observer and *bricoleur.*

5.2 An Evaluation-Driven Design Approach to Develop Learning Environments based on Full-Body Interaction

This Section is based on the articles:

- Malinverni, L., Schaper, M., & Pares, N. (2016, Submitted). An Evaluation-Driven Design approach to develop Learning Environments based on Full-Body Interaction. *Educational Technology Research & Development*.
- Schaper, M., Malinverni, L., & Pares, N. (2014). Participatory design methods to define educational goals for full-body interaction. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology (ACE '14)* (p. 4). http://dl.acm.org/citation.cfm?id=2663867

In this study, we present the design process of the EcoSystem project, a FUBILE aimed at supporting learning of environmental relationships. The EcoSystem project addresses learning goals related to the understanding of the system dynamics in the relation between the amount of pollution in the environment and the resources available to reduce it. For its development, we collaborated with experts in environmental education and with primary school children.

This project allows moving forward the methodological contributions delineate in Section 5.1. First, it integrates the proposed inclusive approach within an iterative design process. Second, it addresses learning goals related with content knowledge (ecosystem relations), hence extending the contributions beyond procedural skills. Finally, it explores further approximations to address the analysis of embodiment within the design process.

To guide this design process we proposed the use of an Evaluation-Driven Design Approach. The aim of this approach is to merge design and evaluation practices in order to employ children's interpretations as a central guide to inform design. To address this goal, we propose a set of techniques to elicit and analyze children's previous knowledge, their in situ interaction and their retrospective interpretations of the experience. The outcomes of this analysis are used to guide an iterative design process. In other words, the design is driven by findings from empirical research and refinements are built upon the analysis of *user-generated meanings*. The application of this approach showed to be highly effective both in facilitating continuous improvements in the proposed design and in reducing misconceptions of children using the environment.

5.2.1 Methodological Issues in the Design and Evaluation of FUBILEs

As mentioned in Section 3.1, research in FUBILEs is grounded on theoretical frameworks derived from cognitive science, developmental psychology and pedagogy. According to embodied cognition, our embodied experiences may facilitate us to construct multimodal representations (Barsalou, 2008) and sensorimotor experiences have a fundamental role in the development of cognitive skills. These assumptions and the importance gained by constructive pedagogies, lead the educational community to promote the need for approaches capable of actively and experientially involving the learners (Kolb et al., 2001; Papert, 1980).

Building on this perspective, Full-Body interaction has been considered as a promising approach for the development of learning technologies. Nonetheless, the review of the research in this field (see Chapter 3) identified relevant shortcomings in design and evaluation methods. At a design level, most projects derive from a Designer-Driven approach in which children and teachers are rarely involved in the design process (Alissa N Antle et al., 2013, 2008; Carreras & Parés, 2004; Charoenying et al., 2012; Edge et al., 2013). This trend leads designers to mainly focus on defining specific affordances, without taking into account how users make sense of and construct meaning during the experience. As a consequence, many FUBILE projects use a top-down workflow, which means that design always precedes assessment and the way in which children interpret and use the system is rarely used to further inform and refine the design. Furthermore, even in cases where end-users are involved in the design process, their involvement is mainly focused on usability testing without considering higher-level aspects such as meaning construction and situated action.

On the other hand, at an assessment level, projects aimed at evaluating the educational effectiveness of FUBILEs are mainly based on a stimuli-response model of learning, where evaluation focuses mainly on what can be assessed by quizzes (See Section 3.2). This tendency automatically excludes a deeper understanding of the meanings that are being created by children within a FUBILE experience and radically contradicts both the embodied and the constructivist framework on which many projects claim to be based.

This incongruence outlines the need for design and evaluation approaches capable of coherently fitting with the embodied learning framework and taking full advantage of the potential of Full-Body interaction. We, therefore, suggest that combining the analysis of user interpretations with a greater involvement of end-users and experts in the design process may benefit research in FUBILEs both at the pragmatic level of designing a specific environment, as well as at the theoretical level of expanding available knowledge in the field.

5.2.2 An Evaluation-Driven Design Approach

The identified limitations in the design and evaluation of FUBILEs point out the need for a critical reflection upon the currently employed methods and to delineate possible approaches capable of coherently fitting with the theoretical framework upon which FUBILEs claim to be based. Taking embodied cognition seriously requires moving beyond reductionist and positivist epistemologies (Steve Harrison et al., 2011) which tend to limit the notion of the learning process as one which is based on knowledge transfer only. Therefore, new methods must embrace relational and situated epistemologies (Overton, 2004) capable of dealing with the complexity inherent to any learning experience.

Relational epistemology proposes a holistic approach, which considers that the identity of objects, events and people derives from the relational contexts in which they are embedded (Overton, 2004). Therefore, it conceptualizes knowledge and meaning as ongoing processes, rather than as objects that exist "out there" or "in the mind of somebody" and that can be directly accessed by or delivered to others (Forsythe, 1993). From a design and evaluation perspective, this approach implies having to reconsider what we are designing and what we are evaluating.

To address this issue we propose an Evaluation-Driven approach to design and evaluate FUBILEs. The approach is based on considering the notion of user-generated meanings as the minimal unit of analysis. This notion refers to the meanings constructed by the users in the iterative connection between the meaning potential of an artifact, the user's previous knowledge and the features of socio-cultural context (Jewitt, 2013). Thus, it proposes using user-generated meanings as a central guide to inform design.

To apply this approach to design requires extending the current focus beyond the definition of object's affordances and encompassing a broader perspective capable of including the analysis of users' previous knowledge, interests and interpretations. At the same time, from an evaluation perspective, it requires the analysis of the meanings that are currently constructed and not only the ones that are expected by the designers (Kress, 2010) .

At a methodological level we define our approach by integrating and articulating techniques coming from Participatory Design (Druin, 2002a; Muller & Druin, 2003), Design-Based Research (Barab & Squire, 2004; Wang & Hannafin, 2005), Formative Assessment (Nicol & Macfarlane-Dick, 2006) and Grounded Theory. Participatory Design and Formative Assessment techniques allow us to grasp users' previous knowledge, interests, understanding and socio-cultural values and to incorporate them in the design process (Muller & Druin, 2003). In our approach, these techniques were therefore applied as tools to elicit users' contributions. In particular, we applied them to elicit children's representations, previous knowledge, misconceptions and *core meanings* (i.e. what children consider relevant to select, remember and recall).

However, our goal was not only to provide a descriptive account of the meanings that are constructed in a FUBILE, but also to use them as informative instruments to guide the design. For this purpose, we draw from Design-Based research to structure the workflow as an iterative design and assessment cycle. By considering design and assessment as inseparable instances, mutually reinforcing and informing each other, this structure allows us to constantly evaluate how the designed environment acquires meaning through user interpretations. Finally, Grounded Theory, understood as a methodological approach to inductively derive meaning from data, was used to analyze children's interpretations and their situated interaction with the FUBILE. From the previously defined techniques we elaborated the design and assessment workflow described in Figure 17.

To sum up, the Evaluation-Driven approach proposes an iterative design process where the analysis of user interpretations, core meanings, misconceptions and situated interaction is employed to inform and refine the design. For this purpose, it suggests a set of techniques aimed at facilitating this analysis. Our hypothesis is that the analysis of user-generated meanings allows the definition of guidelines for the development of a new FUBILE capable of effectively supporting learning. In the following sections we will describe how we applied the Evaluation-Driven approach in the development of a FUBILE aimed at supporting learning about environmental relations and pollution.

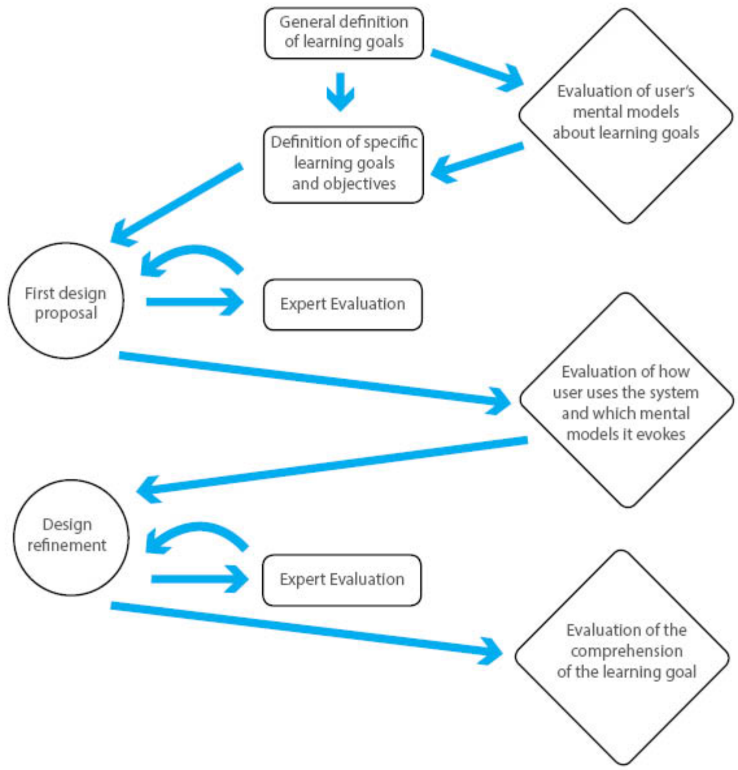


Figure 17. Workflow of the Evaluation-Driven Design process

5.2.3 The Study for the EcoSystem Project

For this study, we applied the proposed Evaluation-Driven approach to the development of the project EcoSystem, a FUBILE aimed at supporting learning of concepts related to environmental education. For this project, we formalized the Evaluation-Driven approach in a three-stage procedure aimed at creating continuous iterations and an on-going feedback loop between design and evaluation. The goal of the procedure was to define an iterative path to guide the design process from an initial ideation phase toward the evaluation of a prototype. For this purpose, children's participation during the process was modulated according to the different roles of children's involvement proposed by Nesset & Large (2004); i.e. co-designers, informants and testers. For all three stages, we worked with children between 10 and 12 years old. Children came from different middle class urban public schools of Barcelona. Each class group participated in only one of the three consecutive stages. Formally, the procedure was organized as follows:

Stage 1: Children as co-designers

This first stage of the study had the goal of defining the educational goals through the use of Participatory Design methods. For this purpose, we analyzed children's interests, representations, previous knowledge and misconceptions on concepts related to environmental education. Then, we employed them to define design requirements and to develop a first prototype of the game.

Stage 2: Children as informants

The second stage of the study had the goal of analyzing children's in situ interaction and interpretation of the first prototype. This analysis was oriented toward using their feedback as instruments to refine our design proposal.

Stage 3: Children as testers

The third stage of the study aimed at evaluating the effectiveness of the designed FUBILE in supporting learning and comparing its use with traditional instructional methods.

5.2.3.1 Stage 1: Children as co-designers

The goal of the first stage was to define specific learning goals according to experts' requirements and children's understandings of concepts related to environmental education. For this purpose, we initially collaborated with experts in Environmental Education from the Civic Centre "La Fabrica del Sol" (Barcelona). In this first stage we carried out two meetings with experts. During the meetings, experts did not proposed any clearly defined goals but instead focused on defining the main current objectives of environmental education (e.g. renewable energies and quality of the environment, global processes, sustainability and use of the resources, etc.). This broad spectrum of potential learning goals let space to define the learning processes according to children's interests and previous knowledge.

Subsequently, in order to frame more precisely the addressed learning goals, we carried out a Participatory Design (PD) workshop with children. The aim of the PD workshop was to ground learning goals on children interests and previous knowledge and to understand the representations that children have around environmental education. We embraced this goal by examining children's misconceptions and their *core meanings* on the topic. Through this approach we aimed at identifying knowledge gaps that needed to be addressed as learning goals. Furthermore, our analysis was oriented toward defining concepts that can bridge the gap between what children already know and novel knowledge, in order to use children's previous knowledge as an entry path for the comprehension of novel concepts (B. Rogoff, 1990). The findings gave us a starting point for the first design iteration. A detailed description of this study is available in (Schaper, Malinverni & Pares, 2014)

5.2.3.1.1 Methods

The PD workshop was carried out on three consecutive days in our university with a total of 68 children (girls = 30, boys = 38) between 10 and 12 years old. Each of the seven sessions lasted for approximately 45 minutes. Three sessions were carried out on the first day, two sessions on the second and two on the third day.

The sessions were guided by two researchers and structured as follows. After a short warm-up activity, we conducted a game based on the mechanics of the board game *Pictionary* using terms related to the environment (e.g. solar energy). The goal of the activity was twofold. On the one hand, we wanted to evaluate which terms the children were already familiar with, their previous knowledge and misconceptions on environmental topics. On the other hand, the activity was used to explore their embodied representations of those specific concepts.

Subsequently, children were divided into groups of four or five members and were provided with a fictive letter from a young boy writing from the future, according to the Narrative Inquiry technique (Dindler & Iversen, 2007). The letter was read aloud by one of the group members. Thus, the children were confronted with the critical situation of the environment in 100 years time. Starting from this letter, they were asked to write a list of positive and negative actions for the environment and to invent a game aimed at making other people aware of strategies to avoid further degradation of nature. The goal of this activity was not to produce workable games but to use game design as a strategy to delve into children's understandings about environmental issues. After a short explanation, the children produced drawings and written game descriptions. Then, each group presented their design ideas to the entire group.

5.2.3.1.2 Results

We analyzed the video recordings of the sessions, children's productions (i.e. drawings, lists, and written descriptions) and observers' annotations. The goal of the analysis was to identify children's previous knowledge, representations, misconceptions and core meanings related to environmental education. Firstly, video clips were transcribed using a narrative format (i.e. a detailed description of the overall unfolding of the session, including verbal and non-verbal behaviors). Subsequently, we inductively coded children's written contributions, video transcriptions and our annotations. Coding was performed using NVivo10 according to the Grounded Theory approach (i.e. key concepts were identified and marked with a series of codes and subsequently grouped into categories). Two researchers performed the analysis and, after individual coding, reached a common agreement through several meetings.

From the analysis, we concluded that previous knowledge and core meanings of children around environmental education were mainly related to the local system of recycling and to natural elements. Out of the 26 proposed games, 14 were related to the topics of recycling or waste and other 8 referred to plants or trees. Regarding misconceptions, we identified that in 9 out of 26 games children were wrongly applying the idea of "accumulation" to environmental aspects such as waste and watering plants. Specifically, the typical game mechanics of rewarding the player that obtains the most items, was inadequately translated into "the player that gathers most waste wins" or "the player that provides most water to the plants wins", which can clearly have a negative effect on the environment. Also, many children believed that the player must be rewarded for activities that are good for the environment (e.g. getting a prize for planting trees), as if the fact of helping the environment were not a reward in itself. Moreover, some children proposed to use actions that are positive for the environment (e.g. recycling or planting trees) as punishment activities for players who lost in the game. Many topics related to abstract concepts, such as light pollution or contamination, were only associated with home practices. Finally, children were also not aware of their own responsibility in global processes and how their actions can have an impact on all living beings on the planet, including themselves.

5.2.3.1.3 Outcomes

From the analysis of the PD sessions, we derived initial insights related to the definition of the learning goals and the bridging concepts. Children were already familiar with the local municipal recycling system and home practices related to saving energy or water. However, they presented relevant knowledge gaps and misconceptions about global and abstract aspects of environmental issues (e.g. pollution, the balance of the ecosystem and the interconnectedness of resources). We discussed our observations and ideas for the FUBILE with the expert in environmental education. Together with the expert, we decided to focus the learning goals of the FUBILE around the system dynamics (Zuckerman & Resnick, 2003) of the relation between the amount of pollution and the resources available to reduce or augment it. This learning goal was consistent with the embodied affinity between group dynamics and system dynamics and with the educational use of embodied exercises to promote system thinking (Sweeney & Meadows, 2010). Furthermore, to incorporate bridging concepts (Rogoff, 1990), we introduced elements such as waste reduction and plant growing in the FUBILE.

At the same time, we derived some insights to be incorporated into the game mechanics. Namely, we had observed that children presented controversial approaches related to positively reinforcing already beneficial actions or using environmentally responsible behaviors as punishment for those losing in the game. This focus on extrinsic motivation was potentially harmful for promoting environmental awareness, since it gives a negative connotation to environmental responsibility. As a consequence, we decided to focus on the intrinsic motivation of caring about the environment for its own sake.

First prototype: The EcoSystem Project

The outcomes of the PD sessions were exposed to an expert in environmental education during two meetings. By merging children and expert's perspective, we designed a first prototype. The game was based on a floor projection depicting a virtual simulation of a semi-urban landscape. Children had to play in groups of four and had to collaborate with each other to reduce the amount of air pollution in the environment. Children had to explore the existing relationships between carbon dioxide emissions and strategies for reduction and absorption of pollution. For this purpose, children played in the following three roles:

- Wind power: producing wind energy to replace the energy produced by a steam power station and hence reduce air-pollution,

- Plants: growing plants and vegetables to facilitate CO_2 absorption and contribute to the consumption of local foods,

- Recycling: recycling and producing compost to increase the growth of plants and reduce waste that would otherwise end up incinerated and hence increasing combustion.

Air-pollution was to be visualized as a cloud covering the game ground. Thus, as pollution increased, the amount of space available for playing decreased. In order to make the cloud decrease children needed to understand the relation between the elements present in the game (see Figure 18) and properly collaborate with other players. This proposal was developed as Wizard of Oz prototype (Markopoulos et al., 2008), where a researcher manipulates the interactivity. Its physical configuration was based on a 2x3 meter floor projection area.

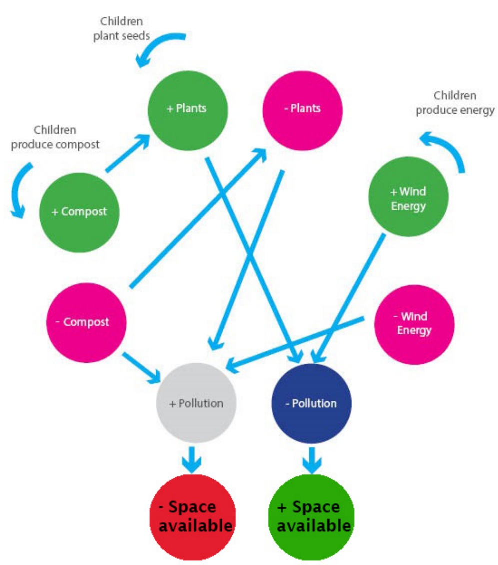


Figure 18. Behavior of the different game elements and their reciprocal relationships

5.2.3.2 Stage 2: Children as Informants

The aim of the second stage of the study was to analyze how children made sense of the environment and what meanings they constructed while playing with the EcoSystem prototype designed in the first stage. This analysis was oriented toward using their interpretations to define design refinements. The research was guided by two main questions:

- *How do children interact with the environment?*
- *How they interpret the experience?*
-

5.2.3.2.1 Methods

This second stage was carried out during one day at our university with the participation of 20 children (girls = 10, boys = 10) aged from 11 to 12 years old, who had not participated in the first stage. Before the sessions, the children were randomly separated into five groups of four. Each session lasted for approximately 30 minutes. To analyze how children interacted with the system the groups were randomly distributed into two conditions:

1) The Designed Actions condition: The children received explicit instructions on the physical action that they had to perform for each activity in the game with virtual and physical objects. The following actions-activity relations were used:

- Stand in front a windmill and spin arms to move the propellers and generate wind power;
- Stand still in whatever location for five seconds to create plants on that spot;
- Grab physical rubbish cards to drop them in the correct litter container and obtain compost.

2) The Intuitive Actions condition: The children did not receive any explicit instruction on the physical action that they had to perform and had to invent and improvise. The observation of children's interaction was performed through field notes and video analysis.

On the other hand, to analyze how children retrospectively understood the system we used the following techniques: an open-ended questionnaire, a conceptual map, a semi-structured group discussion and a short essay on the topic. These data were analyzed by focusing on core meanings and misconceptions.

Figure 19. Role cards: plants (left), wind power (center), recycling (right)

Procedure

One group at a time was taken to the laboratory where the FUBILE was set up. To ground their expectations, we informed them that we would use a low-tech prototype (Hanna, Risden, & Alexander, 1997) and explained to them that they were invited to take part in the improvement of the game. Using role cards (Figure 19), we introduced the common goal and the three different interaction roles (wind power, plants, and compost). Cards were designed in collaboration with experts and provided key information about the elements in the environment and their reciprocal relations.

Figure 20. Floor projection of EcoSystem Project

The cards were read aloud by one child at a time and the children were invited to play for six minutes (Figure 20). When the game finished, the children filled out an open-ended questionnaire. The questionnaire included five questions asking children to explain the role of the different elements (wind power, plants, recycling, and pollution) and their reciprocal relations. Furthermore, they were asked to propose other possibilities to reduce pollution.

Subsequently, they played a second trial of the game, but this time with a larger amount of pollution. At the end of the session, participants individually filled out a conceptual map reflecting the relationships between the different elements of the game. The conceptual maps depicted the different elements present in the game. Children were asked to trace arrows to connect related elements and briefly explain these relationships. Finally, the individual contributions were further elaborated in a semi-structured group discussion. At the end of the session, the children were taken to a different room where they were asked to write a short letter explaining the game to a friend, describing whether they liked it or not and how it could be improved.

5.2.3.2.2 Results

Results were obtained through the qualitative analysis of the video recordings, field annotations, semi-structured discussions, questionnaires and conceptual maps.

Misconceptions and core meanings

We used content analysis based on a Grounded Theory approach to observe misconceptions and core meanings related to wind power, recycling, plants and system dynamics. In relation to wind power, nine children either did not answer or reported misconceptions. The main misconceptions were related to the idea that the movement of the windmill “blows” pollution away. This misconception could have been a consequence of the graphic design strategy used since pollution could give the impression of being “pushed away” by the windmill.

On the other hand, four children related the game only to recycling and several of them mainly focused on picking up the waste from the floor. These responses may have been caused by the salience of recycling both in its representation in the FUBILE as well as in children’s previous knowledge; specifically, in the prototype the waste was scattered on the floor and occupied a large area in the projected environment. While the relation between the spatial arrangement and children's previous knowledge may have focused their attention too much on this aspect, other misconceptions also related to recycling were observed. Several children believed that picking up waste simply freed up more space on the ground and they did not understand the relation between waste and carbon dioxide. Finally, in relation to the role of plants, ten children did not answer or report misconceptions. This was apparently related to a lack of understanding of the process of photosynthesis and its relationship with the reduction of carbon dioxide through absorption by plants.

Children's Interaction

To analyze children's interaction with the environment we transcribed their actions according to a narrative approach. Specifically, we contrasted the interactions of children assigned to the *Intuitive Actions Condition* with our proposed actions in the *Designed Actions Condition.*

A certain consistency was present between the proposed designed actions for windmills and recycling. In the Designed Actions Condition the spinning arms movement in front of the windmill activated the wind energy. In the Intuitive Actions Condition several children also intuitively tried to spin or move their arms to activate the windmill. At the same time, children in the Intuitive Actions Condition also performed the action of picking up waste and throwing it in the correct disposal.

Conversely, for the role of growing plants we instructed children to perform the action of standing still for five seconds in a chosen location, impersonating the seed. The children in the Intuitive Actions Condition did not consider this action at all, but instead tended to touch or rub the floor projection as if they were sowing the seed. Furthermore, in the final essay two children, belonging to the Designed Actions Condition, reported that the assigned interaction for growing plants was strange and that they would like to change it.

5.2.3.2.3 Outcomes

Based on our results, we identified useful aspects to be considered for the development of a second prototype. Concerning design decisions, we decided to change those game elements that clearly caused misconceptions. Starting from the misconception of "air-pollution being blown away by windmills", the visualization of air-pollution was changed in order to make it more homogeneous and dynamic. Waste distribution was modified as children were focusing too much on recycling without considering other tasks. This should also overcome misconceptions related to believing that "recycling had to be done to create more space on the ground", rather than understanding that recycling is directly and indirectly connected to carbon dioxide production. Consequently, instead of being scattered over all the floor projection, waste was placed only in one specific area. Furthermore, the interaction related to plants was substituted with the action of "digging the earth" that was already performed by the children in the Intuitive Actions Condition. Finally, since the children asked for more interaction while playing the game, we decided to introduce a novel role based on the strategies that children proposed for reducing pollution. Therefore, a water power station was added to the game. Before using this new game element, we consulted the opinion of experts on environmental education. Together with the experts, we defined its representation and role in the game. With the described constraints taken into account, we developed a second Wizard of Oz prototype, which was tested in a third stage of the study.

5.2.3.3 Stage 3: Children as Testers

The goal of the third stage of the study was to evaluate the proposed design approach by: (1) evaluating whether the designed FUBILE supported learning and (2) testing whether it could be effective to complement Traditional Instructional Methods (TIM). Our hypotheses were that:

H1: There will be a significant learning gain, measured through pre- and post-test conceptual map assessment, in children that use the FUBILE.

H2: There will be a significant learning gain in children that complement TIM with the use of the FUBILE, with respect to children that use only TIM.

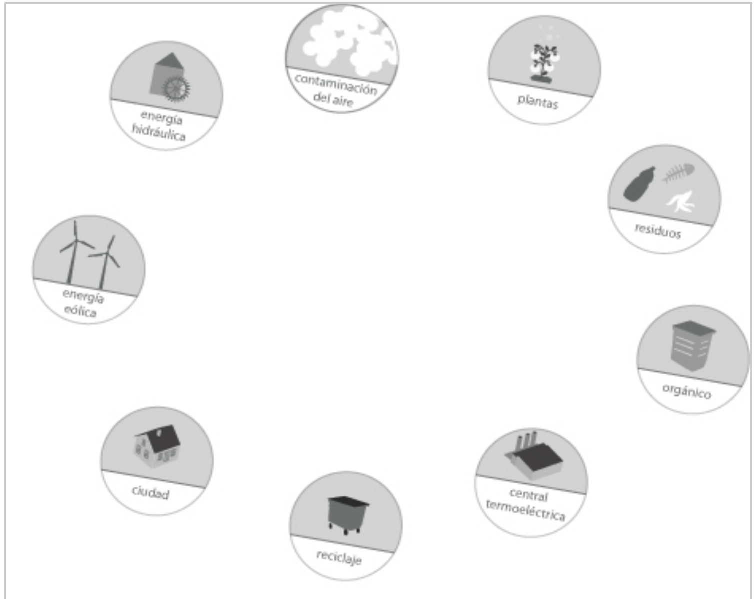


Figure 21. Representation of elements in the conceptual map designed to assess learning gain.

5.2.3.3.1 Methods

These hypotheses were based on the idea that the FUBILE would support learning by grounding abstract concepts in a concrete experience (Glenberg et al., 2007; Goldin-Meadow, 2011) by offering different modes of representation (Paolo et al., 2007). At the same time, from the perspective of the global design process, eventual learning gains should be indicative of an alignment between designers' intentions (i.e. to communicate relationships in the ecological environment) and users' understandings. To carry out this stage we established two conditions:

1) The *FUBILE + TIM condition*, in which we evaluated the complementary use of the FUBILE and the TIM

2) The *TIM Only condition*, in which we evaluated the use of TIM alone.

Children in this third stage did not participate in any previous phase of the research. Assessment methods were based on a conceptual map (Figure 21), a semi-structured discussion and an open-ended questionnaire.

FUBILE+TIM condition

The first phase of this stage was carried out during one day at our university. A class group of 24 new children (age: M = 11.52, SD = .12) participated and were randomly assigned to six groups of four. At the beginning of the activity, the children were taken to a classroom where they were asked to individually fill out a conceptual map to evaluate their initial knowledge on the topic. The participants were asked to draw connections and to give explicit explanations of the relationships between the connected elements. After that, one group at a time was taken to the laboratory where the FUBILE was installed. Here children were introduced to the activity and role cards (constituting the TIM) were distributed. The cards were read aloud by one child at a time. Subsequently, children played with the FUBILE for six minutes. At the end of the game, children were again asked to fill out the conceptual map. A semi-structured discussion was then used to discuss the individual contributions. Finally, children individually filled out an open-ended questionnaire similar to the one used in the previous stage. Each session in total lasted for approximately 35 minutes.

TIM Only condition

The study was carried out during one day at a primary school. A class group of 24 children participated (age: M = 10.79, SD = .41) and were randomly assigned to six groups of four. At the beginning of the activity, the children were asked to individually fill out the conceptual map. Then, one group at a time was taken to a separate room where role cards (TIM) were distributed. The cards were read aloud by one child at a time. After the readings, the children were taken back to the classroom and the teacher distracted them for around ten minutes with an unrelated activity (similar to the time dedicated to playing with the FUBILE in the FUBILE+TIM phase). Finally, the assessment was repeated with a new sheet of the same conceptual map.

5.2.3.3.2 Results

Evaluating learning gains

To evaluate the effectiveness of the FUBILE, we analyzed the pre- and post-test of the conceptual map for both conditions (FUBILE + TIM vs. TIM Only). First, the number of correct connections was identified. Second, each explanation was evaluated by two raters according to a pre-established scale that ranged from 0 to 2 points, based on the level of correctness and completeness of the answers. Individual ratings were compared and discussed until a common agreement was found.

The results obtained were first analyzed within groups for both conditions in order to assess eventual learning gains. Since data were normally distributed we used parametric tests. In both cases, paired sample t-tests reported a significant difference in the number of correct connections between pre- and post-tests. In the FUBILE+TIM condition, children reported more correct connections in the post-test (M= 9.14; SD = 2.88) than in the pre-test (M = 6.24; SD = 2.94), t (23) = -4.370 p < .001. Furthermore, Cohen's effect size value (d = 0.91) suggested a high practical significance. In the TIM Only condition, children also reported more connections in the post-test (M = 6.62; SD = 2.84) than in the pre-test (M =5.75; SD =1.94), t (23) = -2.287, p = .032. However, in this case Cohen's effect size value (d = 0.48) suggested a small to medium practical significance. Therefore, we conclude that in both cases learning gains between pre- and post-test were obtained, but these had a greater significance in the FUBILE+TIM condition.

Comparing conditions

An independent t-test reported no significant difference in pre-test between FUBILE+TIM and TIM Only. Thus, the results of the post-tests of the two conditions were compared. By conducting an independent t-test we found a significant difference in the number of correct connections between the two conditions. Children in the FUBILE+TIM condition (M= 9.14; SD = 2.88) reported a significantly greater amount of connections than children assigned to the TIM Only condition (M= 6.62; SD = 2.84), t (46) = -2.244, p = .03. We conclude that using the FUBILE in combination with the TIM is more effective than using the TIM alone.

Qualitative analysis

The qualitative analysis was performed only on data from the FUBILE+TIM condition. We analyzed the open-ended questionnaires, the conceptual maps and the video recordings of the group discussions. The analysis focused on identifying novel knowledge, resolved and unresolved misconceptions and possible newly created misconceptions, both at the level of individual elements (wind power, plants, compost, water power, pollution) and in their reciprocal relations. The comparison of conceptual maps between pre- and post-test showed improvements in particular in the connections of compost with plants and renewable energies. Misconceptions were related to the connection of wind and water power to other game elements such as the steam power station.

The analysis of the open-ended questionnaires detected a significant reduction in misconceptions when compared with the previous stage. The misconceptions related to the plants and recycling were eliminated. Furthermore, we observed that the children focused less on the recycling action than in the previous stage. However, the comprehension of the mechanism and role of wind power was still not clear, even when the misconception of "having pollution being blown away" had actually disappeared.

Such findings suggest that the design improvements between the first and second prototypes helped children to resolve several misconceptions. However, further design improvements were still necessary since a new misconception related to the water power station emerged. For instance, six children believed that the water power station either cleaning or contaminating the water.

5.2.3.3.3 Outcomes

This third stage of the study showed the effectiveness of combining traditional instructional methods with a Full-Body interaction experience to support learning. At the same time, it supports the benefits of using the Evaluation-Driven Design approach to define design improvements. Specifically, the changes in design, based on the findings of the second stage, led to fewer misconceptions and improved understanding of some critical aspects. However, at a design level, further improvements could be addressed. Especially, possible improvements could involve a better visualization of renewable energies to make the role of these elements clearer. Furthermore, this strategy could help us make the reciprocal relations between the different elements in the game much more evident and "tangible".

5.2.4 Discussion

We presented an Evaluation-Driven Design approach aimed at understanding and integrating children's interests and interpretations as central guidelines to inform the design process. This approach allowed paying a close attention to the analysis of children's contributions during the overall design process. As a consequence, it permitted to attribute a substantial relevance to end-users in the definition of design requirements. Its application in the design of the Ecosystem Project allowed guiding the development of a FUBILE capable of supporting learning. Furthermore, from a broader perspective, the present study contributes to research on design and assessment methods for novel interfaces and extends the understanding on the use of Full-Body Interaction to support learning.

5.2.4.1 Design and Evaluation in FUBILEs

The Evaluation-Driven Design approach is based on an iterative cycle of design and assessment, which focuses on analyzing the meanings that children construct and how designers employ them to guide and optimize design. Its inclusive and participatory nature confirms the importance of collaborating with end-users during the design process (Muller & Druin, 2003). At the same time, its progressive structure endorses the effectiveness of employing cycles of refinements in design research (Barab & Squire, 2004).

From the perspective of designing and assessing FUBILEs, the current approach offers some relevant contributions to practitioners. First of all, it moves beyond Designer-Driven or Technology-Driven Design approaches which depend on the intuition of the designers and neglect the contribution of other stakeholders. Secondly, it contributes to a methodological reflection on the employed assessment methods. In particular, it presents specific contributions related to the structural organization of the research, the definition of the unit of analysis, and the employed elicitation techniques.

At a structural level, the three stages procedure (for a summary see Table 15) allowed tapping into different aspects of meaning construction. The process of constructing meaning emerges in the interplay between the affordances of an experience and "the intentions and knowledge that people bring to that encounter" (Jewitt, 2013). Thus, our previous knowledge makes us engage with an experience in a very specific manner. Subsequently, by combining previous knowledge with the features of the experience and by reflecting on the experience, we may transform it into an object of knowledge. Our three-stages approach, therefore, allowed to take into account different aspects that contribute to meaning construction by observing (i) children's previous knowledge and interests (Stage One), (ii) in situ interaction (Stage Two), and (iii) conceptual learning (Stage Three).

On the other hand, the definition of a broad unit of analysis based on users' interactions with the system, children's representations, previous knowledge and core meanings, allows us to go beyond the risk of reductionism of defining a unit of analysis that is too narrow to properly observe a phenomenon; e.g. focusing only on cognitive aspects through quizzes. In particular, the analysis of misconceptions and core meanings proved to be particularly effective both for defining educational needs and for guiding design improvements. Specifically, the analysis of misconceptions related with children's previous knowledge and provoked by the design of the system helped in framing learning goals and improving the designed experience. An example of this process can be found in the improvements introduced between the first and the second prototypes. In the first prototype the analysis of children's core meanings and misconceptions was used to define requirements for the development of the second prototype. Specifically, this approach allowed filtering and redefining game elements that caused misconceptions.

At the same time, the analysis of in situ interaction showed to be a relevant instrument to provide insights for improving the interaction with the system both at the level of user experience as well as in terms of users' understandings. Furthermore, it suggested possible guidelines for the development of FUBILEs. Although further research is needed to corroborate these initial findings, from the analysis of the Intuitive Actions condition it seems advisable to employ gestures based on a consistent analogy with the addressed phenomenon to design embodied interaction with FUBILEs. Consequently, we suggest that research in embodied interaction should pay a close attention to identify what kind of play the interface suggests and what kind of sensorimotor experience it promotes. This analysis could help in properly guide situated design choices.

At the level of elicitation methods, techniques proceeding from PD (e.g. game-design activity) proved to be particularly effective for gathering data about children's representations and misconceptions. Conversely, techniques such as semi-structured group discussion did not offer us valuable additional insights. A possible explanation of these findings can be related to the agentive nature of PD. In other words, in a design activity children can project and materialize their own interests and representations in the production of an artifact (Kress, 2010). Such artifacts can provide researchers with rich data for investigating the meanings that are generated. However, the purpose of our study was not to systematically compare elicitation techniques, and therefore, further research should be carried out to explore this hypothesis. Within that, one possible research direction could address the exploration and comparison of PD techniques applied to assessing children's meaning-making processes.

Finally, besides the methodological contributions, the current research also broadened our understanding on Full-Body interaction and learning. The experimental evaluation of the second prototype showed a significant improvement in children's knowledge about environmental relations. Furthermore, it indicated that using the FUBILE in combination with a traditional instructional method, such as a reading activity, was more effective than the reading activity alone. These results confirmed previous findings related to the importance of using concrete experience to ground abstract concepts (Glenberg et al., 2007; Glenberg, 2010; Goldin-Meadow, 2011) and revealed the potential for using FUBILEs to complement and strengthen traditional instructional methods. At the same time, these results opened up relevant research possibilities related to evaluating the effectiveness of combining FUBILEs with other instructional methods to reinforce learning.

Table 15. Summary of the application of the Evaluation-Driven Design approach in the development of the EcoSystem Project

Study	Goal	Elicitation technique	Unit of analysis	Research method	Outcomes	Contributions
First stage: children as co-designers	Define specific learning goals	Game- based PD Techniques	Children's previous knowledge, misconceptions and core meanings	Content analysis: grounded approach	- Definition of area of knowledge that needs to be addressed - Identification of bridging concepts (recycling, plants)	Allow the understanding of children previous knowledge
Second stage: children as informants	Analyze what meanings children construct while playing with the first design proposal of the EcoSystem Project	- Open-ended questionnaire - Conceptual maps - Semi-structured discussion	Children's misconceptions and core meanings	Content analysis: grounded approach	- Identification of misconceptions provoked by the system - Improving of the physical interaction - Definition of design refinements	Allow to understand how children build meaning in embodied interaction
Third stage: children as testers	Evaluate the effectiveness of the second design of the FUBILE in supporting learning	- Open-ended questionnaire - Conceptual maps - Semi-structured discussion	- Learning gains - Children's misconceptions and core meanings	- Pre-/post-test between subjects experimental design - Content analysis: grounded approach	- Significant learning gains between pre- and post-test - Significant difference between using or not the FUBILE with traditional instruction methods	Allow to understand how children had transformed the experience into an object of knowledge

5.2.4.2 Limitations and future research

The Evaluation-Driven approach proved to be highly effective for developing a FUBILE capable of supporting learning of ecosystem relations. Although it is not possible to derive a causal relationship between the proposed design approach and the outcomes of the study, we have shown that our method contributes to improving design and assessment strategies for FUBILEs. However, our proposal represents just one of the possible paths to achieving effective FUBILEs. Further research should be carried out to compare the limitations and benefits of applying different design methods.

In addition, while the present study proposes and discusses a number of elicitation and analysis methods, further research should also address the systematic comparison of different techniques. In our study, we analyzed children's in situ interaction with the environment through direct observation and narrative field notes. Although these methods provided useful insights, a deeper methodological effort should be oriented toward improving the analysis of situated interaction in order to better understand embodied meaning construction. Relevant opportunities can be found in methods derived from fine-grain interaction analysis (Streeck et al., 2011) and multimodal analysis (Price & Jewitt, 2013a). Finally, as a preliminary methodological exploration, this study was not oriented toward developing a product for a specific context (e.g. school or museum). Further research, therefore, should address approaches capable of properly integrating this design method within context-specific requirements.

5.3 Understanding and Integrating Children's Contributions: Lessons Learned

The two presented studies address the methodological issues related to understanding and integrating children's contributions in the design of FUBILEs. . The two approaches were designed and tailored to fit the specific requirements of the two systems. Specifically, the first study addressed as target users children with ASD and aims at supporting the procedural learning of social skills. The second study, instead, involves neuro-typical children and address the learning of concepts related to ecosystem's relations. Both approaches showed to be effective in guiding design process by allowing to more properly frame the kind of experience that we want to support and the resources available to design them. In the next sections we will review these aspects in order to extrapolate the lessons learned from these methodological approximations and set guidelines for future research.

5.3.1 Design Methods: Participatory and Iterative Design Processes

Both projects confirmed the relevance of PD techniques to bring design closer to the universes of meanings of the users (Muller & Druin, 2003). At the same time, they reinforced the importance of iterative design processes (Barab & Squire, 2004) and the need of considering each design choice as a hypothesis that needs to be evaluated. Moreover, the two studies allowed extrapolating some initial contributions to guide the design process of FUBILEs.

First, both studies made visible the situated nature of design as a process that emerges from the interaction and mediation of different agents (e.g. children, experts, designers). In this context, we proposed the role of the designer as a listener/observer and *bricoleur*. This standpoint on our role during the design process allowed us to pay attention and to orchestrate the different contributions in the design of experiences that combine multiple requirements. Second, the presented studies offered some concrete guidelines on participatory and iterative design methods. However, besides their similarities, the two studies also present some relevant methodological differences motivated by their different goals and populations.

5.3.1.1 Models of participation

The two studies presented different approaches to the employment of PD techniques. In the first study (Section 5.1), users participation was mainly addressed in the first stage of the process and their subsequent involvement was just as testers. Nonetheless, during the ideation stage, the same children participate in the overall process (five sessions). Instead, in the EcoSystem project, children are involved during different stages, according to different degrees of participation (co-designers, informants, testers). However, their involvement is intermittent and different children are involved in different stages for short time periods.

These different methodological decisions may have relevant implications both on the PD process as well as on the design outcomes. In the first case, the longer-term involvement of the same group of children allowed bringing them closer to the position of being design partners. As a consequence, this model of participation allowed children to get more engaged with the design process, to understand better its specificities and to feel empowered by the perception that they are "working at their own game". This approach can present benefits both for the children themselves and for the quality of the proposed contributions. Furthermore, we considered that this longitudinal involvement could have been particularly beneficial to establish a climate of confidence and familiarity with ASD children. However, this approach may run the risk of reflecting too closely the specific viewpoint of the group of children that is involved. Hence, it may end up defining the design of a product that is meaningful for them but not necessarily for others.

On the other hand, the second study employed PD accordingly to a survey-like structure. This means that PD techniques were mainly employed to facilitate the elicitation of specific information from a large sample of population. This model of participation was selected by taking into account the goals of the experience. Since the designed system aimed at supporting the conceptual understanding of specific aspects, our goal was to delineate a detailed overview of children's knowledge on the topic. Hence, the proposed approach allowed defining a more encompassing understanding on this aspect. Nonetheless, it reduced the weight of their contributions and the benefits that children may have from participating in a PD workshop. However, their longitudinal involvement in the different stages of the design process allowed starting to address more concrete aspects related to embodied interaction and system configuration. In particular, we suggest, that children's involvement as informants with a raw version of the prototype may be a particularly fruitful approach to guide the design of FUBILEs since it allows addressing aspects related to embodiment.

To sum up, both approaches presented their benefits and their limitations. Thus, the tradeoff between these aspects should be carefully considered in relation to our specific research goals and our ethical concerns. Nonetheless, we strongly suggest that longitudinal involvement of end users and the children-as-informant model can be crucial to properly develop a soundly FUBILEs.

5.3.1.2 Participatory Design Techniques

In both studies, we explored different techniques to involve children in the design process. Within them, we considered as particularly useful: *the combination of narrative and game design*, the *Pictionary activity* and the *Intuitive Actions* activity.

Combining narrative and game design

In both studies, even if with different modalities, we choose to combine the use of narrative with activities related to game design. This approach confirmed the effectiveness of narrative in guiding design practices (Dindler & Iversen, 2007; Dindler et al., 2005). Furthermore, especially in the second study (the EcoSystem project), the game design activity showed to be particularly effective to delve into the analysis of children's previous knowledge, representations and misconceptions. This outcome can be related to the fact that the task of designing a game is an activity that is meaningful and engaging by itself. Hence, it facilitates children's involvement and, at the same time, it offers affordances to allow them projecting and materializing their own ideas in the creation of an artifact. We, thus, suggest that this technique may constitute a useful approach to facilitate designers grounding their proposals on children's interests and previous knowledge (Nathan & Robinson, 2001).

The Pictionary activity

In the second study, the use of the Pictionary activity during the first stage of the design process (Section 5.2.3.1) showed to offer relevant affordances to grasp children's representations across different modes. Furthermore, its playful nature was engaging and motivating for children and its time-based structure avoided them focusing too much on surface details. As a consequence, we suggest that this technique may represent a useful tool to playfully and "quickly-and-dirtily" grasp children's conceptions around specific topics.

The Intuitive Actions activity: users as informants in the design of embodied interaction

In the second study, the analysis of in situ interaction in the "Intuitive Actions condition" offered relevant insights to guide the design of the physical interaction with the system. From our experience (Schaper, Malinverni & Pares, 2015), we noticed that addressing aspects related to embodied interaction during the ideation stage might represent a particularly challenging task for children. This difficulty can be due to the decontextualized nature of the task and to the novelty of the proposed interaction paradigm. As a consequence, children may tend either to reproduce traditional interaction modalities or to interpret the task as a sort of theatrical representations.

Instead, we suggest that the user-as-informant model can represent a more fruitful approach to incorporate embodiment in the PD process. This approach, by framing PD around the situated experience that children have with a raw prototype, can help them in properly ground their contributions. Furthermore, the setting of conditions to allow users to intuitively interact with the FUBILE permits to observe the specific affordances of the designed experience and grasping behavioral aspects that cannot be expressed by words. However, further research is still necessary in order to explore how to properly combine PD and the analysis of in situ interaction. Furthermore, we should pay a close attention to the features of the raw prototype, in order to let enough space for children contributions.

5.3.2 Evaluation methods: The selected unit of analysis

In both studies, we made an initial approximation to address the analysis of in situ interaction. In the first study, Pico's Adventure, this approach mainly focused toward understanding the relation between specific game elements and children's social behavior. This approach allowed taking into account the affordances of specific contextual elements for supporting social initiation. As a consequence, it provided initial guidelines and insights to better understand the suitability of specific design choices. Similarly, in the second study, the EcoSystem project, the analysis of in situ interaction allowed understanding and filtering game elements that were provoking misconceptions and improve the design of embodied interaction.

In this second study, besides considering in situ interaction, we also made an initial effort to combine these observations with the analysis of children's retrospective interpretations of the experience. For this purpose, we employed open-ended questionnaires, conceptual maps and the "letter to a friend". These techniques facilitated tapping into relevant aspects of children's interpretations of the experience. Furthermore, the grounded content analysis of *core meanings* and *misconceptions* showed to be particularly fruitful to guide design improvements in projects aimed at addressing conceptual knowledge.

More importantly, both studies proposed a relevant paradigm shift with respect to previous research

(Section 4.1) since they focus more on improving design rather than proving it. This shift allowed gaining a much deeper understanding on the specificity of Full-Body interaction than the studies presented in Section 4 (Archimedes and Phygame). Nonetheless, in both cases, some relevant methodological shortcomings were still present. Specifically, we suggest that future research should address the definition of instruments capable of better systematizing the role of different embodied and contextual resources in meaning construction. At the same time, researchers should pay a closer attention to how embodiment can offer a relevant display through which children communicate aspects that cannot be expressed by words (Goldin-Meadow, 2011).

5.3.3 Design Qualities: Meaning Potential, Embodied Consistency and Salience

Researching the meaning potentials of Full-Body interaction

The two proposed studies allowed to better frame design in relation to the meaning potential of this medium (e.g. what can be expressed through Full-Body interaction). Specifically, they allowed exploring the potential of Full-Body interaction both to support the procedural learning of specific skills (Section 5.1) as well as to provide entry paths to conceptual understanding (Section 5.2). This goal was achieved by combining the knowledge on how the body is employed in traditional education (e.g. use of role-play to support system thinking and social learning) with findings from embodied cognition (e.g. the role of embodiment in social cognition, see Section 2.2) and with the analysis of children's in situ interaction. These three levels of grounding may represent a first step to better understand the potential of Full-Body interaction.

Embodied Consistency and Salience

From an interaction design perspective, the EcoSystem project confirmed our initial insights (Section 2.2 and Section 4.1.3) on the importance of designing physical interactions that are consistent with the addressed phenomenon. It, therefore, strengthened the importance of *embodied consistency* as a relevant design quality for FUBILEs. Furthermore, in this same study, the analysis of the misconceptions provoked by the system showed how certain spatial configurations may help or hinder children's possibilities to focus on what matter of experience (e.g. the visual salience of the waste in the first prototype diverted children's attention from the main learning goal). This issue, therefore, points out that in our design decisions we should pay a close attention to the salience of the specific resources that we are employing.

To sum up, the presented studies offered initial insights and approximations to guide research on appropriate methods to design and evaluate FUBILEs. Furthermore, the analysis of their limitations, allowed tracing the path for subsequent research (Chapter 6).

6 RESEARCHING AND ANALYZING EMBODIED MEANING CONSTRUCTION: TWO CASE STUDIES

In Chapter 5, we presented two case studies aimed at offering examples of methodological approaches to understand and to integrate children's contributions in the design of FUBILEs. They, hence, contributed to situate the design practice at the intersection between users' interpretations and designers' communicative intentions. However, as reported in Section 5.3, some weaknesses were still present in the evaluation of in situ interaction and in the usage of users' embodiment as a source to inform design.

As Ackermann (2007) pointed out, design consists in the effort of giving form to ideas and making them present in the world. In other words, the ultimate goal of designers is to decide which semiotic resources they can use to express certain concepts and to define specific material solutions for embodying ideas in concrete artifacts. These concrete material solutions will constitute the foreground upon which users will construct their understanding during in situ interaction. As a consequence, as introduced in Section 2.2, in the field of Full-Body interaction, the employed material solutions cannot be regarded just for their functional role. Instead, their role in shaping experience and meaning construction should be fully acknowledged. This requirement implies the need for methodological approaches capable of properly researching and analyzing the role of embodied and spatial resources in shaping the understanding of the experience. At the same time, taking embodiment seriously, also, requires a better understanding of the meanings that people express through their bodies. As Antes (1996) highlights, bodies cover a fundamental role in communication and observing people's embodiment can offer a window to their minds (Broaders & Goldin-Meadow, 2010).

To address these methodological requirements, in the next sections, we will present two case studies aimed at researching approaches to properly analyze the role covered by embodied and spatial resources in shaping and expressing meaning. In both studies, we applied an analytical framework derived from multimodal analysis (Jewitt, 2013; Kress, 2010) during an iterative participatory design process based on the users-as-informants model. In the first study, we will present its application in the design of a FUBILE aimed at fostering social initiation in ASD children. In the second study, a revised version of this framework will be applied to the development of a FUBILE aimed at supporting children's reflections on group behavior and discrimination. Finally, the lessons learned from these methodological approximations will be discussed.

6.1 Towards Methods for Evaluating and Communicating Participatory Design: a Multimodal Approach

This Section is based on the article:

- Malinverni, L., Mora-Guiard, J., & Pares, N. (2016). Towards methods for evaluating and communicating participatory design: A multimodal approach. *International Journal of Human-Computer Studies*. http://www.sciencedirect.com/science/article/pii/S1071581916000367

The present study forms part of a research project aimed at developing a FUBILE to support social initiation in children with Autistic Spectrum Disorder (ASD). Similarly to the study presented in Section 5.1, the research addresses the methodological challenges related to understanding and integrating children's contributions in the design of a FUBILEs. In particular, the current research pursues the goal of more rigorously taking into account embodiment during the design process.

Results proceeding from previous research (see Section 5.3) suggested the potential of using an informant model for PD, i.e. children are invited to experiment with a raw prototype and contribute to its improvement (Nesset & Large, 2004). Its benefits are mainly related to the opportunities that it offers to observe in situ interaction and to ground design activities on the experience that children have with the system. Nonetheless, our initial studies highlighted the need for more robust methods to analyze embodiment and to combine this analysis with the outcomes of the design and elicitation activities.

Starting from this perspective, we propose the use of a framework derived from multimodal analysis (Jewitt, 2013; Kress, 2010) to collect, analyze and interpret users' contributions during design activities and during in situ interaction. This analytical model was applied to an informant PD workshop with ASD children aimed at refining the design of a FUBILE.

Results showed that multimodal analysis, by providing concepts and methods to collect and analyze a wide range of resources employed by people to construct meaning (i.e. gestures, gaze, movements, verbal interactions, etc.), allows combining and interpreting participants' contributions and embodied meaning-making from a broad and rigorous perspective. It, thus, allowed gathering meaningful insights for the design and evaluation of FUBILEs. Furthermore, it permitted to extend the analysis beyond the intentional communicational prompts, hence overcoming eventual barriers of communication and expression. This approach, thus, allows addressing some of the methodological weaknesses of the analysis of PD workshop, hence contributing to research related to defining robust and coherent methods to evaluate and communicate PD within the design team and with experts (Frauenberger et al., 2014).

In the following sections, we will introduce the identified methodological issues and report the procedure and results related to the application of multimodal analysis to PD. Finally, the benefits and limitations of the proposed approach will be discussed.

6.1.1 Issues in the Analysis of Participatory Design

The importance of Participatory Design is increasingly acknowledged in the HCI community. According to ACM digital library database, there has been a 580% growth, from 2003 to 2013, in the number of papers published on PD. Given this impressive growth, it becomes evident the need for defining more rigorous methods for the analysis of PD (Frauenberger et al., 2014). Nonetheless, in the quest for methodological appropriateness, it becomes necessary to consider the implications and assumptions underlying different methodological approaches. As Bachelard (2002) stated, knowledge always acts as a light that casts shadows. As a consequence, it is necessary to pay a close attention on the employed research methods, as they shape the way in which information is constructed, collected and interpreted (Harding, 1989).

Participatory Design originates in Scandinavian countries, where from the 1970s a new design approach was developed to meet requirements related to the pragmatic necessity of understanding users' needs and to the political claim for horizontality and participation (Muller & Druin, 2003). Thus, at a political and philosophical level, the roots of PD can be traced in postmodern tradition, phenomenology, Marxism and feminist epistemologies (Frauenberger et al., 2014; Harrison et al., 2011).

This theoretical background indicates that, when we define methods for the evaluation of PD, we cannot employ approaches based on positivistic stances but instead we need to consider methods that allow investigating meaning and interaction from a situated perspective (Hoepfl, 1997). This claim is supported both by the need for coherence within the epistemological roots of PD and by the practical evidence that PD does not typically allow for quantification and generalization (Frauenberger et al., 2014).

To tackle this issue, different evaluation approaches have been proposed, addressing different units of analysis such as the evaluation of the overall process, the assessment of the proposed elicitation activities, the analysis of users' contributions, etc. Frauenberger et al. (2014) propose a holistic approach to evaluate the overall PD. They define a "tool-to-think-with", composed by four lenses (epistemology, values, stakeholders, outcomes) aimed at critically analyzing the global coherence of the different aspects of PD. On the other hand, Mazzone et al. (2012) provide two dimensions (suitability and capability) to evaluate whether the elicitation activities are engaging and effective. Finally, both Moser et al. (2014) and Schaper et al. (2014), focus on the analysis of users' contributions by performing content analysis of the games created by children. These frameworks provide valid and useful contributions to understand and analyze PD. However, additional research is needed to further improve research methods, especially in the context of designing for embodied interaction. Specifically, we identified major shortcomings in the availability of robust and coherent methodological tools for collecting and analyzing stakeholders' contributions. This lack can affect research in three main aspects: 1) the reliability of PD outcomes, 2) the dynamics of multidisciplinary teams involved in PD and 3) the richness of data available to inform design.

As Scaife & Rogers (1999) suggested, the lack of robust methodological tools may produce confirmation biases when researchers collect and select the contributions that will inform the design, such as the tendency to prioritize contributions that confirm their initial ideas. As a consequence, these biases may hinder communication and decision-making in a multidisciplinary team, due to the lack of robust evidence, upon which design decisions can be grounded and justified.

On the other hand, even in the cases where users' contributions are robustly analyzed, the data collection tends to focus only on intentional communicational prompts (i.e. written and verbal reports, drawings) thus excluding other resources employed for meaning construction and expression (e.g. gaze, movement, actions, etc.). This neglect could be particularly problematic in PD activities, as they involve a wide variety of employed media and resources. Participants may draw, build low-tech prototypes, discuss or enact specific actions (Giaccardi, Paredes, Díaz, & Alvarado, 2012; Hummels, Overbeeke, & Klooster, 2006; Walsh et al., 2010), hence distributing meaning across a wide range of possible resources.

The need for attending to a broader range of resources is even more relevant when designing technologies based on novel interaction paradigms or when PD addresses children or populations with special needs. Novel interaction paradigms (e.g. tangible interfaces, Full-Body interaction, wearable, etc.), by involving an explicit use of the body and the space, need to meaningfully incorporate physicality and spatiality in the very design and evaluation process (Malinverni & Pares, 2014). Furthermore, when working with children or users with special needs, the eventual difficulties in verbal articulation can drastically reduce the amount of contributions taken into account. This claim is supported by studies that show that paying attention to children's embodied forms of expression (e.g. gestures) allows capturing ideas that are not verbally reported (Broaders & Goldin-Meadow, 2010; Church, 1999).

To sum up, three main needs have been identified for the analysis of PD. First, the necessity of employing methods that coherently fit with its philosophical roots. Second, the need of defining robust evaluation methods to adequately analyze and interpret users' contributions. Third, the importance of analytical frameworks capable of going beyond the limitation of language-based approaches and suitable for interpreting contributions produced across a wide range of different modes (e.g. drawing, verbal reports, prototypes, actions, etc.). To address these needs we propose the use of multimodal analysis to analyze and interpret users' contributions in PD.

6.1.2 Multimodal Analysis

Multimodality is an interdisciplinary approach, derived from socio-semiotics and aimed at analyzing communication and situated interaction from a perspective that encompasses the different resources that people use to construct meaning (Jewitt, 2013). At a theoretical level, multimodality is grounded on the key concept of *mode*, which constitutes a set of socially and culturally shaped resources for making meaning, for instance, 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). In this context, thus, meaning is considered to be realized in the iterative connection between the affordances of a material artifact, the affordances of the socio-cultural environment and the resources, intentions and knowledge that people bring to that encounter (Jewitt, 2013).

Therefore, if we consider the relational nature of meaning construction, this approach coherently fits with the need for situated approaches in the analysis of PD. Furthermore, if we also consider the interplay between embodied and material resources, this approach allows us to compensate for the weaknesses found in other analytical approaches. Specifically, at a methodological level, multimodal analysis provides *"concepts, methods and a framework for the collection and analysis of visual, aural, embodied and spatial aspects of interaction and environments"* (Jewitt, 2013). The wide range of included units of analysis allows a fine-grained understanding of in situ interactions and permits to overcome the limitations of frameworks that focus only on intentional communication prompts such as written or spoken language (Crescenzi, Jewitt, & Price, 2014; Jewitt, 2013).

This approach has been applied in a wide range of contexts, including the analysis of ASD children's gaze in naturalistic settings (Korkiakangas & Rae, 2014), workplace interactions (Hindmarsh & Pilnick, 2002), learning contexts (Mondada, 2011), playgrounds (Goodwin, 2000). tourist spaces (Jaworski & Thurlow, 2009) and classroom interactions (Bezemer, 2008). Through utilizing contextual, embodied and visual resources, these studies have shown the effectiveness of this methodology to properly grasp meaning in its situated and multimodal nature.

Hence, an increasing number of studies are employing this method for the analysis of user interaction with digital technologies (Crescenzi et al., 2014; Price &Jewitt, 2013). This approach is shown to be particularly suitable for the analysis of highly multimodal experiences, such as digital environments based on embodied interaction, where different semiotic resources are employed to construct meaning. For instance, Crescenzi et al. (2014) employ multimodal analysis to analyze losses and gains in children's drawing by comparing finger painting with painting on an iPad. Price and Jewitt (2013) also use multimodal analysis to examine communication in children interacting with tangible interfaces to understand real time cognition and action in meaning making.

Relevant opportunities can be found in extending this approach to the analysis of PD. A preliminary study in this area has been proposed by Derboven et al. (2015), which employed multimodal analysis to identify values in PD with children. Starting from this perspective, we propose to broaden this research field, hypothesizing that the use of multimodal analysis in PD can provide a fine-grained understanding of participants' contributions across different modes, hence including embodiment in the research and evaluation process. Furthermore, it can be embedded in an iterative design process by offering insights to guide design refinements.

6.1.3 Applying Multimodal Analysis to Participatory Design

In the present study, we describe a PD workshop based on the "children as informants" model (i.e. testing raw prototypes with children in order to get inputs during the design process (Nesset & Large, 2004)). As mentioned in Section 5.3, this approach can have a relevant potential to understand embodiment since it allows grounding children's contributions on their in situ experience and include this situated interaction in the analysis.

The workshop was aimed at evaluating and improving a serious game based on Full-Body interaction for ASD children. Specifically, the goals were, on the one hand, to analyze how children interact with and interpret the initial design proposal and, on the other, to include children's interests and contributions in the design of the experience. In the following sections, we will describe the analyzed environment, the structure of the workshop and the framework used for its analysis.

6.1.3.1 The Full-Body Interaction Environment

The design of the system was derived from the requirements established by the psychologists of the team to achieve an experience capable of fostering exploration and social interaction in ASD children. Since impairments in social skills represent one of the target goals of therapeutic treatments in Autism (DSM-V) they hypothesized that exploration and discovery could lead to surprise and a need to communicate such surprise. On the other hand, exploration could also entail the need to search for help and/or collaboration in order to discover new situations. These hypotheses were also supported by observations of children with ASD interacting in other Full-Body interactive experiences in the past (see Section 5.1).

The initial proposal was based on having children playing together in pairs to explore a space (physical and virtual) in which interaction with the virtual elements could offer a trigger to promote social interaction. The aforementioned requirements led to a physical configuration of the prototype that was based on a circular floor projection approximately 6 meters in diameter (Figure 22). In this setting, children can explore the virtual environment through the use of a physical object (a butterfly net), which acts as a pointer and contributes to focus their attention only on a limited portion of the space.

For the workshop, we designed a preliminary version of the environment for pilot testing. The aim of this prototype was to offer a "flavor" of the possibilities of the interactive experience, so children can have an initial starting point to ground their contributions. In particular, we were interested in making children exploring the affordances of the physical space, while letting the features of the digital environment partially unspecified. For this purpose, this first prototype only presented the main scenario of the experience, which was a land covered with fog. Its design was based on merging the requirements of the psychologists with the designer's knowledge. We decided not to include any virtual elements, specific content, or game mechanics in order to provide space for children's contributions.

During the workshop, the basic prototype was implemented and deployed as a Wizard of Oz system. Hence, although the behavior of the fog was already computationally implemented, a researcher actually remotely controlled the fog's reactions to children's behavior. Specifically, a researcher manually tracked the position of the butterfly net of the child and made the fog opening as a peephole that allowed the children to see a small portion of the underlying world (Figure 23).

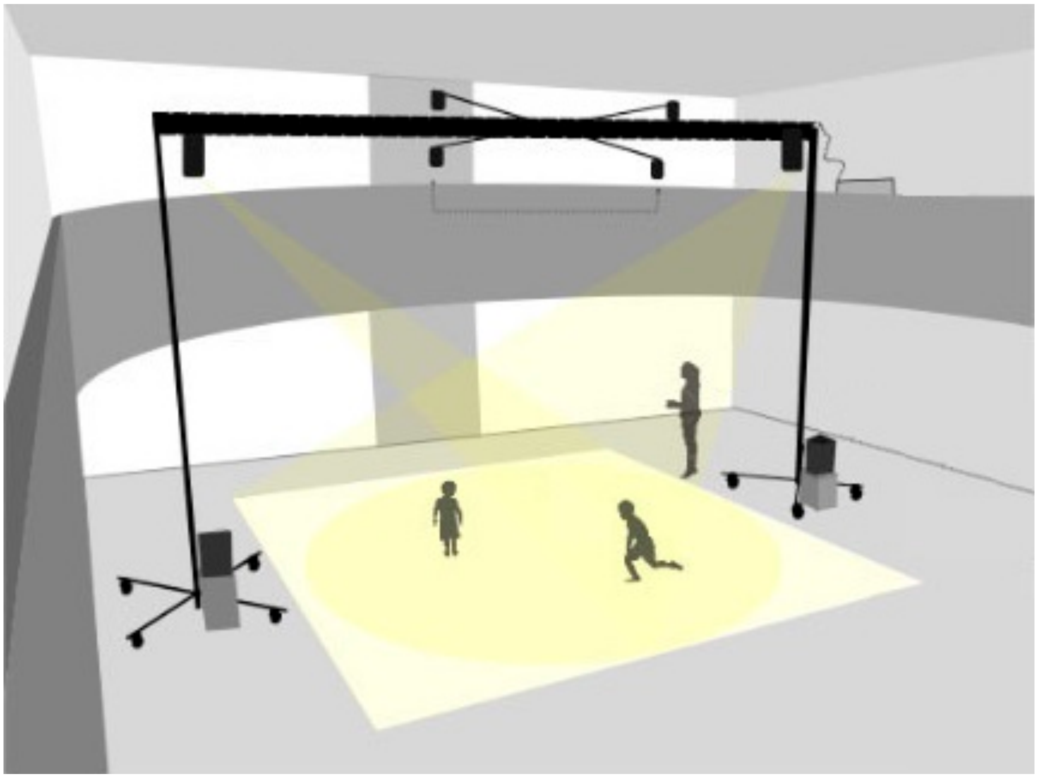


Figure 22. Physical configuration of the system

Figure 23. Children interacting with the system during the PD workshop

6.1.3.2 The workshop

The workshop took place in a large multi-purpose room in our university. The overall workshop lasted for three sessions of one and a half hours each. In the first session, we focused on children's embodied interaction and on their interpretations of the environment, whereas in subsequent sessions we addressed the design of the visual appearance and behavior of the game's characters. Since the purpose of this study was to address the construction of meaning through embodied interaction, this paper will focus on the first session only. The participants, selected by a psychologist, were four high-functioning ASD children (A, B, C & D), all male, between 10 and 12 years old, who had not previously visited the university. Some of the children had previously met from sharing group therapy sessions. All four children presented normal cognitive capabilities and functional language. During the session, three researchers and a psychologist were present as observers and facilitators.

6.1.3.2.1 Workshop structure

After introducing ourselves, we explained to children the goals of the workshop and the importance of their participation in the design. During the session, two main activities were carried out: the "exploratory activity" and the "drawing activity". The aim of this structure was to provide children with activities that offered different resources to approach the environment (e.g. physical interaction, verbal explanations, drawings, etc.), hence offering different modal affordances to communicate their understanding.

The exploring activity

After the presentation, children were divided into pairs. Each pair received a specific role, either "explorer" or "detective". One of the explorers was given a camera while the other was given a butterfly net, and both were invited to enter the floor projection area showing the digital environment (Figure 22). Specifically, they were instructed to walk over the floor projection and explore the space together. The butterfly net served as a magic wand to open the fog wherever it was placed. The child holding the camera was instructed to take pictures of anything that captured his interest. They were, also, told that they could exchange their tools (net and camera) whenever they wanted. The interaction with the digital environment was reduced to a minimum. When a child moved the net, the fog opened, generating a circular area through which they could see part of the underlying world. In this prototype, the "world" was merely a number of colored areas to provide a sense of moving through different types of land or water.

The children assigned to the "detective" role went to a balcony in the upper floor, which overlooks the entire multi-purpose room. From this vantage point, they could see the environment from a bird's-eye view. Here, along with two researchers, they were asked to try to work out what the environment looked like, any possible creatures that could inhabit it and what their peers should do in their exploration. After 15 minutes children swapped roles; those acting as "explorers" became "detectives" and vice versa. This activity was planned to observe children's spontaneous interactions with the digital environment and with each other, and to analyze the kind of interpretations evoked.

The drawing activity

After finishing the exploring activity, children were conducted to a part of the room with tables, chairs and crafting materials (pencils, markers, scissors, magazines, different types of paper, etc.). They were debriefed about the previous activity and asked to draw what they would like to see under the fog. Children were invited to produce drawings on white paper, where only a circular shape, representing the digital environment, was provided. To produce their drawings, children could freely choose between the different materials. After finishing the drawings, we asked children to describe the drawings to their peers.

6.1.3.3 The analytical framework

At an analytical level, three main concepts derived from socio-semiotic and multimodal analysis were employed to frame the research: the situated and embodied meaning-making, the relevance of the interpreter's interests and the notion of motivated sign. The goal of the analysis was to get insights on two fundamental aspects. First, we wanted to analyze how children naturally interact with the environment and which aspects grab their attention. This analysis would facilitate the definition of design solutions capable of engaging children in the exploration. Second, we wanted to explore which contents could motivate children. This research would facilitate the design of valuable situations for the children to become sufficiently motivated to communicate, thus promoting social interaction between users.

To analyze the data, one researcher first transcribed the videos according to a narrative style, in order to have an overall view of the experience. After that, she performed specific transcriptions, using different formats, for each unit of analysis (e.g. different forms of graphical transcriptions). This approach was based on the method proposed by Flewitt et al. (2009) to analyze multimodal data.

6.1.3.3.1 Situated and embodied meaning making

Multimodal analysis stems from the acknowledgment that people use multiple resources to construct meaning. Thus, it allows the analysis of the different semiotic resources that humans employ to make meaning and the analysis of how these resources interact with each other (Streeck et al., 2011). By taking into account the specificities of the analyzed environment and of the proposed PD activities, we focused our analysis on the following embodied resources:

- Children's exploration of the space (their position, paths, pauses and relative speed),
- Movements of the butterfly net (the position of the butterfly net in relation to the child and the pattern of movements performed with it),
- Gaze direction.

The choice of focusing on these aspects was motivated by some fundamental considerations. First, to understand embodiment the unit of analysis should be able to encompass the relationship between the agents and their environment (Clark, 1998). Second, the physical nature of the experience requires to carefully considering how users engage with it by using their bodies, the space and material artifacts.

The analysis of these aspects was performed on the video recordings of the exploratory activity. Specifically, we analyzed the first minute of the children's interaction while holding the net and exploring the environment. We chose to perform a fine-grain analysis of this first stage of exploration only, in order to gather insights about which aspects immediately called their attention and curiosity, and which aid in framing their initial impressions and interpretations of the environment. This transcription was carried out through repetitive frame-by-frame visualization of videos. Children's exploration of the space and net movements were transcribed in a map-like format for each child. Gaze direction instead, was annotated in a written format during the video observation.

6.1.3.3.2 The relevance of interpreter's interests and focus of attention

According to the semiotic theory proposed by Kress (2010) communication follows this sequence: A message is sent → The attention of the receiver engages her with some aspects of the message → Some aspects of the message are selected according to her interests→ These aspects are framed and interpreted. This flow suggests the central role of the interests and focus of attention of the receiver in the selection, framing, interpretation and understanding of a message.

This concept, applied to digital technologies, implies considering the designed experience as a message that needs to be interpreted by the users. This approach could be particularly valuable in Full-Body interaction, as these settings are characterized by a plethora of stimuli, all of which can potentially attract the interest of the users. At the same time, it can be suitable when working with ASD children since, by relying on embodied resources, it overcomes the barrier of verbal communication. In the context of PD, we propose that the multimodal analysis of the users' focus of attention can provide the basis for grasping their understanding of the system and can allow for identifying relevant insights to guide design refinements.

At a methodological level, we evaluated children's focus of attention by combining the analysis of: (1) their paths in the interactive space and (2) the pictures they took during the exploration. These techniques were based on literature on the analysis of users' engagement and interests. The tracking of users has been widely employed for analyzing their engagement with physical and digital environments. Eye-tracking systems (e.g. in websites) or tracking of users' physical exploration (e.g. in museums) have shown to be an effective tool to capture areas of interest and exploratory behaviors (Lorigo et al., 2008; Serrell, 1997). At the same time, pictures taken by children have been widely employed in social sciences to research on children's perspective and experiences (Einarsdottir, 2005; Harper, 2002; Jorgenson & Sullivan, 2009). Moreover, the triangulation of these techniques can offer a wider panorama on what aspects of the digital environment capture (or do not capture) the attention of the users, thus providing guidelines to understand their interests.

Specifically, to perform this analysis we traced the graphical transcriptions of all children's paths (described in Section 3.1.1) over the image of the environment. This graphical solution allowed us to obtain a representation of their overall traversal of the space. At the same time, the pictures taken by the children during the course of the exploratory activity were analyzed using a topological approach. In other words, the pictures were mapped onto the image of the environment, so as to obtain the correspondence with the area depicted in the picture. As a result, we produced two maps, one summarizing the paths (Figure 24) and the other showing the position of the pictures (Figure 25). Furthermore, the pictures were analyzed according to a grounded approach, understood as the process to inductively define codes that group the pictures into categories that describe what was depicted.

6.1.3.3.3 The notion of motivated sign

According to multimodal social semiotics, when somebody makes a sign, they are projecting their individual interests into the world by making choices from the available resources. As a consequence, “the inner constitution of a sign reveals the interests of the sign maker” (Kress, 2010).

This idea has direct implications for the evaluation of user-generated artifacts during PD activities. In particular, we suggest that the analysis of resources and cultural references employed by children can reveal their interests and offer relevant insights for deepening on their expectations about the system. Furthermore, this analysis can offer relevant guidelines to improve design and to make it more appealing and engaging for children.

To perform this analysis we focused on the following activities: children’s explanations during the exploratory activity, children’s drawings and the narratives accompanying these drawings. This approach was grounded on research showing that drawings and related narratives represent a valid research method to access young children’s views and experiences (Clark, 2005; Cox, 2005). This evaluation was mainly performed through grounded content analysis, understood as a methodological approach to inductively derive meaning from data. Its goal was to identify resources and cultural references employed by children.

6.1.4 Results

6.1.4.1 Situated and Embodied meaning making

The analysis of embodied meaning making was derived from the maps produced to describe children's exploration of the space and the movement of their net (Figure 24). In the following sections, we provide a detailed analysis of these different aspects.

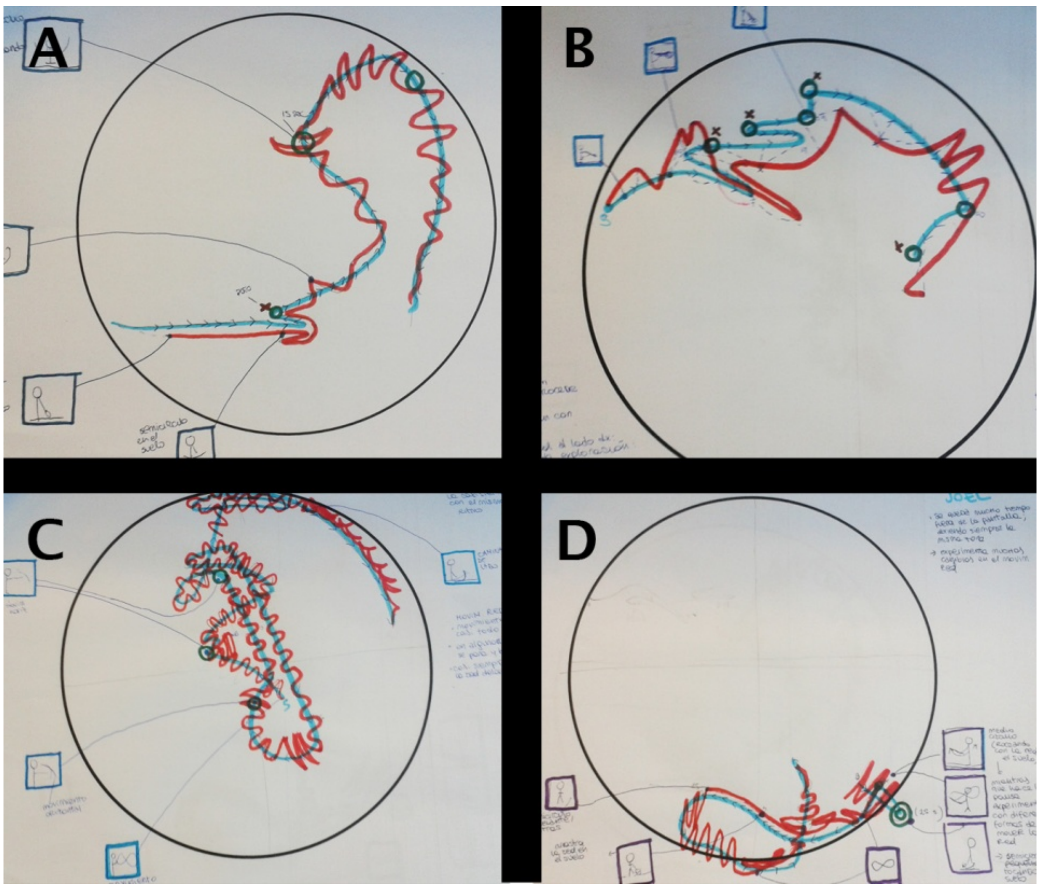


Figure 24. Maps showing the children's exploration of the space(blue line), the movement of their net (red line) and salient actions (square inserts)

6.1.4.1.1 Children's exploration of the space

For the analysis of children's exploration of the space, we transcribed the child's position, his path, the pauses and the relative speed in each individual map. The maps of children's paths (blue line in Figure 24) reveal that the children tended to move in similar ways. Specifically, they either remained on the edge of the environment, where they tended to follow circular paths, or they performed straight trajectories to cross the space through its center.

However, different patterns of movement were present. While child A tended to move forward almost all the time, children C and D preferred to explore the same areas several times by repeating similar paths. Child B, instead, tended to move in a straight path and alternated forward and backward movements aimed at passing through the same path he had just walked through.

The differences in their paths indicate different exploratory behaviors. While the first child seemed to prefer to cover the largest possible space during a short lapse of time, the other children showed a more fine-grained approach, carefully and deeply exploring a specific area. These tendencies were partially confirmed by the pace of their exploration (speed and pauses).

All children experimented with and alternated different walking speeds and they all performed some pauses during their exploration. Pauses were associated with: 1) changes in direction, 2) exploration of the area by standing still and moving the net, 3) changes in the movement pattern of the net and 4) repetitive behaviors. In particular, child D stood for more than 20 seconds in the same position, outside the edge of the projected play area, performing repetitive actions with the net. In the context of autism, repetitive behaviors are associated with self-stimulation, understood as patterns of movements that are performed to cope with over-excitement. This finding, thus, suggested the need for designing improvements to reduce this kind of behavior. At the same time, we found other important points related to interaction design. Considering that one of the project's requirements was to offer affordances that promote exploration (see Section 3.1), the following questions were raised: *What happens when the child stands in the same position for a long time? What happens when he goes back and forth several times through the same area? Could the system recognize and react to repetitive actions and how could it do so? Should the system reward differentiation and variability in the exploratory paths? How could this reward be formalized?*

6.1.4.1.2 Movements of the butterfly net

To analyze the movements that the children performed with the net, we focused on the position of the net in relation to their bodies (red line in Figure 24) and on the patterns of movement that they enacted with it. All children tended to maintain the net in front of them, by moving it horizontally left and right. However, three children performed some changes in their patterns of movement of the net (A= 4 changes; D= 6 changes; C= 4 changes), while child B did not perform any changes and just slightly modified the inclination of the net.

Explored patterns of movement were related to performing semicircular movements on a side or in front of the body, or dragging the net on the floor and using it to draw figures in the fog. The latter behavior suggests an interest towards exploring the changes in the visual appearance of the fog when it is "opened" by the net. It thus suggests eventual design refinements related to the variability of the fog's visual appearance in order to promote exploration. Taking into account the goals defined for the design of the system, the high variability in performed patterns of movement elicits relevant questions for design and for the definition of technical requirements: *How does the system react to different kinds of movement? Does the system reward variability and exploration of the net's movements? Which is the best technical solution for facilitating tracking the net's position while simultaneously promoting exploration?*

6.1.4.1.3 Gaze Direction

During the first minute of interaction all children's gazes were completely focused on the floor, where the digital environment was projected. No shifts in focus were reported, neither looking at the surroundings nor at their peers. This observation suggests children's interest in the digital environment and coherently relates to autism literature, which shows that ASD subjects tend to avoid making eye-contact and have a poor interest toward their peers (Phillips, Baron-Cohen, & Rutter, 1992; Zeeland et al., 2010).

However, it also points out some relevant design considerations. Showing interest towards other people and making eye contact are important learning goals for ASD children. Furthermore, since one of the requirements of the project was to promote social interaction, future design refinements should address proposals for facilitating functional forms of social interaction (e.g. performing eye-contact when communicating with somebody). Possible research paths can address questions related to: *Which physical affordances can invite the user to look at their peers? Which game mechanics can promote eye-contact between users?* Potential sources of inspiration can be found in the exploration of novel physical interfaces and in the "head-up games" paradigm (Soute, Markopoulos, & Magielse, 2009), which proposes design solutions to liberate players from facing down to attend to screen-based interactions.

6.1.4.2 Children's Focus of Attention

The analysis of children's focus of attention was derived from the maps produced to describe their overall traversal of the space and the topographical arrangement of the pictures that they took during the activity (Figure 25).

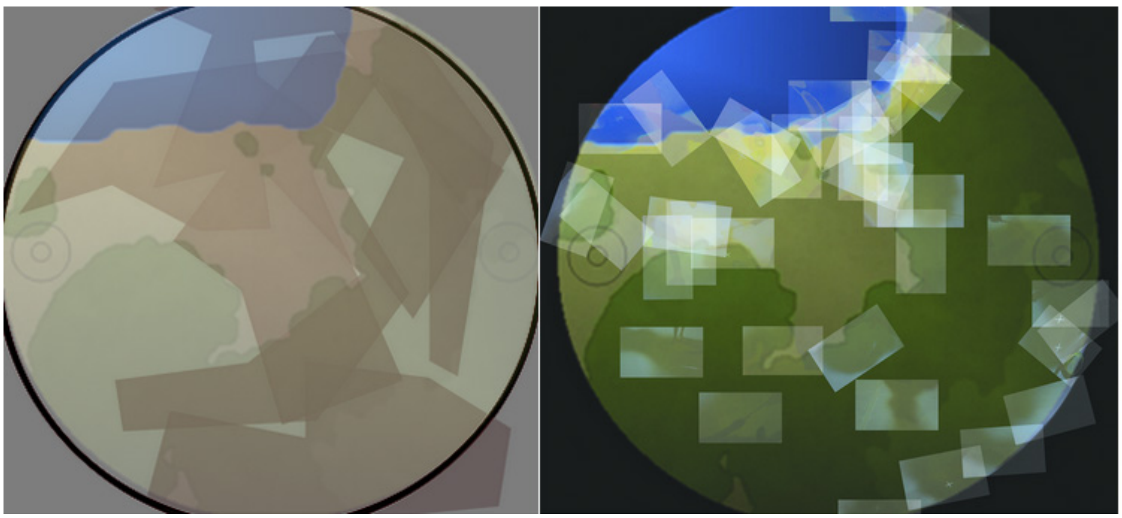


Figure 25. a) Representation of overall displacements (left); b) Map of pictures taken by the children (right)

From the map of the overall traversal of the space, we observe that almost all children concentrated their exploration on specific areas. Children's movements focused mainly on the borders between different types of environments (e.g. borders between a blue area and a green area). These observations are confirmed by the topological analysis of the distribution of the pictures they took (Figure 4) where we can see that the pictures are concentrated mainly on border areas. Content analysis of the 56 pictures showed that roughly 45% depict borders between two different terrains, 35% include the virtual pointer and the others were distributed between images of the net, shadows and plain areas. Within that, it is particularly relevant to notice that plain areas were depicted only in 9% of the pictures, even though they constituted the biggest proportion of the underlying environment. At the same time, the children did not take any pictures of their peers or of the surroundings beyond the projected environment.

These findings suggest that children tended to direct their interests toward detailed and liminal areas, where some salient visual changes were present. These aspects can be interpreted according to the role of salience in facilitating perception (Price & Scaife, 2002) as well as in the light of ASD children's interest for detailed images (Happé & Frith, 2006) and in relation to the evocative power of liminal areas. While exploring the environment, children were engaged in trying to discover what was hidden under the fog. Thus, areas that depict borders and visual changes can be much more informative than plain areas.

At a design level, this analysis suggests some important reflections. First of all, it strengthens the previously identified need for defining strategies that allow children to gain interest in other users instead of focusing only on the environment. Secondly, it can provide relevant insights for guiding the design of the visual appearance of the environment, for instance through the spatial distribution of different kinds of salient features to promote children's exploration or to guide them toward certain locations.

6.1.4.3 Analysis of Children's Productions

To analyze children's productions, we used three sources: the explanations given by "detectives" during the exploratory activity, the drawings made by children and their associated narratives.

6.1.4.3.1 Children's explanations of the FUBILE

During the exploratory activity, children assigned to the "detective" role were situated on a balcony from which they could see the environment from a birds-eye view. They were instructed to work out what was represented in the digital environment and what their peers, who were exploring, should do. Here, two researchers asked children questions related to their interpretations of the environment. We used content analysis to analyze children's answers.

During this activity, all children dedicated full attention towards looking at the environment. Interpretations were focused in two main directions. Three children understood it as a geographical map representing a large space such as a continent or a state. In contrast, child B suggested that there was a figurative image (a bat) hidden under the fog, which had to be discovered.

At an interaction level, all children related the activity performed by their peers with the act of hunting or collecting. Interestingly, all children explained it 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 and to the positive reinforcement nature of several cognitive-behavioral therapies for autism.

At a design level, the video gaming culture posits relevant questions on the need for balancing expectations derived from gaming experience with educational requirements. Furthermore, the goal-oriented approach suggests that the presence of a narrative "mission" structure could facilitate children's understanding of the experience. This consideration is consistent with ASD literature, which points out the difficulties of ASD children in dealing with open-ended and ill-structured problems and their preference for well-structured and goal-directed situations (Strickland, 1997). However, from an interaction design perspective, relevant research paths could explore whether the difficulties of open-ended situations could be fruitful for promoting social interaction, by requiring the child to ask for external collaboration. Nonetheless, this difficulty level should be carefully balanced to avoid overwhelming situations.

6.1.4.3.2 Children's drawings

In the drawing activity children were very engaged and put a lot of effort and time in refining their drawings. Unfortunately, due to the position of the camera, it was not possible to perform a fine-grained analysis of the drawing process. Thus, only the final drawings and accompanying explanations were analyzed.

The analysis of children's drawings points out their preferences for a rich and detailed natural environment. Following the ideas they explained in the exploratory activity, one child depicted a bat, while the others drew landscapes. Within that, two children depicted highly realistic environments where natural elements dominated the scene (i.e. wood, sea, mountains, etc.) and human elements were minimized, mainly representing anachronistic settings (e.g. a temple, a coliseum). The third child also proposed some fantasy elements (e.g. "a cotton candy valley"), however this lack of realism was not well accepted by the other children, who criticized it because "that is fantasy".

At a formal level, drawings were composed using mixed techniques, mainly combining drawing with collage. The use of collage was mainly due to economy of work. Children were interested in representing detailed and dense natural areas: thus, collages using magazine pictures gave them a quick way to include highly detailed representations with less effort (e.g. foliage). In this context, it is relevant to notice that children strongly preferred natural and detailed pictures and rejected some images because “it has too few leaves”. This need for realism and detail can inform the design of the visual appearance of the environment. However, further research should address how detailed visual representations may affect exploration. At the level of cultural referents, children’s proposals were mainly grounded on their gaming and audiovisual culture, which was shown to have a high priming effect on children’s expectations.

6.1.4.4 Merging perspectives

During physical interaction with the environment, children focused on exploring and photographing detailed border areas. This preference is consistent with their choices during the drawing activity, where they mainly elaborated highly detailed and realistic representations of geographic landscapes. Thus, from the perspective of defining the visual appearance of the virtual world, these findings suggest that realistic and detailed representations may be adequate to capture children’s attention and foster exploration behaviors.

On the other hand, we used two different approaches to elicit children explanations: the first during the detective activity and the second after the drawing activity. Their explanations during the detective activity were more focused toward describing the space in terms of actions (“you need to capture animals”). Instead, their explanations of the drawings were mainly in a map-like format (“here we have a forest, there a river...”). This difference points out how the two activities, by offering different affordances, have elicited different ways of describing the space: one in terms of the actions of the user and the other in terms of the coexistence relations between objects (de Certeau, 1984). Hence, in the context of the workshop, the shift between different modes (e.g. exploring, explaining, and drawing) and the use of multimodal analysis, allowed identification of relevant esthetic as well as functional interests. These considerations, thus, suggests that enabling multiple expressive modalities can represent a meaningful resource to plan PD activities.

On the other hand, from the analysis, it emerged that children were mainly interested in a space that is “actionable” with video game-like tasks. The priming role of video games was evident both in their explanations and in the elements in their drawings. The influence of video game culture may suggest possible design solutions to foster children’s interest in the experience and provide hints to define motivators of social interaction. However, it also points out challenges related to properly defining the educational experience. For instance, these children were mainly used to games in which players compete and fight against enemies or other players. However, these common game mechanics were in conflict with the very educational goals of the experience. As a consequence, when designing serious games, relevant research challenges should aim for a balance between children's expectations on "what a game is" and the values or educational goals that need to be achieved. Involving children in the process and understanding their interests, forms of usage, values and cultural references, constitutes an essential starting point. At the same time, strategies to balance knowledge and requirements from different stakeholders constitute principal contributions to the design process. Nonetheless, in order to properly address this challenge, further research is still needed. We suggest that future research should address the analysis of the construction of specific socio-cultural values and the ethical reflection on the dilemma between reproducing them or diverging from them.

In summary, the employment of multimodal analysis proved to be an effective and coherent approach for capturing, analyzing and interpreting a wide range of users' contributions in a PD workshop with ASD children. This helped us gain insights related to precise aspects of interaction design, technical requirements, content definition and educational goals, hence providing solid guides for design refinements.

6.1.5 Discussion

Our study presented an initial approach to methodologically combine the analysis of in situ interaction with the analysis of children's productions during a PD workshop. For this purpose, we used a "users as informants" model (Nesset & Large, 2004) and structured the analysis accordingly to a multimodal approach. The presented research confirmed previous studies on the suitability of multimodal analysis for the evaluation of digital technologies (Jewitt, 2013) and widens its application to design processes that are based on PD workshops. Within this context, we suggest that multimodal analysis can offer both direct and indirect benefits to PD for embodied interaction.

At a methodological level, multimodal analysis has shown to be suitable to address the challenges related to analyzing PD and embodiment by systematically attending to the multiple resources and by providing solid empirical data upon which inferences may be grounded. These benefits contributed to offer guidelines to orient the design process. At the same time, the outcomes proceeding from the analysis served as a fruitful ground to facilitate the communication between experts, designers and researchers.

6.1.5.1 A multimodal approach to analyze PD

During Participatory Design workshops, participants may offer a huge diversity of possible contributions, choices and interpretations. These contributions can be displayed across a wide range of modes (e.g. verbal interactions, craft production, physical enaction, etc.). In this context, our proposal uses multimodal analysis to combine the analysis of in situ interaction with the analysis of design and elicitation activities' outcomes to track how children engage with the experience and their interpretations across different modes. Specifically, we consider that the observation of *embodied and situated meaning making*, *children's focus of attention* and *children's productions* provided relevant guides for the analysis of the workshops.

On the one hand, we suggest that the analysis of aspects such as children's exploration of the space, their interaction with the material artifact (the butterfly net) and their focus of attention, may offer some important contributions. First, it allows grasping embodied meaning-making and understanding what kind of physical exploration does the interface evokes. This aspect is particularly relevant in the quest for methodological appropriateness in embodied interaction research since it allows grasping how the bodily interaction and the configuration of the physical/digital environment shape the experience and contribute to construct meaning. On the other hand, the employed design activities (e.g. drawings) allowed children to project and materialize their own interests and representations in the production of artifacts (Kress, 2010), hence providing researchers with rich data for investigating their interpretations. Thus, combining the observation of embodied and situated meaning making with the analysis of children's productions, showed to be an effective approach to deepen on the meanings that children attribute to their actions and their interpretations of the experience.

Second, in going beyond the limits of analyzing only intentional communication, it allows paying attention to nuances of meaning and behavior that may otherwise pass unnoticed. Hence, it enables insights that would have not been otherwise accessible and enhances the richness of the users' contributions that can be obtained. Furthermore, the inclusion of physicality and spatiality does not only have a practical methodological value, but also presents some important epistemological implications, since it conceptualizes the user from a holistic and encompassing perspective.

Third, the analysis of multimodal resources can be crucial especially when working with populations that may have difficulties in expressing and communicating their interests, e.g. children with special needs. This aspect addresses the ethical and pragmatic concerns related to involving a population with special needs in the design process. Finally, the use of a fine-grain approach to analyze these aspects allowed gathering robust data upon which specific inferences on future design iterations and research can be grounded.

To sum up, the aspects proposed in the analytical framework (Section 6.1.3.3) may be useful as guidelines for researchers involved in design and assessment in this field. Nonetheless, the situated and context-specific nature of this framework requires that researchers carefully tailor their tools and approaches to the characteristics and concrete features of their specific contexts and applications.

6.1.5.2 Grounding a multidisciplinary dialogue

During the design process carried out by our multidisciplinary team, the outcomes obtained from the multimodal analysis provided a useful bedrock upon which to build dialogue. This process was carried out by framing and linking back the outcomes of the analysis with the project's requirements. This connection was shaped through the formulation of specific design questions. The presentation of the empirical data, together with the raised design questions, covered a fundamental social and maieutic function by serving as a starting point to guide communication and foster reflection between multiple stakeholders (i.e. mental health professionals, designers, etc.). This aspect is particularly important in multidisciplinary teams where the different perspectives, worldviews and vocabularies may constitute a barrier for the proper flow of dialogue (Frauenberger et al., 2014; Mora et al., 2014).

We thus suggest that multimodal analysis, by providing a broad, robust and coherent analysis of PD, can facilitate the orchestration of multiple perspectives for the definition of design features. This encompasses both approaches to include children's contributions as well as to facilitate dialogue in a multidisciplinary team. At the same time, its maieutic function does not only allow refining of design and facilitating of interdisciplinary communication, but it also opens relevant paths for further studies.

6.1.5.3 Limitations and future works

As this paper is based on an exploratory case study, a number of relevant improvements for future work are apparent. First, improvements should address technical issues aimed at facilitating data recording. A careful consideration of the disposition and quality of the recording devices becomes of crucial importance. Furthermore, since the proposed approach requires a considerable time-consuming effort which may be unsuitable for certain contexts, automatic systems for data logging and analysis should be considered (e.g. in our case for tracking user and net position). We are currently working on the development of a software tool to help in this regard.

Secondly, relevant research and design possibilities could address the combination of this method with iterative design approaches, such as Design-based research (Barab & Squire, 2004; Wang & Hannafin, 2005). In this context, multimodal analysis could provide analytical tools to guide and orient design iterations and evaluation.

Thirdly, when combining in situ interaction with design activities relevant considerations should focus on defining the amount of information that we embed in the prototype. In other words, we should carefully reflect on how much of the experience is already defined and how much is let open to children's contributions. In our case, for instance, we decide to limit the definition of the digital environment to the fog behavior and to the underlying image. Nonetheless, the features of the underlying image strongly primed children's imagination. Thus, in this tradeoff between structure and freedom is important to carefully balance between stimuli that are evocative enough to trigger children's imagination but without constraining it too much.

Fourth, the proposed framework does not aim at being a prescriptive general-purpose tool, but a flexible and situated approach, which should be adapted and reconfigured according to the specificities of different research contexts and projects.

Finally, in the presented analysis, the reduced number of users and the relatively short interaction time that was analyzed may have offered only a limited perspective. Thus, the design refinements that we have identified and discussed should be implemented and evaluated in future iterative studies.

6.1.6 Considerations for this Thesis

In relation to the global goals of the thesis, this study ameliorated the previously proposed inclusive design approach (Chapter 5) by more deeply considering children's embodiment and interpretations. It, hence, addressed previously identified shortcomings and offered relevant tools to ground design decisions on the users' experience of the system. In this context, we especially suggest that combining the observations of embodied and situated meaning making with the analysis of children's productions, could represent an effective approach to delve in the meanings that children attribute to their actions and their interpretations of the experience. The proposed analytical framework (Section 6.1.3.3), hence can constitute a useful instrument for researchers involved in design and assessment in this field.

In the proposed study, we employed this framework to guide the design of a system that addresses the learning of procedural skills related to social initiation in ASD children. In order to move forward the research, therefore, in the following sections, we will describe the application of an adapted version of the proposed framework in an iterative design process (Section 6.2.2).

6.2 The Medium Matters: Analyzing the Impact of Embodied and Spatial Resources on Collaboration

This Section is partially based on the article:

- Malinverni, L., & Pares, N. (2015). The Medium Matters: the Impact of Full-Body Interaction on the Socio-Affective Aspects of Collaboration. In *IDC '15 Proceedings of the 2015 conference on Interaction design and children*. ACM.

In the previous study, we explored the use of a multimodal analytical framework to gather robust empirical data for guiding the design of a FUBILE aimed at fostering social interaction. Following the research line previously traced, the current study aims at exploring how different interfaces can offer different affordances to mediate collaborative and social behaviors during the interaction with FUBILEs. Specifically, the current research aims at investigating the impact of Full-Body interaction on the socio-affective aspects of collaboration and the role that embodied and spatial resources may have in this relation. For this purpose, in the next sections, we will present the theoretical framework upon which this research is grounded and two studies aimed at addressing these research questions. The first study is a preliminary exploration aimed at comparing two interaction paradigms: one based on Full-Body interaction and the other on Desktop computer interaction. The second study, instead, addresses the influence that the specific configuration of a FUBILE may have on collaboration and analyze the role of embodied and spatial resources. This empirical research would allow setting the basis for discussing the implications about media affordances on collaboration, future research and educational policies.

6.2.1 The Research Framework: Collaborative Learning and Embodied Interaction

Collaboration is strongly recognized as an effective approach to support learning. Research in this field has shown that children obtain better results when doing tasks in collaboration compared to doing them alone (Doise, Mugny, & Perret-Clermont, 1975). Moreover, collaborative learning facilitates critical thinking (Gokhale, 1995), allows a longer retention of the concepts and promotes positive attitudes toward the learning materials (Kreijns, Kirschner, & Jochems, 2003). These findings are consistent with main developmental theories. The systemic theory of child development, Vygotskian and Neo-Vygotskian approaches, all show that the interactions with the social environment are core for development and knowledge construction (Ackermann, 2004; Rogoff, 1990; Vygotsky, 1979).

Starting from this perspective, research in HCI has a long trajectory in the development of Computer-Supported Collaborative Learning environments (CSCL), understood as the design of artifacts to mediate collaborative practices of meaning-making (Dillenbourg et al., 2009). Although this area has several sub-fields, for the purpose of the current research we will focus on *co-located collaborative learning environments*.

A number of different perspectives have been adopted to support collaboration in co-located CSCL environments. On the one hand, some studies focus on exploring the impact that different collaboration paradigms (e.g. enforced collaboration), game mechanics or widgets may have on collaboration (Ben-Sasson, Lamash, & Gal, 2013; Marwecki, Rädle, & Reiterer, 2013). These studies can offer relevant contributions to designers. However, by emphasizing the content, they tend to neglect the specific affordances of the medium. As a result, the physical interface and interaction modality are often relegated to a purely instrumental and functional role (Meneghelli, 2009), rather than analyzing their role in shaping collaboration.

On the other hand, other studies explored the effectiveness of novel interfaces for CSCL. Within this context, a number of studies have shown the potential of embodied interaction to encourage co-located collaboration (Jacob et al., 2008; Price & Rogers, 2004). Nonetheless, this research has especially focused on tangible interfaces and multi-touch tabletops (Antle et al., 2011; Falcão & Price, 2009; Hornecker & Buur, 2006), neglecting the analysis of other forms of embodied interaction, such as Full-Body interaction. Furthermore, research in this field tended to focus on evaluating specific prototypes, hence neglecting the analysis of the specificities and affordances related to the employment of different spatial or embodied resources.

6.2.1.1 Full-Body interaction, embodied resources and social interaction

Recently, there has been an increasing interest in the educational potential of multi-user Full-Body

Interaction Learning Environments (For a detailed description see Section 3.1). These environments propose different patterns of social interaction. For instance, the “Climate change” project (Lyons et al., 2012) and “Bar Graph Bouncer” (Charoenying et al., 2012) are based on the competition between two users. On the other hand, projects such as “Feed yer Alien”, support collaboration and distribute different roles among the users (Johnson-glenberg et al., 2010). Finally, projects such as “Wooble” or “Connections” (Carreras & Parés, 2004; Kynigos et al., 2010), also promote collaboration but do not differentiate between users and assign the same role to all of them.

Even if these approaches propose co-located CSCL environments, as far as we are aware, none of them have specifically addressed the impact of FUBILEs on collaboration. Rather, they have focused on evaluating learning gains or user experience (Malinverni & Pares, 2014). However, we suggest that research in Full-Body interaction can offer relevant insight for the design of co-located CSCL, due to the crucial role of the body and spatial configuration in social interaction and social cognition.

As pointed out in Section 2.2, research in cognitive science, developmental psychology, social psychology, ethnographical studies and conversation analysis point out the fundamental role of the body in organizing social interaction and in social cognition (Barsalou, Niedenthal, Barbey, & Ruppert, 2003; Iacoboni, 2009; Mondada, 2011; Streeck et al., 2011). For example, studies in ethnographical and conversational analysis have shown that embodied resources are central for mutual understanding, generation of shared meaning (Hindmarsh & Pilnick, 2002) and to establish and maintain rapport (Delaherche et al., 2012; Grammer et al., 1998). Furthermore, research in social cognition is increasingly supporting the fundamental role of the body in providing an immediate understanding of the mental states, actions and intentions of the other (Fuchs & Jaegher, 2009; Gallese, 2007).

Summarizing related research, we suggest that Full-Body interaction, by allowing the use of different spatial and bodily resources, can have a relevant role in supporting the quality of social interaction, thus enabling conditions for collaborative learning. Grounding on this viewpoint, the current research aims at addressing questions related to the impact of Full-Body interaction on collaborative behaviors and at the role of embodied and spatial resources in shaping this relation.

In the next sections, we will describe the research carried out to address these research questions. Specifically the research has been structured following a mixed methodological approach, based on an exploratory – explanatory design. Thus, the first study reports an initial exploration to research the impact of Full-Body interaction on the socio-affective aspects of collaboration. This research is carried out through the comparison of a Full-Body interaction interface with a Desktop-Computer interface. The second study, instead, delves into these initial findings and proposes a fine-grain analysis of the role of spatial and embodied resources in shaping collaborative behaviors and socio-affective aspects of collaboration.

6.2.2 Comparing the Impact of Full-Body Interaction and Desktop Computer Interaction on the Socio-Affective Aspects of Collaboration

As Kreijns et al. (2003) pointed out, the effectiveness of collaborative learning is mainly influenced by the *quality of social interaction,* understood as the socio-affective aspects of group dynamics (i.e. reciprocal trust, impressions about the others, perception of being a community, and the feeling of being mutually dependent on each other to accomplish the goal, etc.). However, as pointed out by several authors (Dillenbourg et al., 2009; Jones & Issroff, 2005; Kreijns, Kirschner, & Jochems, 2002), research in CSCL has often focused only on the cognitive aspects of collaboration, hence neglecting research on the motivational and socio-affective aspects. This lack was already identified by McGrath and Hollingshead (1994)who, in their review of the impact of technology on group behavior, showed a scarcity of research on the influence of technology on how group members feel about each other. This neglect can constitute a relevant shortcoming in research in the field. On the one hand, it ends up proposing a view of collaboration as disregarded from its holistic nature (emotional, cognitive, behavioral). On the other, it neglects the fundamental role of psychosocial processes as pre-requisite of collaborative learning (Kreijns et al., 2003).

Starting from this perspective, this first exploratory study aims at investigating the impact of Full-Body interaction on the socio-affective aspects of collaborative learning. Our hypothesis is that Full-Body interaction supports the construction of a positive social space for collaborative learning, given that it enables the use of embodied resources that are fundamental for social communication and social cognition. To test this hypothesis we compared two interaction paradigms, specifically a Full-body interaction interface and a Desktop Computer interface. For the Full-Body interaction interface we used the Interactive Slide exergame platform, a large inflatable slide augmented with digital technology (Soler-adillon & Pares, 2009). For the Desktop configuration, we implemented a collaborative system based on the idea of Single Display Groupware (Stewart, Bederson, & Druin, 1999). In this system, co-located users interact by using a mouse each and obtain feedback on a single output display; a projection on a screen on the wall (Figure 26)

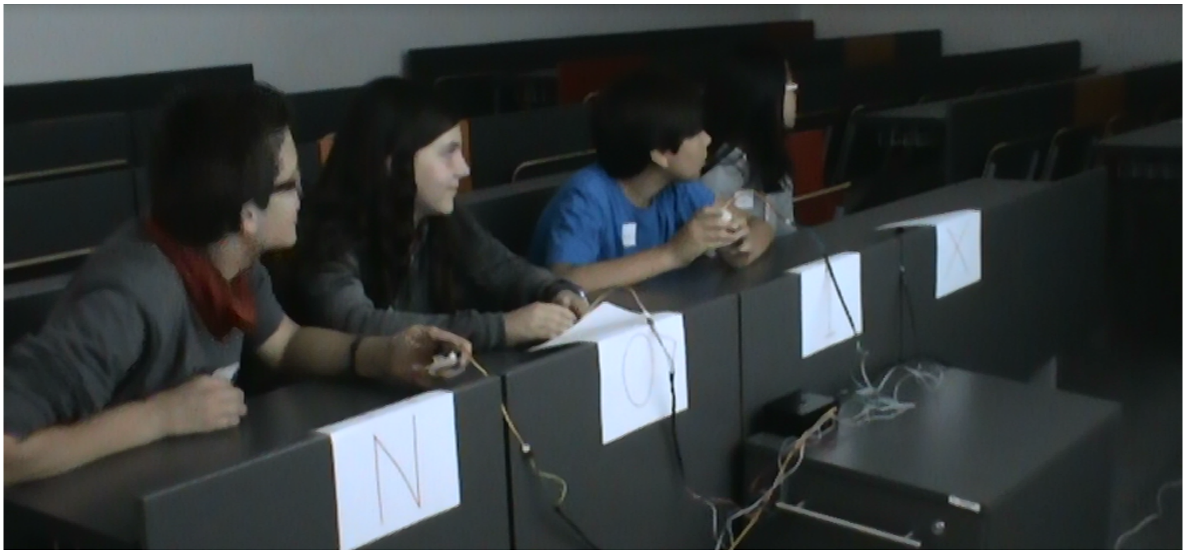


Figure 26. Children playing with the Single Display Groupware system

The two interfaces were tested twice using in each trial a different game: either "Hamsterball" or "Archimedes". In each trial, two versions of the games were developed: one for the Interactive Slide and one for the Single Display Groupware. The games offer the same gameplay (game mechanics or rules) and content for both interfaces. This choice allowed us to properly discriminate between the impact of the game's content and the impact of the used medium. Furthermore, testing our hypothesis with two games permitted to strengthen the reliability of the research.

Hamsterball

This game was designed to support collaborative problem solving. The goal of the game is to carry a hamster ball from its initial starting position, on the top left of the playing area, to its house, situated on the lower right (Figure 27). To do so, the players must get coordinated and create bridges. A circle represents each player and constitutes a node for building bridges. When two nodes are sufficiently near a line connects them, serving as a segment of the bridge for the hamster ball to roll down. When children successfully manage to bring the hamster ball to its home, the game goes up one level, the position of the elements is reconfigured and obstacles appear. In the Interactive Slide, the nodes represent the physical position of the children on the sliding surface, while in the Single Display Groupware system the nodes correspond to the position of the mice's pointers.

Figure 27. Children playing with the Hamsterball game

Archimedes

This game (Figure 6, Chapter 4) was originally designed to support learning about the notion of buoyancy and the Archimedes principle. The goals of the game are: 1) to allow a cat to cross a pool of water by building a bridge on the left pool and run after the mouse; 2) to raise the level of water in the right pool to allow a green fish to jump to the left pool and meet its pink friend. To do so, children have to make a strategic use of the objects that scroll in the top part of the scenario (a rock, a wood log and a ball).

6.2.2.1 The experimental procedure

For this exploratory study, the same experimental procedure was employed in both trials for both games. In both cases, the experiments were carried out at the university on different days. Specifically, we firstly conducted the trial employing the game "Hamsterball". Subsequently, we replicated it using the game "Archimedes". For both experiments, we worked with 11-12 years old children from local schools and used a similar procedure.

After their arrival, children were divided into groups of four members. Each group was then randomly assigned to either the Experimental Condition (Interactive Slide) or the Control condition (Single Display Groupware system). Then, one group at a time was taken to either the room where the Interactive Slide was set-up or the room where the Single Display Groupware system was installed.

In both cases, children were introduced to the game by a short video tutorial that explained the main goals and rules of the game. After that, children were invited to play with the game for a six minutes session. After playing, children were asked to individually fill out a questionnaire.

6.2.2.1.1 The questionnaire

The questionnaire was elaborated using as foundation already existing questionnaires aimed at assessing socio-affective aspects in working group dynamics (Kreijns, Kirschner, Jochems, & Van Buuren, 2004, 2007). We selected questions that were suitable for the specificities of the environments and for the developmental level of the target population (11-12 years old). Questions were adapted to a language suitable for children and translated into Spanish. An initial version of the questionnaire was elaborated including two questions to be rated on a 1 to 10 scale and three questions based on a five-level Likert scale.

Questions were designed to assess how group members felt about each other and to evaluate their level of perceived collaboration. Specifically, the questions concentrated on the following aspects: the *amount of perceived collaboration*, the *performance of their peers,* the climate of *reciprocal listening*, the level of *reciprocal help* and the *extent to which the game enabled collaboration.* A translated version of the questionnaire is given in Table 16. A detailed description of the overall experimental procedure and questionnaire elaboration process is available in (Malinverni & Pares, 2015)

Table 16. Questionnaire to evaluate the socio-affective aspects of collaboration

	Please answer the following questions
1: rate collaboration	- from 1 to 10, how much did you collaborate between each other?
2: rate peers	- from 1 to 10, how well did your peers play?
	Rate from 1 to 5 the following statements (1 = totally disagree; 5= totally agree)
3: rate listening	- some group members were not listening to the others
5: rate help	- some group members helped a lot to solve the game
6: rate enabled collaboration	- the game allowed a strong collaboration between each other

6.2.2.2 Exploratory Study's Results

6.2.2.2.1 "Hamsterball": questionnaire results

In the experiment employing the game "Hamsterball", a total of 48 children participated (mean age: 11). Since data was not normally distributed, a nonparametric Mann-Whitney test was used to compare the results of the questionnaires of children assigned to the Full-Body interaction condition (Interactive Slide) with those of children assigned to the Desktop condition (Single Display Groupware). Mann-Whitney tests indicated that for all items, except item number 5 ("*some group members helped a lot to solve the game*"), children gave higher rates in the Interactive Slide condition than in the Single Display Groupware condition (for a summary see table 17). Furthermore, the overall construct of perceived collaboration and group impressions was rated significantly higher in the Interactive Slide condition (Mdn = 30) than in the Single Display Groupware condition (Mdn = 24), $U = 104.5$, $p < 0.001$, $r = .55$.

Table 17. Summary of the results of the questionnaire for "Hamsterball"

	Interactive Slide	**Single Display Groupware**	**U value**	**P value**
1:rate collaboration	Mdn = 8.25	Mdn = 7	U= 104.50	**p< 0.001**
2: rate peers	Mdn = 9	Mdn = 6.5	U= 110.50	**p< 0.001**
3:rate listening	Mdn = 4	Mdn = 3	U= 162.00	**p= 0.007**
5: rate help	Mdn = 4.5	Mdn =4	U= 253.00	p= 0.44
6:rate enabled collaboration	Mdn = 5	Mdn = 4	U= 177.50	**p =0.016**
Overall	Mdn = 30	Mdn = 24	U= 104.50	**p< 0.001**

6.2.2.2.2 "Archimedes": questionnaire results

In the experiment employing the game "Archimedes" a total of 48 children participated (mean age: 11) from a different school with respect to the previous study. As in the previous case, since data was not normally distributed, Mann-Whitney tests were used to compare the results of questionnaires of children assigned to the Full-Body interaction condition (Interactive Slide) and of those assigned to the Desktop Computer condition (Single Display Groupware). Results confirmed the findings of the previous study. Children in the Interactive Slide condition rated all the items significantly higher (except for item 5) compared to those in the Single Display Groupware system condition. The overall score of the questionnaire was also significantly higher for children assigned to the Interactive Slide condition (Mdn = 33), compared to children assigned to the Desktop Condition (Mdn = 26), U = 76.50, p < 0.001. For a summary of the results see table 18.

Table 4. Summary of results of the questionnaire for Archimedes

	Interactive Slide	**Single Display Groupware**	**U value**	**P value**
1:rate collaboration	Mdn = 9	Mdn = 7.5	U = 132.50	**p = 0.001**
2: rate peers	Mdn = 10	Mdn = 8	U= 112.50	**p< 0.001**
3:rate listening	Mdn = 5	Mdn = 4	U= 108.00	**p< 0.001**
5: rate help	Mdn = 5	Mdn = 5	U= 232.50	p= 0.183
6:rate enabled collaboration	Mdn = 5	Mdn = 4	U= 152.00	**p = 0.001**
Overall	Mdn = 33	Mdn = 26	U= 76.50	**p< 0.001**

6.2.2.3 Discussion

Results from both studies, where a total of 96 children participated, showed that Full-Body interaction had a highly significant impact on perceived collaboration and on how group members feel about each other. These similar results confirm the internal validity of the research, the reliability of the questionnaires and the independence of the results from the specific games used. Furthermore, they have relevant implications for design and research of CSCL environments. As Kreijns et al. (2003) pointed out, a positive social climate is a fundamental prerequisite for effective collaborative learning. Therefore, media and interfaces that promote a higher quality of social interaction can have a crucial impact on the implementation of effective CSCL.

Nonetheless, this initial exploration presents some relevant limitations. First, the active and engaging nature of the Interactive Slide offers an experience that is radically different from desktop computers. Hence, other variables may have shaped the results. Second, this exploratory study was oriented at comparing two very specific interfaces: the Interactive Slide and a Desktop system based on a Single Display Groupware system. As a consequence, it offers information that is only barely indicative for the design of FUBILEs. Thus, further research is needed to properly understand the role of specific affordances. At the same time, in this study we chose to use questionnaires in order to provide reliable results from a relatively wide sample (n= 96 children). Nonetheless, qualitative evaluation of situated collaboration between children would be beneficial to compare the results of the questionnaires with their behavior during the interaction and obtain richer information of the role of bodily and spatial resources.

6.2.3 Analyzing the Impact of Spatial and Embodied Resources on the Socio-Affective Aspects of Collaboration

In the previous study, we showed that Full-Body interaction favorably impacts the socio-affective aspects of collaboration. Nonetheless, due to the exploratory nature of that study, several research and design questions remained unanswered. In particular, in the context of FUBILEs, further research should address the role of the spatial and bodily resources in shaping collaborative processes. This research's focus may allow identifying the physical affordances that can be more appropriate to support collaboration, hence providing concrete guidelines for designers.

Starting from this viewpoint, the current research has two main goals. One the one hand, it aims at analyzing how the physical affordances of the environment, by eliciting specific kinds of embodied interactions, may shape social relationships and social perception. On the other hand, at a methodological level, its objective is to delineate an adequate analytical approach to properly understand the relation between physical affordances and sense-making of the experience. To this end, the current research will describe the methodological approach and the results of a study aimed at comparing two of the most common FUBILEs physical configurations (vertical screen projection and floor projection) and their impact on the socio-affective aspects of collaboration.

For this purpose, we designed an application to be tested in the two interfaces. The application, called "BetweenBodies", aims at supporting collaborative behaviors and fostering reflection on group dynamics. The design was based on the elicitation and integration of requirements from multiple stakeholders. For its initial evaluation, which constitutes the first iteration of the design process, we employed a methodological triangulation that combines a revised version of the multimodal analytical framework proposed in Section 6.1 and the questionnaire described in Section 6.2.3. In the next sections, we will describe its design process and the study we carried out. Finally, we will conclude discussing the design guidelines and methodological contributions offered by this study.

6.2.3.1 The Design process

The goal of the "BetweenBodies" application was to support collaborative creation of drawings and to serve as a starting point for guiding children's reflection on group dynamics and discrimination. Thus, in its foreseen context of usage, the application is not a stand-alone self-sufficient device, but an experiential object to ground subsequent pedagogical activities and reflections on the topic. For its design, we used an inclusive and iterative model aimed at involving multiple stakeholders in the design process. Specifically, this process was derived from the methodological approach proposed in Section 5.2 and was structured in two stages:

- An ideation stage aimed at eliciting and integrating requirements from experts and children
- A preliminary evaluation stage where we tested the first prototype and compared its usage with the two different interfaces (Vertical Screen and Floor Projection).

For both stages, we worked with children between 10 and 12 years old. Children came from different middle class urban public schools of Barcelona. Each group participated in only one of the two consecutive stages.

6.2.3.2 The ideation stage

6.2.3.2.1 Elicitation of requirements from experts

In the initial ideation stage, we consulted experts to properly delineate relevant aspects that need to be addressed. Specifically, we carried out a total of three meetings with a psychologist who is also an expert in intercultural communication, and one meeting with a cultural association dedicated to conflicts resolutions. From these meetings, it emerged that long-lasting conflicts in children's group dynamics often find their roots in in-group or out-group perceptions and discriminatory behaviors (Gini, 2006). According to social psychology, these processes are deeply connected to perceived social identity and categorization of the others (Tajfel, 1970). In other words, the categorization of somebody as belonging to a "group" different than mine could constitute a trigger of discriminatory behaviors. As a consequence, relevant starting points to guide children's reflections are related to the concepts of identity, categorization and discrimination. Grounding on these ideas, we decided to use these concepts as an initial indicative framework to define a design proposal and structure the activities of the PD workshop.

Alongside with these conceptual aspects, from an interaction design perspective, we decided to ground the embodied experience of the FUBILE in activities related to proximity, synchrony and co-creation. According to research in embodied cognition, mimicry and behavioral alignment can promote acceptance and likeness of others (Barsalou et al., 2003) and foster the feeling of being part of the same group (Csordas, 2009). At the same time, collaboration in creative tasks is widely employed in socio-educational interventions to improve group dynamics and facilitate conflict's resolutions.

6.2.3.2.2 Children as partners in the design ideation stage

In order to define the features of the experience, we carried out an initial workshop with children aimed at delve into their representations and connotations about discrimination and groups' dynamics. The goal of this workshop was to understand how children interpret these concepts in order to develop a FUBILE that is close to their universes of meanings. For this purpose, we employed a set of PD techniques, according to an approach similar to the one described in Section 5.2.

6.2.3.2.2.1 Workshop Methods

The workshop was carried out during one day in our university with 22 children. Two sessions of the same workshop were carried out. In the first session, 10 children participated, in the second 12 children. Each session lasted approximately one hour. The workshop started with a short warm-up activity aimed at making children explore the space and break the ice. After that, we conducted an activity aimed at making children reflect on grouping behavior and discrimination. We stick a little colored sticker on the forehead of each child. A total of four colors were available. After that, we asked children to make groups according to their own criteria. Subsequently, we shortly discussed the criteria that they used for grouping.

After introducing the topic of grouping and discrimination through the stickers' activity, we conducted a game based on the mechanics of "Pictionary" using terms related to diversity and discrimination (e.g. identity, diversity, difference, etc.), according to the model described in Section 5.3. Subsequently, children were divided into groups of four or five members and were provided with a fictive letter from inhabitants of another planet. The letter described a planet where the inhabitants, called "Pimpis", do not get along with each other since they are divided by color codes. It, thus ask children to help the planet by designing a game that allows the "Pimpis" to understand that is important to get along with everybody and collaborate between them. Children read the letter aloud. Thus, they were asked to make a list of possible actions and ideas to help the "Pimpis" to get along with each other. After that, they were provided with craft materials and asked to sketch out their game proposal. Children were let working on their idea for approximately 25 minutes. Then, each group presented their design ideas to the entire group.

6.2.3.2.2.2 Workshop's outcomes

During the workshop, three researchers were taking notes and all the sessions were video recorded.

Subsequently, two researchers transcribed the videos of the Pictionary activity and of the children's explanations of the games. The transcriptions were carried out employing a narrative format and focusing specifically on children's gestures and verbal explanations. After that, the two researchers jointly analyzed and interpreted data proceeding from children's productions (i.e. drawings, lists, games' prototype), observers' annotations and transcriptions. The analysis was performed accordingly to a grounded approach, aimed at spotting out relevant and transversal features.

Pictionary Activity

In the Pictionary activity, the following words were picked up and represented by children: *immigrant, racism, discrimination, different, dignity, equality, poverty, group, and identity.* Instead, the following words were rejected because they don't know exactly their meanings or because it was too difficult for them to draw it: *segregation, machismo, categories, stereotype* and *cultural diversity.* The analysis of children's drawings and related gestures allowed spotting out some relevant insights to guide the design of the experience. Specifically, the following aspects were identified:

- *The role of emotional expressions as a mediator of meaning construction:* in depicting concepts such as *racism, discrimination, dignity* and *poverty*, children employed emotional facial expressions to reinforce the concepts depicted in their drawings. Specifically, in the drawings related to *racism*, *discrimination* and *dignity* children drawn two human figures, where the one that is discriminated is depicted with a sad face while the other is depicted with a happy face. The depicted emotional expressions were reinforced by children's facial mimicry when they peers were trying to guess the proposed word. The use of this resource both in their sketches and in their physical enactments suggests the importance that emotions, feelings and empathy play in the understanding of these concepts. Thus, from a design perspective, it suggests the potential of implementing either emotional expressivity or emotional gestures in the design of the experience.

- *Visual identity and proximity as a resource to express similarity and difference:* in depicting concepts such as *racism, discrimination, different*, *equality* and *group* all children employed clearly recognizable visual markers to convey notions related to "being different". For instance, in the drawing used to depict the word "group" a girl drawn a group of girls all wearing the same t-shirt. Instead, to represent the word "different", another girl drew an apple and a strawberry separated by a line. Alongside with visual identity, also proximity was employed as a resource to convey meaning. This aspect was observed both in their drawings (e.g. drawing the character either closer o farther to each other) and in the associated hand gestures (e.g. moving the two hands one close to the other in a sort of “container” shape or moving them apart). From a design perspective, we confirmed our initial idea of using physical proximity. Furthermore, we identified the need of employing clearly different visual elements (e.g. different colors) to depict the concept of difference.

- *Pointing as discriminating:* in drawing the words *discrimination* and *dignity* two girls proposed the act of pointing at somebody as a form of describing the concept. This action was reinforced by their gestures during the guessing phase. From a design perspective, this gesture can be considered as a possible action to express specific concepts in the experience.

Game activity

During the workshop, each group proposed a game, thus a total of 5 games were proposed. Almost all groups worked well together, except group four who presented some conflictive behaviors during the activity, undermining the process of designing the game. Due to this reason, data related to group four were excluded.

Children were let free to invent all possible kinds of games (e.g. videogames, outdoor games, board games), nonetheless all choose to focus on outdoor and physical games. All games were based on using the characters of the letter, the “pimpis”, as the players of the game and using their story to structure the narrative of the game.

Two groups proposed games based on the mechanics of tags instead, the other two groups proposed games related with the idea of racing to the end. Interestingly, the two “tag” games, even if they were proposed during different sessions (thus, excluding the role of mutual influence), were based on the same mechanics. A player has to “tag” the other, then whoever is tagged should remain blocked and wait until somebody of a different color come to save him. At the same time, also the race games showed some commonalities: in both cases, players were confronted with obstacles (e.g.

levers) which need to be deactivated through collaboration and cannot by solved by a player alone. Three of the four analyzed games proposed some sort of physical contact to solve the game's challenges and foster collaboration. In the first tag game, blocked players can be liberated only if somebody of a different color hugs them. In the second tag game, the player that is tagged needs to lie on the floor and wait for somebody of a different color to pick him up. Finally, in the first race game, a player should climb one in the shoulder of the other to solve the obstacles.

From a design perspective, children proposals suggested the following hints: 1) The role of an underlying narrative structure to orient children understanding; 2) The importance of actions that can be accomplished only if two different players collaborate; 3) The role of touch and physical contact.

6.2.3.2.3 The first prototype

According to the outcomes of the workshop and the information that we gathered from the experts, we designed a first proposal of the application. For this first prototype, we decided to use the narrative employed in the PD workshop (the fictional letter from the Pimpis,) as a game back-story. The game presents the world of Pimpis, the inhabitants of a faraway planet. Their world was destroyed due to the continuous conflicts between the different tribes, each one characterized by a different color (blue, yellow, red, green). Due to the extreme situation of their planet, the different tribes decided that they have to work together in order to build again their environment.

In the experience, children are faced with an almost empty scenario (Figure 28), where four characters of different colors are present. Each child can manipulate one character and move it in the environment. To control the character each child is provided with a hand-held little lantern, whose position corresponds to the character position. Children are thus asked to draw a new world for the Pimpis. In order to be able of drawing, a minimum of two children, with characters belonging to different tribes (e.g. of different colors), needs to work together and put their characters close to one other. When two characters get close enough, they change their facial expression (from sad to happy) and a drawing line starts to appear. If the children move in the space maintaining the physical contact between their characters, the drawing line follows their paths and they can draw whatever they want.

This configuration requires children to perform a sort of "synchronized" choreography in order to create content. Its design was motivated by the intentions of creating conditions for having children paying a close attention to their reciprocal embodiment. Furthermore, we considered that proposing a sensorimotor experience that does not belong to everyday practice would have been helpful to allow children focusing on their bodies. Finally, children can change the identity (color) of their character by moving it to one of the color stain placed at the corners of the screen. The game ends after 5 minutes of play.

Figure 28. Screenshot of the initial scenario of the BetweenBodies application

6.2.3.3 The preliminary evaluation

The goal of this study was to analyze whether the affordances offered by the two different interfaces (Vertical Screen and Floor Projection), by facilitating specific kinds of embodied interaction, may shape social perception and influence the socio-affective aspects of collaboration. For this purpose, in the study, we compared the use of the same application "BetweenBodies" on the two different interfaces (Figure 29 and 30) and employed data proceeding from different sources. Specifically, the following sources were employed:

- The questionnaires for assessing social perception (described in Section 6.2.3).

- The analysis of children's in situ interaction with the two systems.
- The analysis of the outcomes of the PD activities carried out in a Redesign workshop after the play experience.

In the next sections, we will describe the procedure of the study and the analytical approach employed to analyze in situ interaction and children's productions.

Figure 29. Children playing with BetweenBodies in the Floor projection

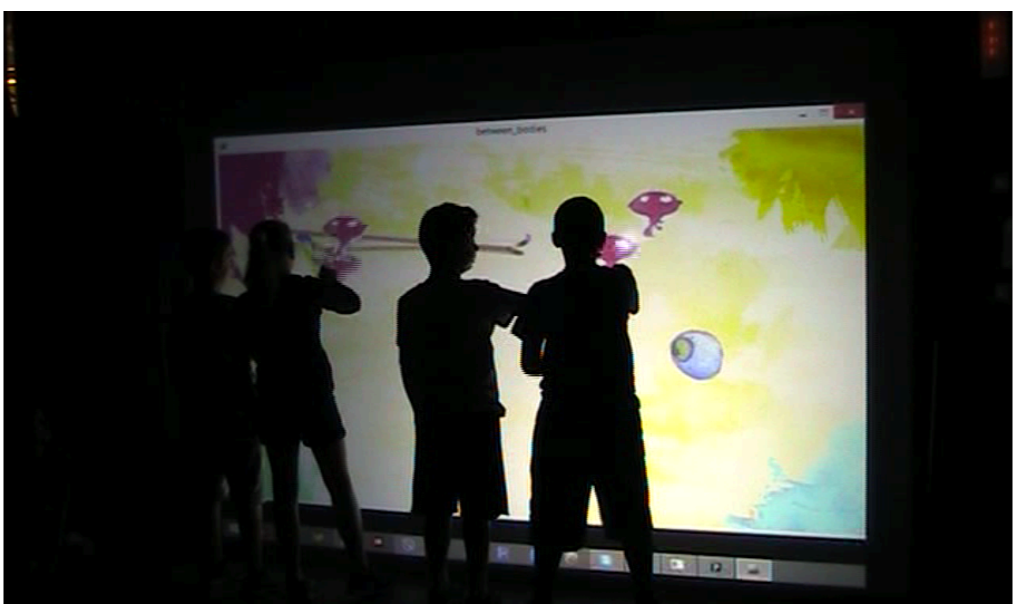


Figure 30. Children playing with BetweenBodies in the Floor projection

6.2.3.3.1 Procedure

The study took place at our University during two consecutive days. During first day, 24 children (Mean age= 10.35; Female = 12; Male = 12) of a local school participated. During the second day, we counted with 16 children from another local school (Mean age = 10.37, Females = 9, Males = 7). In order to address the different research questions two slightly different procedures were employed during the two days.

In both cases, after they arrival at the University, children were randomly separated into groups of four members each. Groups were randomly assigned to two conditions: a) Vertical Screen or b) Floor Projection. One group per time was accompanied at the facilities where either the Vertical Screen or the Floor Projection was set up. Each group was handled with a letter that briefly explains the goals of the experience through the game back-story. In the letter, children were asked to help the aliens to reconstruct together their planet. After received these instructions, each group played during 5 minutes.

After the playing activity, children who participated in the first day were accompanied to a room were the Redesign workshop took place. Instead, children who participated during the second day were asked to fill out the questionnaire individually. We choose to organize the activities according to this structure to avoid biasing children either with the questionnaires or with the workshop activity.

The Redesign workshop

In order to collect children reflection on the experience and understand how they interpreted it, we decided to organize a participatory Redesign workshop. The main structuring axis of the workshop was the idea of involving children as design critics (Frauenberger et al., 2013) and consequently asking them on possible improvements. This strategy was based on the practice of critique as an instrument to reflect on design production and on the idea that, during the unfolding of creative activities, people inevitably projects their own meanings and representations in the creation of an artifact (Kress, 2010).

For this purpose, the Redesign workshop was structured as following. First, children were asked to propose a possible title for the game they played and to write it on a post-it. Subsequently, they were asked to stick their post-it on a whiteboard and to explain the reasons behind their choices. After that, children were asked to express their opinions on whether it could be possible to learn something from this game. As in the previous activity, children wrote their proposals on post-its, which are later discussed in the overall group. Finally, children were divided again into the previously assigned groups and were provided with a reduced scale model of the interactive space and with figures depicting the main characters. Children were, therefore, asked to redesign the game in order to improve it and build low-tech prototypes of their proposal. Finally, each group presented their idea to the others.

6.2.3.3.2 The analytical approach

In order to analyze children's in situ interaction and their productions during the Redesign workshop, we employed a revised version of the multimodal analytical framework described in Section 6.1. This revised version focused on two main aspects. On the one hand, it aims at analyzing the situated and embodied meaning making through a fine grain observations of in situ interaction. On the other, it aims at collecting children's retrospective interpretations of the experience through the analysis of the outcomes of the participatory Redesign workshop. To analyze in situ interaction we focused on the following aspects:

1. **The sensorimotor exploration:** To analyze how children interact with the two systems and the kind of sensorimotor exploration promoted by two interfaces, we focus on the following embodied resources:

- *Paths of exploration*, understood as children's bodily displacements in the space. To analyze these aspects, we transcribed each child's paths according to a graphical map-like format (For an example of the path see Figure 31)

- *Variations and repetition of bodily movement,* understood as the bodily movements that the child explores or uses to interact with the system. These variations were annotated in the individual maps accordingly to the position where they were occurring.

- *Immersion and reflection*, understood as the pauses that children made to step-aside and observe the experience. These pauses were annotated in the path's map of each individual child.

2. **Relational aspects:** In order to analyze the relational aspects, understood as all the verbal and non-verbal behavior related to social interaction, we observed and annotated the following aspects: *verbal social interactions, avoidance or seeking for contact, number and variety of collaborative interaction with other group members, synchrony*. Verbal social interaction and synchrony were transcribed according to a narrative approach. Instead, contact seeking/avoidance and collaborative interactions were annotated on the path's map developed for each child.

On the other hand, to analyze children's retrospective interpretations, we focused on the data proceeding from the Redesign workshop. Two researchers transcribed data proceeding from the video recording of the workshop using a narrative format. Subsequently, these transcriptions and the material produced by the children (game's prototypes, notes) were analyzed according to a grounded approach.

6.2.3.4 Results

In the following sections, we will report the results proceeding from the questionnaires and from the multimodal analysis of in situ interaction and workshop activities.

6.2.3.4.1 Questionnaires

A total of 16 children participated in the study during the second day and completed the questionnaire (mean age: 10.37) Since data were not normally distributed, we used a Mann-Whitney test to compare the results of questionnaires of children assigned to the Vertical Screen condition and of those assigned to the Floor Projection condition. Results showed that children assigned to the Floor Projection condition rated all the items significantly higher (except for item 4) than those in the Vertical Screen condition. The overall score of the questionnaire was also significantly higher for children assigned to the Floor condition (Mdn =10.9), compared to children assigned to the Vertical Screen condition (Mdn =4), $U = 76.50$, $p < 0.001$. For a summary of the results see Table 19.

Table 19. Summary of results of the questionnaire comparing Vertical Screen and Floor Projection

	Floor Projection	**Vertical Screen**	**U value**	**P value**
1:rate collaboration	Mdn = 9.6	Mdn = 3.2	U = 2.25	**p = 0.005**
2: rate peers	Mdn = 8.5	Mdn = 5.2	U= 10.50	**p = 0.042**
3:rate listening	Mdn = 10.5	Mdn = 4.5	U= 3.5	**p = 0.003**
4: rate help	Mdn = 8	Mdn = 7	U= 21	p= 0.31
Overall	Mdn = 33	Mdn = 26	U= 76.50	**p< = 0.001**

6.2.3.4.2 Analysis of in situ interaction: situated and embodied meaning making

To analyze in situ interaction we employed the video recordings of the children playing either with the Floor Projection system or with the Vertical Screen system. A total of four videos were analyzed (2 for the floor system and 2 for the vertical screen system; 2 belonging to the first day and 2 to the second day). Each video lasts 5 minutes, corresponding to the time of play of the children.

For the Floor Projection, we used videos proceeding from a camera set-up in a zenithal position in a balcony adjacent to the interactive environment. For the Vertical Screen, we used videos proceeding from a camera set-up behind the children. The analysis was performed individually for each child (n = 16, 8 boys, 8 girls) by three researchers. To perform the analysis, first, the three researchers jointly performed a narrative transcription and multimodal analysis of one of the videos to agree on the coding conventions. Subsequently, each researcher individually analyzed and transcribed one of the remaining videos. These transcriptions were carried out through repetitive frame-by-frame visualization of videos and through the use of the above-described graphical representations. Finally, the analysis of the different videos was summarized and interpreted through a series of meetings between the involved researchers.

6.2.3.4.2.1 The Sensorimotor Exploration

Paths of exploration

To analyze the paths of exploration we employed the individual maps produced for each child (Figure 31 and 32). From this analysis, we noticed relevant differences in exploration between the

Floor Projection and the Vertical Screen conditions. In the Floor Projection, children tended to explore more the space, by moving around it and covering almost the whole surface. In this configuration, thus, children did not show to have a "preferred area" of exploration but tended to homogeneously explore the whole interactive surface. Instead, in the Vertical Screen condition, 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. In the few the cases where children started to explore other areas, they mainly tended to do sporadic movements and then go back to their initial position. Moreover, within this reduced area they tended to use mostly the upper part of the screen, which corresponds to the nearest positions that can be covered by arms movements without a body displacement or a change in their reciprocal positions in front of the screen.

These differences in the way in which children explored the space pointed out how the different affordances of the spatial configuration supported diverse ways of making sense of the space and consequently of understanding the experience. In the Floor Projection, children did not have the perception of having "an assigned/preferred area" and they, instead, explored the space as a "smooth space", where movements can easily and freely occur (Deleuze & Guattari, 1988). On the other hand, the Vertical Screen promoted explorations related to the notion of property and territoriality. Each child mainly interacted and explored "his own area", just slightly and seldom intersecting other's users' spaces.

These differences in the perception of the space may have significant effects on children's understanding of the experience and especially in relation to the collaborative aims of the installation. The Floor, by being used as a "smooth space", supported the idea that the space "belong and can be used by everybody", thus possibly offering more appropriate affordances to promote collaboration. On the other hand, the Vertical Screen offered affordances that remind the idea of property and individualization of the space, which, in turns, may end up limiting the collaborative potential of the interface.

These findings are, thus, consistent with the results of the questionnaires, which pointed out how the Floor Projection supported a higher level of perceived collaboration. Furthermore, these results highlighted relevant considerations about the structuring of collaborative activities. In this case, the Floor Projection may have offered more robust affordances to promote self-organization and negotiation of the tasks. These aspects are fundamental elements upon which discussion on collaboration, group behavior and conflict resolution can be grounded. In other words, it is not the same if the system affords a “pre-given” division of tasks (e.g. “you are in charge of that area and I’m in charge of this one”) or if it requires a shared decision-making and negotiation of these aspects. Thus, from a design perspective, these findings indicate the importance of the relational affordances of the space and suggest how different features of the physical/digital environment may change the perception of collaborative tasks and of fundamental processes such as negotiation and self-organization.

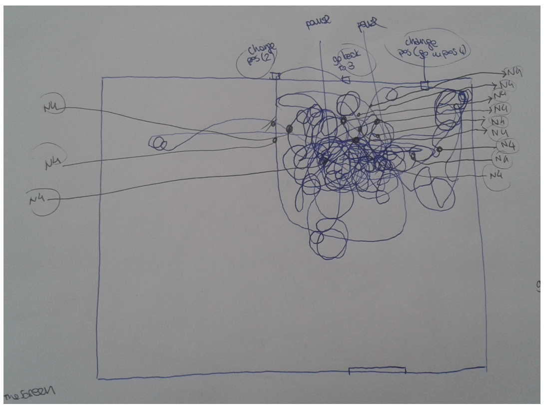


Figure 31. Example of the map of one child assigned to the Vertical Screen

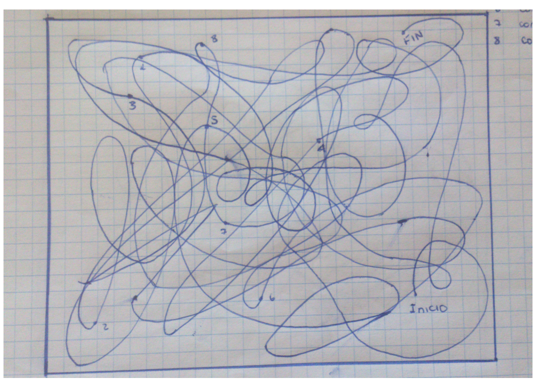


Figure 32. Example of the map of one child assigned to the Floor Projection

Variations of movements

We analyzed the variations and repetitions of movements by observing researchers’ annotations on the individual maps of each child. From this analysis, it emerged that children showed different patterns of movements in the two conditions. Specifically, the Floor Projection offered a broader spectrum of affordances to promote sensorimotor exploration. In particular, the following variations of movements were observed: alternating walking backward or forward, making circles and semi-circles (either walk in circular paths or perform circles with the arm), wave the arms, jumping, change the walking speed, walking sideways, turning around on oneself, making circles (in a Round-a-Rosie style) with other children, step over some digital element. Instead, in the Vertical Screen, movements' variations were mainly limited to changes in the performed arms movements (e.g. making circles and semicircles, do a coloring like movements, alternate straight lines with circular lines). Nonetheless, in both cases, repetitive behaviors were related to the performance of straight lines and circular movements. These movement's patterns were clearly reflected in children produced doodles. In both conditions, children almost did not created any figurative drawings. Instead, they produced mainly scribbles.

As described in Section 6.2.4.2.3, a child can draw only when his character is touching the character of another player . Hence, in order to draw, children have to follow each other and to negotiate their patterns of movements. This design solution proposed a different way of "embodying drawing", which diverges from the usual way in which this activity unfolds. At a sensorimotor level, drawing is generally an individual activity that requires a fine motor control of one own hand and arm. Instead, in the proposed configuration, it implies coordination, synchrony and a "shared motor control" between the two children. Thus, children's scribble activity may be interpreted in the light of the difficulty of the required motor control and of the novelty of the experience (as when toddlers start to scribble and making marks). This discrepancy between the initial goals of the experience (i.e. design the planet's environment) and its usage requires focusing design improvements toward better framing the relation between the proposed sensorimotor experience, the task and the digital outcomes.

Reflection / immersion

To analyze the moments for reflection and observation, we counted the frequency of the pauses in both conditions. No differences were present in the number of pauses or in the specificities of the observing behaviors. Nonetheless, for both conditions we observed different patterns of engagement and immersion in the activity through the time span. Both in the Vertical Screen and in the Floor conditions, all children started the game focusing their attention on the interactivity and on the control of the character's movements. This experimentation with the controls was particularly evident in the Floor Condition, where several children spent the first minute of the experience figuring out how to move their characters around and how to draw together with their peers. Nonetheless, changes in the focus on the experience were reported in both conditions. Both in the Floor Projection and in the Vertical Screen, many children seemed initially engaged with the experience but, toward the end of the game, they started to lose their attention. This time-related shift suggests the need for improving the design of the experience in order to maintain the level of engagement for a longer time span.

Relational aspects

In order to analyze the relational aspects during in situ interaction, we observed verbal social interactions, avoidance/seeking for contact behaviors and the number and variety of collaborative interactions with other group's members. In relation to verbal social interactions (i.e. commentaries, instructions, demands, responses), children showed similar behaviors in the Floor Projection and in the Vertical Screen. Verbal interactions were mainly related to giving instructions (e.g. "come here"), asking questions about the specific functioning of certain elements (e.g. "What happen if we put all the pimpis together?") or with specific commentaries on the experience (e.g. "Oh..that's so nice"). Nonetheless, any verbal interactions explicitly addressed a shared decision-making on "what to draw". This aspect is consistent with children's tendency to just scribbling, reported in the previous section.

Similarly, behaviors related to actively avoiding making contact with others were distributed in an analogous way in both conditions and were mainly associated with specific temperamental features of the children (e.g. being more introvert). However, some relevant differences were reported in collaborative interaction related to making contact with other children and draw together. To perform this analysis we quantified the number of contacts that children make and collected the information about the specific pairing dyads. We, thus, compared the amount of total contact made for the two conditions. Since data were not normally distributed we used a Mann-U-Whitney test to compare between Floor and Vertical Conditions. Results show that children assigned to the Vertical condition (Mdn = 25) performed significantly more contacts than children assigned to the Floor condition (Mdn = 12), $U= 6$, $Z=42$, $p = 0,005$. These differences can be explained in relation to the reduced amount of space explored by the children in the vertical screen condition, where proximity could facilitate a higher number of contacts.

Subsequently, to evaluate the variability of the collaborative interactions we quantified how many times each child uses his character to make contact with each one of the characters of the others group members. Results of this analysis are reported in Figure 33. As it is possible to notice the groups assigned to the Floor condition displayed a higher variability in the selection of the partner for the interaction. Both in the group 1 and in the group 2, each child made at least one contact with each one of the other players. This observation pointed out how the Floor Projection may offer affordances that are suitable to foster children to interact with all of their peers during the experience. Instead, in the Vertical Screen condition, children showed patterns mainly related to having a preferred partner for the interaction. This feature is particularly evident in the third group, where each child interacted with just one of their peers. This difference between the affordances offered by the two interfaces can be explained in terms of spatial configurations. In the Vertical Screen, children tended to remain in the same position and to interact mainly with the peer that was at their side, thus excluding the interaction with children that were standing in other positions. Instead, in the Floor Projection, the absence of the feeling of "having an assigned space", allowed children to freely move and promoted a higher variety in their interactions.

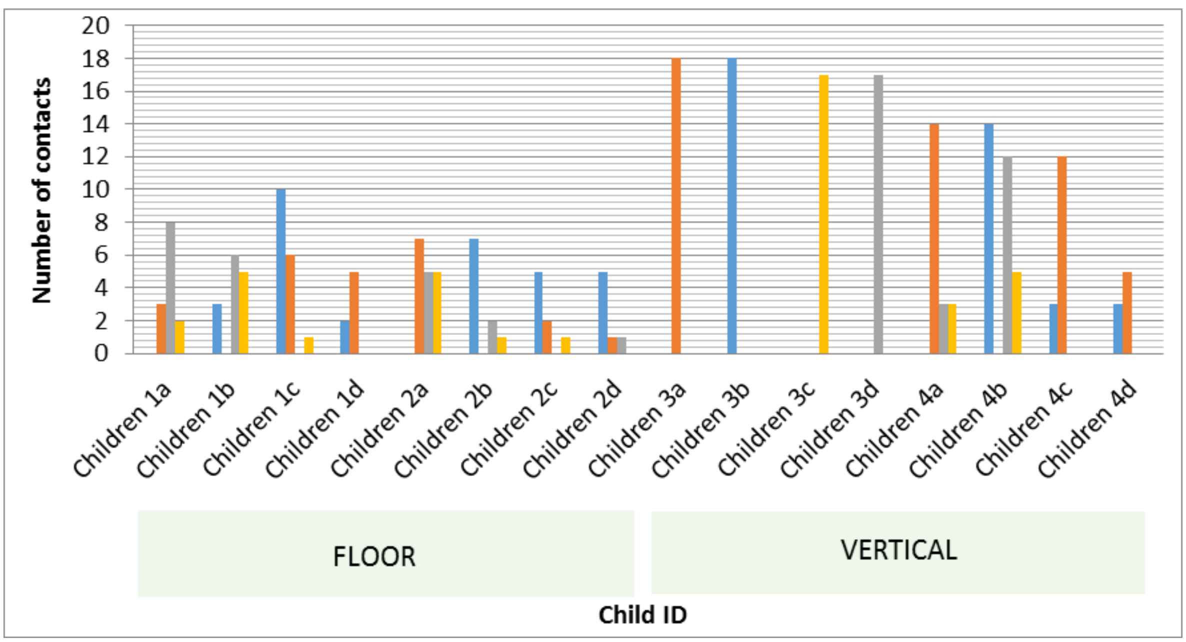


Figure 33. Summary of the number of interactions performed by each child with his peers

Despite the differences in the quantity and variability of the interactions, children in both conditions showed similar behaviors in the act of drawing together with their peers. In both cases, children drawing's activity mainly relied on some sort of tacit and embodied coordination, where only few verbal instructions were reported. This form of coordination was mainly framed around the unspoken establishment of a leading figure (who guide the movements) and a follower, in a sort of proto-dance pattern. This behavioral alignment, which requires paying a close attention to the body of the other, displayed a more complex range of coordinated behavior in the Floor condition, thanks to the affordances that this interface offers for sensorimotor exploration. As a consequence, it may be possible that the Floor Projection contributed to shape the perception of groups members since it enabled a higher variability in peers' interactions and a broader range of sensorimotor possibilities.. This hypothesis would be consistent with the studies on the correlation between behavioral alignment and reciprocal likeness.

6.2.3.4.3 Analyzing children's retrospective interpretations: the Redesign activity

During the workshop, children were asked to: 1) propose a title for the game; 2) guess the potential educational goal of the experience; 3) suggest possible design improvements.

From the analysis of the video and of children's productions, we observed that the 71.4% of them suggested that the game might be useful to learn about how to work in teams, help each others or make friends. Instead, the 28.6% suggested topics related to art education such as drawing or color mixing. These results, thus, suggested that the experience meaningfully managed to express aspects related to collaboration and social interaction, hence generating a common communicational ground between designers' intentions and children's appropriations.

On the other hand, in the activity of having to suggest a title, the 85% of children suggested titles mainly related with the underlying narrative structure (e.g. "Save the pimpis", "Pimpi's city"). This focus toward using the narrative as guiding elements was consistent with several of their design proposal. Within this context, children proposed solutions related to making more consistent the relation between the experience and the underlying narrative (e.g. having to draw buildings and public spaces for the planet). These suggestions about having to draw more figurative elements were consistent with our initial design proposal but diverted from the observations related to in situ interaction, where children were mainly scribbling. A possible issue that can explain this aspect has been identified in the complexity of the motor control required by the drawing tool. Thus, children may have initially enjoyed the sensorimotor experience of scribbling together and they had correctly understood the goal of the experience. Nonetheless, they may have felt frustrated by the difficulty of the drawing activity and considered that this sensorimotor experience did not offer affordances good enough to produce drawings that requires more fine-grain manipulation. As a consequence, they gradually lost their interest in the experience and felt frustrated about it. This issue may confirm a relevant weakness of the designed experience: the poor consistency between the goal of the task (drawing figurative elements) and the nature of the proposed sensorimotor experience. As a consequence, further design refinements should address strategies to mediate between these two aspects.

On the other hand, two children complained about the fact that the game did not have a clear purpose and suggested to add elements that can provide a stronger goal-orientation to the experience (e.g. making points, antagonist, time constraints) These requirements suggest how a loosely structured experience may have resulted unfamiliar for children. Children tend to be used to digital games that have a strong goal-oriented approach (e.g. you have to fulfill a specific goal). In our design strategy, we decided to let the game intentionally open-ended and to limit the number of constraints in order to let more space for children's interpretations and forms of usage. This dichotomy between exploratory experiences and goal-oriented ones (already reported in Section 5.1), again points out the dilemma between reproducing "usual" experiences or push toward the difference. At the same time, it requires dedicating further research to exploring the balance between freedom and structure.

Finally, children suggested improvements related to specific technical issues (e.g. sometimes the system lost track of the user) and usability. Within that, most complaints addressed the interaction with the Floor Projection system. In this case, children had to hold a little light and to maintain it pointed toward the ceiling. Some children found this interaction tiring and suggested possible improvements related with making it smoother (e.g. using a stick that can be placed on the ground).

6.2.3.5 Discussion

Designing for CSCL requires a careful reflection on the kind of collaborative behaviors that we want to foster and on the most appropriate resources that we can employ to support them. In this research, we focused especially on the role of spatial and embodied resources in shaping collaborative tasks and influencing the social affective aspects of collaboration.

Our study showed that Full-Body interaction had a highly significant impact on perceived collaboration and on how groups' members feel about each other. And the same time, it highlighted how the different spatial configurations, by eliciting specific kinds of embodied interactions, determined different ways of making sense of the experience and shaped social relationships and social perception. From a general perspective, the current research offers contributions both for guiding design practices as well as for defining appropriate research method to understand the relation between physical affordances and sense-making of the experience. In the next sections, the main implications related to these aspects will be discussed.

6.2.3.5.1 Design Contributions

6.2.3.5.1.1 The relational qualities of the space

In the first study, we showed that Full-Body interaction impacts the socio-affective aspects of collaboration. From these results, we hypothesized that this outcome can be due to the fact that Full-Body interaction enables the use of spatial and embodied resources fundamental for social communication and social cognition. In the second study, we delve into this idea and explored the role of specific spatial affordances in shaping this relation. The comparison between two of the most common physical configurations of FUBILES, Vertical Screen and Floor Projection, allowed identifying that these different design solutions can determine changes in how group members feel about each other and in the collaborative behaviors displayed during in situ interaction. These findings are consistent with research in social psychology, which indicated that even small changes in the physical configuration of the environment can drastically shape the establishment of social relationships (Festinger et al., 1950).

Specifically, in our study, we showed that children assigned to the Floor Projection rated significantly higher aspects related to collaboration and group behavior with respect to their peers assigned the Vertical Screen condition. Possible explanatory reasons behind this difference have been found in the analysis of children's behavior during in situ interaction. In particular, we showed that the floor projection, by evoking the idea of "smooth space that belongs to everybody" avoided individualistic patterns related to caring just about one's own area. Furthermore, it promoted variations in the paths of exploration and in sensorimotor activities, hence facilitating the diversification of group interaction and avoiding limiting collaboration only to dyadic relationships.

These differences point out that, when designing for CSCL, we should pay a careful attention to the relational qualities of the space. Different physical configurations can promote diverse patterns of collaboration, which may be more or less aligned with our intentions (i.e. collaboration as a division of tasks or collaboration as a shared endeavor; collaboration as framed around pre-given roles or as emerging from negotiation). As a consequence, when choosing the configuration of the physical interface, it becomes necessary to go beyond its functional role or its technological easiness. Instead, our choices should be carefully motivated by our social and pedagogical goals.

This issue does not only address considerations on design practice but may also have relevant implications on educational policies related to implementing technology in formal and informal learning contexts. Our research showed that interacting with different media could influence the quality of social interaction and the impressions that children have of their peers (e.g. being more or less collaborative or prone to listening). In the present study, this finding is circumscribed to a laboratory experiment lasting only a few minutes. However, when implementing learning technologies in real world contexts, it is necessary to consider that the use of different media may have implications that go beyond the short term of a sporadic experience. Instead, their impact may also extend to a more broad perspective, especially when interacting with technology becomes a habit. As Turkle (2012) points out, technology can shape the way in which we consider and behave in everyday social relationships. Thus, careful ethical considerations should address the social and psychological aspects that certain media can support and how these aspects can have long-term consequences.

6.2.3.5.1.2 The sensorimotor and experiential qualities of the experience

In both configurations (Vertical Screen and Floor Projection), our goal was to design an experience capable of requiring children to pay attention to their reciprocal embodiment and take advantage of their sensorimotor resources for coordination and collaboration. For this purpose, we focused our design strategy on proposing a bodily experience that did not belong to everyday practices and that is unlikely to be experienced through other media. This strategy was derived from embodied practices (i.e. performance, theatre, dance), which often employs unusual patterns of movements to increase the practitioners awareness on their own embodiment (Loke, Robertson, & Sydney, 2013).

Nonetheless, while in the initial testing, researchers and developers managed to produce figurative drawings, this outcome was not reproduced in children's experience due to the difficulty of the proposed motor control. As a consequence, this difficulty provoked a certain frustration in children and reduced their engagement even in a short time span.

This weakness requires paying a close attention on the consistency between the nature of the sensorimotor experience, the goal of the proposed task and the digital outcomes offered by the application. In the effort of unpacking this relation, researchers should carefully scrutinize the relative relevance of the different aspects and how they relate between them. Or, in other words, designers should carefully reflect on two main aspects. On the one hand, clearly define "what matter" of the experience (e.g. in our case, is it more important the sensorimotor experience of shared motor control or the task of producing figurative drawings for the Pimpis' world?). On the other hand, they should identify solutions to meaningfully enhance this focal point in order to make it stands as the real nucleus of meaning of the experience.

In our specific case, the central focus of the application was the proposed sensorimotor experience of shared motor control. This sensorimotor experience offered a certain richness per se. Nonetheless, its relation to the goal of drawing figurative elements and its mapping with the digital output of the drawing lines, changed the focus of attention from the sensorimotor exploration to trying to use it to draw something precisely. As a consequence, it transformed the proposed sensorimotor experience in a poorly functional tool to obtain a goal that can be better achieved through other media, hence ending up being poorly gratifying and meaningful.

This limitation, thus, requires of future design improvements aimed at properly adding value to the experiential and sensorimotor qualities of the shared motor control instead of weakening it by trying to make it fit for another purpose. Thus, future design iteration should focus on defining strategies to augment and meaningfully enhance the richness and the value of the sensorimotor experience through the use of digital technology (e.g. improve the system by making it responding to children's variation of movement, make content creation easier and suitable for gross manipulation, etc.).

6.2.3.5.2 Methodological contributions

In the second study, we proposed the employment of a methodological framework derived from multimodal analysis to investigate the role of spatial and embodied resources in shaping experience. This approach provides a coherent viewpoint for researching in embodied interaction since it acknowledges the situated nature of meaning construction and offers adequate instruments to understand the relation between physical affordances and sense-making of the experience.

In particular, by combining the analysis of multiple embodied resources during in situ interaction with children's retrospective interpretations during design activities, it allowed to taking into account the relational nature of experience as a process that unfold between what is offered by the experience and what users to bring to that encounter (Jewitt, 2013). Furthermore, by encompassing both aspects related to reflection-in-action (Schon, 1983) and reflection-on-action, it can allow unveiling processes related to construct knowledge from concrete experience.

From this perspective, thus, the proposed approach overcomes the limits of evaluation strategies that focus either only on retrospective measure or only on in situ behavioral data. As a consequence, it can constitute a relevant contribution to research aimed at deepening the understanding of embodied experiences and guiding their design process.

6.3 Researching and Analyzing Embodied Meaning Construction: Lessons Learned

In this chapter, we presented two case studies aimed at exploring methods and instruments to fully take into account the embodied nature of the experience. This approach was applied to build knowledge to guide design iterations and better understand the role of embodied resources in constructing and expressing meaning. In the next sections, we will review the main contributions of the proposed studies in order to extrapolate the lessons learned from them.

6.3.1 Design Methods: Improving and Enriching the Evaluation-Driven Design Approach

The presented research moves forward the insights derived from the studies presented in Chapter 5. In particular, in the BetweenBodies project (Section 6.2), we replicated and refined the Evaluation-Driven Approach proposed in Section 5.2. We, hence, confirmed its suitability to guide a design process and its adaptability to be tailored to fit with different content goals. In this context, the main refinements were related to the following aspects: the use of PD activities during the users-as-informants workshop and the inclusion of a careful analysis of embodiment. This approach showed to be suitable to derive rich insights on children's understandings of the experience, hence allowing spotting out relevant considerations for design refinements. On the other hand, in order to improve the analysis of children's embodied interactions with the prototype, we made a consistent effort to properly take into account the physical and spatial resources. From a design perspective, this focus of analysis allowed defining refinements grounded on robust empirical data and related with different design aspects (e.g. content, visual appearance, interaction design, physical interface, etc.). Furthermore, this approach facilitated the task of merging contributions proceeding from different stakeholders and different sources. Framing these methodological improvements around the notion of the designer as a listener/observer/*bricoleur*, we suggest that the presented methodological approach can offer useful instruments to improve our practice as designers.

6.3.1.1 Participatory Design Techniques

From the perspective of the employed PD techniques, also, some contributions can be identified. Specifically: the employment of a "transmodal translation" approach and the improvement in the analysis of the Pictionary Activity.

Transmodal Translation

In the first study (Section 6.1) we observed that the use of techniques that require the use of different modal resources (i.e. drawing the "imagined" environment or investigating it as a detective) elicited different ways of describing a phenomenon. As a consequence, they allowed tapping into different representations that the children may have around the topic. We, therefore, suggest that possible future research in the design of PD activities could address the exploration of *transmodal translation*, understood as requiring participants to translate the same idea across different modes or media (e.g., drawing, video recording, written reports, etc.). We consider that this approach may allow researchers to tap into different shades of children understandings. Nonetheless, these tasks should be carefully designed in order to avoid being repetitive.

Improving the Pictionary Activity

The BetweenBodies project confirmed the usefulness of the Pictionary and game design activity to elicit information on children knowledge and representations in a playful way. Furthermore, in this study, we proposed a deeper analysis of the Pictionary activity by carefully observing the specific formal features of their drawings and children's embodiment during the task. This analytical approach allowed getting richer and more precise insights to inform design.

6.3.1.2 Evaluation methods

From the perspective of evaluation methods, the present chapter offered two main contributions: the Multimodal Analytical Approach and the use of Redesign as an evaluation method.

6.3.1.2.1 The Multimodal Analytical Approach

In both studies, we employed a methodological framework derived from multimodal analysis (Jewitt, 2013; Kress, 2010) to combine the analysis of embodied resources during in situ interaction with the analysis of children's retrospective interpretations.

The proposed framework had been slightly modified in the two studies in order to fit with their specificities. In particular, in the first study (Section 6.1) we focused on the following aspects: the observation of *embodied and situated meaning making*, *children's focus of attention* and *children's productions*. Instead, in the second study, we addressed: *the embodied and situated meaning making*, *the relational aspects* and *children's productions*. These modifications of the framework showed its flexibility to fit with different research questions. At the same time, in both cases, it showed to be a valuable methodological approach for understanding the role of concrete design decisions and semiotic resources in shaping experience. Furthermore, it allowed tracking the meanings that children express through embodied resources and to use them in guiding future design iterations.

As a consequence, it offered relevant methodological contributions to research FUBILEs. First, by fully acknowledging and taking into account embodiment, it constitutes an appropriate and consistent research method to better understand meaning construction and learning in this kind of environments. Second, it provided relevant insights to guide Design-Based research processes and defining design improvements. Third, in the second study (section 6.1), it showed to offer a much more robust and insightful approach for carrying out comparative media studies. Thus, it allowed tackling the shortcomings of using only post-task instruments to address this kind of research questions (Kozma, 1994).

As lessons learned, we thus suggest that combining the fine grain analysis of embodied meaning making during in situ interaction with children's retrospective interpretations can constitute a valuable contribution to research in FUBILEs. Nonetheless, potential methodological improvements could address a more careful analysis of the indicators of learning. Or, in other words, we suggest the need for a more accurate observation of how children use concrete experience to construct conceptual representations and objects of knowledge. At the same time, additional research may explore novel strategies and techniques to facilitate the elicitation of children’s retrospectives interpretations.

6.3.1.2.2 Redesign as an evaluation instrument

In the presented studies, we started an initial exploration aimed at proposing Redesign as an evaluation method. For this purpose, we involved children as critics in the design process and employed techniques from PD to delve into their interpretations of the experience and eventually get their feedbacks on how to improve it. The use of critique and Redesign showed to be quite effective to grasp children's understandings and to complement our observations of in situ interaction. Nonetheless, we suggest that these techniques should be further refined to properly take full advantage of them.

6.3.1.3 Design qualities

The proposed studies allowed extending relevant insights related to design qualities for FUBILEs. Specifically, the following aspects were observed:

- <u>Embodied consistency:</u> As previously mentioned research in embodied cognition (Kontra et al., 2012) and our previous studies (Chapter 4 and 5), showed that users' embodied interaction with the system should be consistent with the phenomena that we want to address. However, the outcomes of the BetweenBodies Project suggested that this consistency should include a broader range of aspects, instead of focusing only on embodied interaction. In particular, in building this relationship, designers should pay a close attention to the physical configuration of the space, its digital augmentation and the nature of the task. In order to guide designers in dealing with this network of elements, we suggested that a fundamental starting point is represented by clearly define "what matter of the experience" and hence coherently augment this focal point.

- <u>The relational affordances of the environment:</u> in Section 6.2, we presented two studies aimed at exploring how the physical configuration of the system may affect collaborative behavior and the socio-affective aspects of collaboration. This research pointed out the suitability of Full-Body interaction in supporting collaboration. Furthermore, these results also pointed out that the different affordances of the system, by shaping the way of physically interacting with it, may enable different sense-making of shared tasks. As a consequence, we suggest that, when designing for multiuser FUBILEs, a careful attention should be dedicated to exploring the relational affordances of the interface in order to enable conditions for a fruitful collaborative learning experience.

- <u>The balance between freedom and structure:</u> both studies proposed two open-ended experiences that were not framed around clearly defined goals. In both cases, some children reported this lack of directiveness as a missing part in the design. This issue posits relevant questions in the design of educational technologies. In particular, further research should address the exploration of the range of possibilities that lies between a goal-oriented approach and more open-ended experience. In this context, both to the pedagogical implications of the two standpoints as well as the balance between freedom and structure need to be addressed. Furthermore, additional reflections should address the dilemma between reproducing familiar configurations and diverting from them.

- Salience: As previously mentioned (Section 5), in the design of FUBILEs, we should enable conditions to allow children focusing on what matter of the experience. In this context, two main contributions can be derived. On the one hand, the analysis of children's focus of attention (Section 6.1) allowed spotting out relevant elements that can serve as anchors for design improvements. On the other hand, in the second study (Section 6.2), we explored the use of an unusual body experience to promote children focusing on their embodiments. Outcomes related to the exploration of this approach showed controversial findings. Hence, further exploration should address its feasibility and potential.

Chapter 7

7 TRANSFORMING EXPERIENCE: FROM EMBODIED EXPERIENCE TO EMBODIED LEARNING

In the previously reported studies (see Chapter 6) we focused on analyzing the meanings that children construct out of embodied experiences and the role of spatial and embodied resources. The proposed methodological approach provided tools to get closer to a better understanding of embodied meaning construction, hence informing the design of FUBILEs. These preliminary steps allowed grasping the relational nature of meaning construction, or, in other words, the way in which meaning emerges at the intersection between the environment's affordances and people's appropriation. Nonetheless, in order to get closer to a deeper understanding of learning in FUBILEs, additional analytical lenses are needed.

As mentioned in Section 2.3 learning from concrete experience is a transformative process, where experience is re-elaborated to become an object of knowledge available for thinking about abstract concepts and derive implications for action. This perspective requires overcoming the naive notion of "you do, there for you know". Furthermore, it implies the need for analytical approaches capable of being sensitive to indicators of learning and to situate them in their context of occurrence.

Starting from this viewpoint, in the next section, we will report a study aimed at the exploring how embodied experiences may be transformed into ‘objects–to-think-with’—in other words, how users’ sensing-in-action can lead them to make sense of action, taking *action* itself as an entity to operate upon. For this purpose, the presented qualitative and idiographic study will analyze how children create bridges between embodied experience and construction of meaning and identify indicators of learning.

This perspective will be applied to the analysis of the first FUBILE we developed, Archimedes (described in Chapter 4). The choice of going back to analyze this environment is motivated by the intention of making visible the path of methodological approximations to which this thesis is dedicated. Furthermore, this analysis, faced with the methodological approach we initially employed to analyze this environment, will highlights how different methodological approaches, by constructing knowledge from different perspectives, shape the kind of insights that we can derive from research.

7.1 Experience as an Object to Think with: from Sensing-in-action to Making-Sense of action in Full-Body Interaction Learning Environments

This Section is based on the article:

- Malinverni, L., Ackermann, E., & Pares, N. (2016). Experience as an Object to Think with: from Sensing-in-action to Making-Sense of action in Full-Body Interaction Learning Environments. In *Proceedings of the TEI'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 332–339). ACM. http://dl.acm.org/citation.cfm?id=2839477

7.1.1 Research Framework

As described in Section 2.3, the embodiment framework proposes a distinction between online and offline embodied cognition. Specifically, *online* embodied cognition constitutes one of the mechanisms upon which knowledge is constructed, and refers to meanings that people generate during a specific concrete experience. On the other hand, *offline* embodied cognition refers to the uses of previously acquired embodied knowledge in tasks that do not involve a specific physical experience (Wilson, 2002).

This difference highlights that FUBILEs are mainly designed to address the "online" aspect of embodiment by offering rich experiences, where children can interact through their bodies and senses. At the same time, it indicates the necessity of paying attention to an aspect that is often neglected in the design practice, namely, the ways in which concrete and embodied experiences may or may not be transformed into explicit knowledge.

Nonetheless, in the design of FUBILEs, several projects were still grounded in the premise of a *direct and unmediated one-to-one* relation between embodied experience and the construction of abstract concepts. This tendency is reflected both in the claims of designers about their intentions, as well as the choices of specific design and evaluation strategies. A clear example is the widespread use of pre and posttest assessment methods such as multiple-choice questionnaires (Malinverni & Pares, 2014). On the other hand, designers' intentions are often grounded on some kind of alleged isomorphism that can be summarized in the idea that "If the user does X, then she should understand Y". This notion of "*you do, therefore you know*" amounts to little more, in its naïve form, than a new Cartesian dualism applied to experience design. Such reductionism calls for further examination of how experience can be transformed into knowledge (to properly inform design).

As reported in Section 2.3, research in developmental psychology and learning sciences pointed out that concrete experience needs to be transformed in order to become available and put to good uses in thinking about abstract concepts (Ackermann, 2004; Karmiloff-Smith, 1995; Kolb et al., 2001; Papert, 1980). Furthermore, these studies pointed out how, in this transformative process, concrete experience interacts with the network of meanings, resources, previous knowledge and interests that are specific of each learner and their contexts.

7.1.1.1 Design for learning: unpacking 'experience as an object to think with'

Designing for FUBILEs implies defining situated embodied experiences susceptible of being transformed into "objects-to-think-with". To facilitate this process, different possible strategies may be adopted. From a trans-disciplinary perspective, *framing* and *reflecting* are generally foregrounded as key drivers in the transformation of personal experience into an 'object-to-think-with'. Both designers and users (each in their own ways) resort to intentional framing and reflecting. And the techniques used come in many different forms. Examples of *framing* for design may include museum labels, or suggested paths, to help visitors focus on aspects of an exhibit deemed important. Here, by providing an interpretative context or additional information, museum curators seek to guide people into understanding their experience. Examples of *reflection*, on the other hand, can be found in the mediation of group discussion or echoed in embodied practices such as psychodrama, art therapy and Forum Theatre. Both *framing* and *reflective* techniques represent effective strategies to enhance the impact of a FUBILE, even if, quite surprisingly only a reduced number of projects employ them.

Nonetheless, we suggest that, in the context of FUBILEs, the designers' effort to help learners leverage their "lived" experience should not be limited to providing extra information, or even reflection time, just before or after the experience. In other words, designers should avoid the dualistic trap of "*this is the moment for doing; this is the moment for thinking*". Instead, they must address how experience can be reflected and externalized during action, i.e. during the situated interaction with a FUBILE [24]. In order to address this need, we propose a case study related to the analysis of children's genres of engagement during the interaction with a FUBILE.

7.1.2 The Study

In this study, we report observations proceeding from the analysis of children's interaction with a Full-Body Interaction Learning Environment, named "Archimedes" and based on the Interactive Slide platform (a detailed description is available in Section 4.1). Specifically, the purpose of the current analysis is to describe four case studies to illustrate the different paths that children may undertake to create bridges between embodied experience and the construction of meaning.

For the study, participants were recruited from a local school and a total of 48 children participated (mean age: 11). A week before the study, we administered a short open-ended questionnaire at the school premises to evaluate children's previous knowledge on Archimedes principle and buoyancy. The study itself was carried out at our university during two mornings. Upon their arrival, the children were divided into groups of four. Thus, a total of 12 groups of 4 children played with the game. Then, one group at a time was taken to the room where the Interactive Slide was set-up. Children were introduced to the game by a short video tutorial that explained the main goals and rules of the game. After that, children were invited to play with the game over the course of a six minutes session. Subsequently, children were asked to fill a short questionnaire about user experience and then they were individually interviewed by a researcher according to a semi-structured format. Questions were related to their understanding of the game and to the physical properties of the objects of the game.

7.1.3 The Case Studies

Children activity during the game and interviews were video-recorded. A researcher reviewed the overall video materials of children playing and performed a narrative transcription of the 12 videos by focusing on the overall group behavior. After that, results were discussed between two researchers and four case studies were identified. Each case study has been selected as being representative of one of the observed paths that children used to create bridges between embodied experience and meaning construction. One of the researchers then performed an in-depth multimodal transcription by focusing on the behavior of each child, during the game and during the interview. These transcriptions were performed by annotating both data proceeding from verbal interaction, as well as from embodied resources (the child's position and sensorimotor exploration). Finally, results were further discussed and elaborated by the two researchers. In the following sections we report a summary of the four case studies. Furthermore, the case studies were labeled according to their specific features in order to facilitate the discussion.

7.1.3.1 Child 1: The observer

L. is an extroverted 11 years old girl. She started by experimenting with different forms of sliding down, first doing a somersault and then trying to roll down horizontally. In her sensorimotor exploration, she did not pay attention to the scrolling objects nor did she try to drag them down. After this initial exploration, she suddenly moved to one side of the bottom of the slide and observed the game and the other three players from there. She then climbed up the stairs again, experimented with a new form of sliding down and went back to her "observation tower" (the lateral position). From this location, she started to give suggestions to other players. She told them that they needed to raise the water level by throwing objects and gave them instructions on where to slide down. Finally, she climbed back up again and rolled down without trying to drag any objects. During the interview she gave detailed explanations to the researcher about the game's goals and the strategies that the children used, explaining how they moved between different strategies: "*For moving the fish at the beginning we were throwing only balls because we didn't know what to do, but then we thought that we needed to raise the water level so we started to throw stones*".

In her own uses of the "exergame", she seemed perfectly at ease separating the nature of the sensorimotor exploration (using the slides' built-in affordance to explore sliding) from her understanding of the “additional required” game that had to be played. When she was physically immersed, she did not care about performing any strategic actions, focusing instead on exploring the opportunity of different types of movements. Yet, she was equally able to focus on the “other” game goals; and to do so, she chose to step aside and watch the game as an observer. From this perspective, and by looking at her peers playing, she built a clear understanding of the goals and properties of the objects.

7.1.3.2 Child 2: The sensorimotor explorer

V. is a shy 11 years old girl who did not speak to the other children playing, during the entire session. At the beginning of the game, she quickly climbed up the stairs and slid down without paying attention to the scrolling objects projected at the top. On reaching the bottom, she immediately climbed back up again without looking at the projection on the slide’s surface. When she arrived to the top she slid down from the position closest to the stairs. She repeated this sequence five times, exploring small variations in the way she slid down. At a certain point, one of the other children dragged a virtual rock which fell on the cat and the cat made a noise of complaint. V. then moved closer to the cat area and slid over it. After that, she went back to her previous game. During the interview, when asked about the goal of the game, she explained that it was about a cartoonish cat and the goal was to slide down without hitting the cat.

In her exploration V. mainly focused on exploring the sensorimotor aspects of the experience (i.e. enjoying the sliding). She did not seem interested in the structured game and her attention was driven to it only when the audio of the cat was triggered. While eagerly pursuing the thrills of sliding down, she integrated the incident of the cat to fit her own rules and make up for a narrative to enhance the game she wanted to play.

7.1.3.3 Child 3: The action-perception looper

N. is an 11 years old girl. She started the game by sliding over random virtual objects. Nonetheless, every time, after reaching the bottom of the slide, she turned around toward the projection to watch the effect of her actions. After three initial trials, she began to have a strategic approach toward the game, showing a clear understanding of the properties of the different objects. Her game mainly unfolded as follows: she stood on the upper part of the slide waiting for the appropriate virtual object to pass below her; she then slid down dragging the object with her; and finally, reached the bottom and turned around to check the result. Toward the end of the game she, too, started to give suggestions to the other players. She told them that they should only throw rocks in the pond of the green fish to make a pile of rocks which would force the water level up and hence allow the fish to jump to the other pond.

During the interview, she showed a clear understanding of the game and described how they (she and other children) modified their strategies during the unfolding of the experience. Furthermore, she explained that she enjoyed the game because it was not only about sliding down but "*you have to wait for the correct moment*".

N. showed a strong goal-oriented behavior. Her game was continuously modulated by the loop between action-observation and reflection. She was not specifically exploring variations in the sensorimotor experience but she used her actions to systematically test out cause-and-effect relations, until she understood the correct strategy and communicated it to the others.

7.1.3.4 Child 4: The framer

D. is an extrovert 11 years old boy. He started the game by dragging different virtual objects in his sliding actions. On reaching the bottom of the slide, he did not look back at the projection and climbed back up again. He suggested to the others that they should hit the fish so as to make it jump. After trying three times and complaining that it would not work, he took a short pause and stood on the stairs observing the play area. Suddenly, he asked the other children: "*Do you remember some questions they asked us in school? About sinking objects? We have to think.*" He then climbed back up again and dragged a log into the pond of the green fish. He looked back at the projection and stated: *"this way we will never achieve it…we need to think something to help the fish!*" Unfortunately, the game ended at that point.

During the interview he explained that the game was quite complex since "*you have to think about it.*" He correctly described how, in the end, they managed to build a bridge for the cat and that they did not manage to make the fish jump: "*you have to put something...but I'm not sure what*".

D. started the game mainly exploring the sensorimotor aspects of the experience. Yet, he soon changed his perspective and connected what he saw in the game with previous knowledge. This shift allowed him to start with a more experimental approach, oriented toward figuring out the correct strategy.

7.1.4 Discussion

These vignettes illustrate how four children focused on different aspects of the game and adopted different paths to build insights and understandings from their concrete and embodied experience. This approach allowed spotting out relevant indicators of learning processes and situating them in relation to the affordances offered by the system.

The first girl (*the observer*), for instance, showed a certain spatial and temporal separation between her sensorimotor experience and the way she constructs meaning. Her activity on the Interactive Slide mainly focused on exploring variations in "sliding down". She knew there was more to the game than sliding and chose to take an "observer" standpoint. She physically changed her position to one side of the playing area to build her understanding of the task. In her case, she used the relation between the actions of her peers and their effects in the game to mediate her sensorimotor exploration and the construction of her understanding. In this process, she used both the *social construction of meaning* through the actions of others as well as a *shift in her role* to transform embodied experience into an 'object-to-think-with'. This shift allowed her to metacognitively explore the task, hence planning an adequate strategy to solve it.

On the other hand, the third (*the action-perception looper*) and fourth children (*the framer*) construct their meanings by creating a close loop between action and observation, even when using different temporalities. This strategy is consistent with Kolb's theory of experiential learning which proposes a cycle where concrete experience subsequently leads to reflective observation, abstract conceptualization and active experimentation (Kolb et al., 2001). At the same time, interestingly, in both cases, their understanding starts to emerge when they change their movement patterns. While, at the beginning both mostly focus on the action of sliding down, when they start to turn around and take time to observe the effects of their actions on the sliding surface, they both engage in a more strategic approach to the "learning aspect" of the game. Nonetheless, while the third girl assumes a systematic trial and error approach, the fourth boy all of a sudden fathoms specific insight on the game by recalling previous knowledge. This case, thus, highlights the display of a fundamental indicator of constructive learning: the capacity of connecting novel experiences with previous knowledge. Furthermore, both cases point out the role of the action-perception loop in mediating between embodied experiences and meaning making. Nonetheless, in this relation, different strategies may be employed suggesting the importance of self-regulating the pace of the experience to build one's own understanding.

Furthermore, in the three previous cases, it is relevant to notice how children's physical change in their standpoint, offers an embodied instantiation of Ackermann's (2004) model of framing and reframing experience. This suggests the crucial role of adopting different points of view to build understanding (dwell-in, bird-eye view, other people's shoes).

On the other hand, the second girl (*the sensorimotor explorer*), presented completely different patterns from the other cases. She mainly focused on the sensorimotor aspects and built an interpretation that fits with her interests. In this case, it could well be that the act of sliding down was already sufficiently interesting for her and hence chose not to pay attention to the layer of interactive content. This latter case points out how designers should not consider the mapping between concrete experience and meaning construction as a process which is "given" by default or as a univocal interpretative path.

To sum up, the four cases point out how transforming embodied experience into 'an-object-to-think-with' vary and may (or may not) be aligned with the designer's intents. In addition to describing the children's use —and appropriations— of the proposed game, this analysis suggests two important dimensions to take into account when designing for embodied learning.

Firstly, the study highlights how embodied experience may become an 'object-to-think-with' by using different paths, which are situated in the network of meanings that the system can afford. In this study, we found examples of instances such as: *the social construction of meaning, the action-perception loop, the adoption of different perspectives, and the use of previous knowledge*. Secondly, the study points to the importance of *reflection-in-action* (Schon, 1983). These reflective moments are embedded in the experiential flow and their embodied nature is displayed in users' bodily actions, pace and use of the space (e.g. adopt an "observer position", turn around to see the screen, etc.), and selective engagement (e.g. chose to use the exergame for exercise!)

Framing this outcome within Kolb's theory of experiential learning (Kolb et al., 2001), helps understand how children may display (or not) reflective moments during the interaction by using different resources. These embodied and situated reflective moments fulfill a fundamental epistemic function, since they allow children to transform concrete experience into an 'object-to-think-with'. Furthermore, from a designer's and researcher's perspective, the surprising variety of uses calls for a closer look into the implications of environmental affordances for the design and the evaluation of FUBILEs.

7.2 Transforming Experience: Lessons Learned

The choice of going back to our first study with the baggage of knowledge gained during this research allowed making visible the path of methodological approximations and construction of knowledge that we developed during this thesis. From a methodological perspective it, thus, pointed out how shifting from our initial focus on post-task cognitive aspects (Chapter 4) to the interpretive analysis of in-situ interaction allowed to get closer to a deeper understanding of embodied learning. At the same time, it allowed getting deeper and more consistent insights to guide design. Hence, even if the use of an already existing FUBILE does not allow to derive any novel contributions on design methods, nonetheless it contributed to broaden our knowledge on evaluation methods and design qualities. Furthermore, it provided a reflexive standpoint from which to look at our research.

7.2.1 Evaluation Methods: Indicators of Learning

From a methodological perspective, the present study focused on analyzing the paths that children employ to transform concrete experience into an object of knowledge. This approach allowed spotting out relevant indicators of learning and situating them in relation to the affordances offered by the system. The contextual analysis of these indicators (e.g. strategy formation, metacognitive supervision version of the task, connection with previous knowledge, etc.) can constitute a relevant analytical lens to guide research in FUBILEs.

Furthermore, this case study allowed us to address some relevant questions such as: *When, how and in which conditions do children display moments of reflection? Which resources do they use in this process? How do they embody or enact the transformation of the concrete experience into 'an-object-to-think-with'? How do they use the space and their body in this process? How crucial* *indicators of learning processes are displayed during in situ experience and how specific resources are shaping them?*

We, thus suggest that focusing both on the indicators of learning as well as on the questions raised can represent a relevant contribution to guiding the structuring of an interpretive framework for analyzing in situ interaction and reflection-in-action. These analytical lenses, therefore, provide an additional layer to the multimodal framework employed to analyze in situ interaction (Chapter 6). Especially, they allowed taking into account the temporal dimension of knowledge construction during situated experiences (i.e. get engaged with it, experiment with it, reflect on and with it). As a consequence, they provided an interpretative standpoint to observe both the relational aspects of embodied experience (e.g. meaning as emerging from the relation between the system's affordances and users' appropriation) as well as its temporal and transformative nature.

7.2.2 Design Qualities to Transform Experience into an Object to Think With

From a broad perspective, the proposed analysis allowed identifying environmental affordances that may better support the transformation of embodied experience into 'an-object-to-think-with'. Specifically, in this study, we have identified the following qualities: 1) Spatial and temporal qualities for reflection; 2) Relational qualities; 3) Mindful qualities.

7.2.2.1 Spatial and temporal qualities for reflection

The first, third and fourth children show how the physical use of space as a place that enables multiple points of view, perspectives and roles (e.g. observer, performer, etc.) may facilitate instances and conditions for reflexivity. At the same time, the difference between the third and the fourth children points out the importance of the pace of the experience to facilitate reflection. From a design perspective, these findings suggest that certain spatial and temporal configurations may be more useful to facilitate conditions for reflexivity.

From the point of view of designing spaces, relevant opportunities can be found in design solutions that allow users to embody or inhabit different perspectives and standpoints during the experience, since this shift in their role may afford moments for reflection. An example of this can be found in a project by Nemirosky et al. (1998), where children can switch between using their bodies and controlling a remote device, to explore graphs of motion. At an applied level, a relevant guideline is, therefore, related to considering the physical space of the interactive system as a “third teacher”, which can offer affordances to navigate into different action-reflection paths. Such aspect is particularly important in FUBILEs where, despite the claim for spatially meaningful experiences, the final design tends to be mainly shaped around technological constraints (e.g. most FUBILEs use mainly vertical screen or floor projections).

Further considerations should address the definition and calibration of the pace of the activity. This implies that we must design the temporality of experiences in such a way that it may support the self-regulation of different moments, such as experimentation and reflection, “dive in” and “step out”. From this perspective, when designing a FUBILE, it becomes necessary to analyze how the experience, physical activity and reflexivity can be aligned to support different phases in the process of moving between sensing-in-action to making sense of action, using different resources.

Also in the first study with the Archimedes game (Section 4.1), we already foresaw the role of the pace of experience in shaping learning processes. Nonetheless, in that case, we were proposing, as a design solution, a sort of “pre-build” modulation of the different stages of the experience. However, as the current study points out, enabling conditions for reflecting on experience does not necessarily mean we need to create pre-established “place/time for reflection” and “place/time for action”. Instead, it implies that we should think about spatial and temporal configurations to enable different types of “journeys” and ways of engaging during the experience.

7.2.2.2 Relational qualities

The present study deepens on the reflection on the relational qualities of the experience (Section 6.3) and showed how the social affordances of the system have enabled instances for transforming experience, either through the observation of peers’ actions or through the externalization of their own reflections (or that from other children). From the perspective of designing FUBILEs, this suggests a need for further research on how the system may afford both the identification with other people’s actions as well as instances for co-constructing meaning. In this context, relevant design opportunities can be found in combining knowledge proceeding from computer-supported collaborative learning with the use of embodied resources for social understanding (e.g. gaze, mutual orientation, joint attention).

7.2.2.3 Mindful qualities

As previously mentioned, when designing a FUBILE, its overall configuration should enable conditions for children to focus on what matters of it and being sensitive to relevant changes (Langer & Moldoveanu, 2000). Furthermore, as the case of the second girl pointed out (the sensorimotor explorer) we need to avoid situations where either the sensorimotor experience or other interactive features act as distracters (i.e. in our study, the sliding experience was already sufficiently interesting on its own for the second girl, thus inhibiting her interest in the superimposed game). Possible strategies to tackle these risks may be found in rethinking the relations between sensorimotor experience and content and in providing hints to frame children interpretations toward the educational goals.

7.2.3 Conclusions

The reported research path described the process-oriented iterative effort of improving our methodological approach to better understand how to design FUBILEs. On the one hand, from a self-reflective standpoint, the described path showed how constructing scientific knowledge represents a process that is not far from the experiential learning phenomena that we are studying. In other words, also our own process of constructing knowledge on learning in FUBILEs grounds itself on transforming and elaborating the experience gained in order to use it for subsequent research. To conclude, we suggest that a critical self-reflection and analysis on this latter aspect can constitute a fundamental tool to guide practitioners in the effort of figuring out appropriate methodological approaches.

8 CONCLUSIONS: MERGING PERSPECTIVES

"L*a connaissance du tout et de ses lois, de l'ensemble et de sa structure, ne saurait être déduite de la connaissance séparée des parties qui le composent : cela veut dire qu'on peut regarder une pièce d'un puzzle pendant trois jours et croire tout savoir de sa configuration et de sa couleur sans avoir le moins du monde avancé : seule compte la possibilité de relier cette pièce à d'autres pièces, et en ce sens il y a quelque chose de commun entre l'art du puzzle et l'art du go ; seules les pièces rassemblées prendront un caractère lisible, prendront un sens"* (Perec, 1978)

In this thesis, we have made an effort to delve into the understanding of FUBILEs and proposing appropriate methods for designing and evaluating them. This research was guided by three main research questions, specifically:

- "Which design methods can be appropriate to design FUBILEs?"
- "Which evaluation methods can be appropriate to analyze meaning construction and learning in FUBILEs?"
- "Which qualities of Full-Body Interaction Learning Environments can support experiential learning processes?"

To address these questions we informed the research through three main perspectives: a detailed overview of embodied cognition framework and experiential learning theories (Chapter 2), a systematic and critical review of related research (Chapter 3) and an empirical methodological exploration (Chapter 4, 5, 6 and 7). These three strands of research offered us the opportunity to look at the research questions from multiple perspectives and to learn from theory, learn from others and learn from our own experience.

In order to summarize and merge the knowledge gained through this process, in the next sections, we will describe the main contributions related to the three addressed research questions. Finally, we will conclude discussing the implications of the current research from a broad perspective and its limitations and potential areas for future works.

8.1 Design Methods

As reported in Chapter 6, designing a FUBILE implies to undertake several decisions on the specific features of the experience. Furthermore, these decisions need to be motivated by a proper understanding of the affordances of the employed resources and of the ways in which users signify them. To guide this process, we suggested the need for an informed theoretical background and for a proper understanding of users' worldviews.

However, often the design of FUBILEs derives from a Technology-Driven approach that poorly takes into account the implications of the theoretical framework (Alissa N. Antle, 2013). At the same time, most studies employ a Designer-Driven approach, where users are involved just as eventual testers (Laura Malinverni & Pares, 2014a). We identified a possible explanation behind this tendency in the challenges related to combining a complex theoretical framework with children's involvements. On the other hand, also, specific difficulties arise in the effort of properly addressing the features of embodied interaction within a participatory process (i.e. the legacy of well-known interaction modalities may strongly influence participants' ideas).

In order to tackle these issues, in the present thesis, we proposed a set of methodological explorations aimed at researching on appropriate methods for designing FUBILEs. Specifically, our research focused on the following issues: 1) define strategies to properly integrate interdisciplinary theoretical frameworks (e.g. embodiment, learning theories) with stakeholders' contributions and 2) defining potential guidelines to address embodiment in PD process. In order to describe our contributions to these research goals, in the next sections, we will summarize the approaches we employed in the studies described in this thesis. To conclude, we will provide guidelines for practitioners and a detailed description of the main PD techniques employed in this thesis.

8.1.1 Situating Design as a Relational Process

The studies reported in Chapter 4, where we described the design and experimental evaluation of the games Archimedes and PhyGame, showed the limits of a Designer-Driven Approach for developing learning experiences for children. Specifically, we pointed out how the adopted design approaches, where all design decisions were only informed by the designer's worldview, failed to offer conditions to support learning. This methodological failure offered an experiential and first-person perspective to understand the need of situating design in a close relationship with the universes of meanings of the users. Furthermore, it highlighted the need of making visible the network of agents and discourses that informs and shapes design decisions. To tackle these issues, in the subsequent stages of development, we made a consistent effort to pursue a design practice that situates itself at the intersection between the stakeholders' requirements, the affordances of the environment and the end-users appropriations.

The first step in this direction was the definition of an inclusive design approach (Section 5.1) aimed at integrating and orchestrating the contributions of different stakeholders (experts, children and designers) in the design of FUBILEs. This approach was defined in the context of the project "Pico's Adventure", a FUBILE aimed at supporting social initiation in ASD children. By taking into account the specificities of this project, the inclusive approach was shaped according to a "building construction metaphor" and articulated through the use of a narrative structure. Specifically, the "building construction metaphor" helped in distinguishing between the elements that constitute the laying foundations of the experience- the deepest parts of the construction which support and structure all the other building blocks – and those that characterize and specify the experience. Hence, the former elements (e.g. learning goals, therapeutic techniques, etc.) were defined in collaboration with experts. Conversely, the experiential elements were defined in collaboration with ASD children, in order to ensure the pleasurability and enjoyment of the game. The orchestration of these two strands was guided by the use of a narrative structure, which served to provide a common vocabulary to the different stakeholders and to articulate the different parts. For this purpose, the model was organized according to the following structure:

- The elicitation of requirements from experts aimed toward properly defining the goals of the experience.
- The elicitation of contributions from children with ASD aimed toward identifying their interests, motivations and preferences.
- The integration of contributions from experts and children in order to define the mechanics

of the game, its elements and the experience as a whole.

- The exploratory evaluation of game suitability with children.

The basic structure of this model was later reproduced, with slight variations, also in the studies presented in Section 5.2 (the EcoSystem Project) and 6.2.2 (the BetweenBodies project). This approach, hence, showed an appropriate degree of flexibility to be tailored and extended to different contexts.

In particular, the main variations were related to the model of children involvement and with the relative weights of the contributions of the different stakeholders. In relation to the former aspect, for instance, we proposed two different models of children's involvement: either longitudinal involvement of the same group of children (Section 5.1) or the sporadic involvement of a wider sample of children during different stages of the design process (Section 5.2 and 6.2.2). Both approaches showed to offer specific qualities, gains and losses (for a summary see Section 5.3).

On the other hand, from the perspective of considering the relative weights of the different stakeholders, in the study presented in Section 5.1 (Pico's Adventure), the involved experts clearly defined the specific learning goals and techniques to be employed. Instead, in the studies presented in Section 5.2 (the EcoSystem project) and in Section 6.2.2 (the BetweenBodies project), the involved experts mainly provided a general educational framework and the specific learning goals were defined together with children.

The employment of this inclusive model and the presented variations allowed spotting out the network of agents and discourses that shape the design process. Hence, it provided critical and self-reflexive lenses to look at the way in which specific stakeholders or specific areas of knowledge may influence the design process (e.g. it may be different to collaborate with psychologists trained in cognitive-behavioral therapies or with psychologists belonging to a psychoanalytic tradition). As a consequence, this inclusive approach can provide designers with methodological instruments to guide the task of listening, paying attention and merging different perspectives. Hence, it may help them in improving their practice as listeners/observers and *bricoleurs*.

To sum up, the proposed inclusive approach contributes addressing some of the identified shortcomings in the design of FUBILEs. Specifically, it allows going beyond the tendency of excluding users from the design process. Furthermore, its critical usage can contribute to self-reflexive practices on design choices.

8.1.2 The Role(s) of the Designer/Researcher

In the thesis, we experimented with different roles that the designer may assume. On the one hand, in Section 4.1, we assumed a Designer-Driven perspective to develop the game Archimedes and PhyGame. In these studies, we, therefore, embodied the viewpoint of the designers in charge of taking all decisions according to our knowledge and intuitions. This perspective transforms the designers as a sort of omniscient narrator, who considers having enough knowledge to determinate what other people want, need or know. Even if this standpoint can have its strengths, especially to guide disruptive design processes, nonetheless, in our case, it showed to be insufficient to properly guide the design process. This shortcoming, therefore, required a radical shift, which was not only reflected in the employed methodological approaches but also in the definition of our role as designers/researchers.

To tackle this issue, in Chapter 5, we reformulated our role and assumed a listener/observer and *bricoleur* standpoint. This standpoint conceptualizes the researcher/designer as a two-sided figure. One the one hand, she is in charge of listening, collecting, understanding, orchestrating and mediating between different voices (to follow with the narrative comparison, as a sort of writer of a choral narration[3]). On the other hand, as the Levi-Strauss's *bricoleur* (1962), she is in charge of using her knowledge to adapt and to recombine the available materials (that include material artifacts, knowledge, values, wishes, etc.) in order to construct an overall gestalt, which is greater than the sum of its parts. In this role, the researcher/designer becomes inevitably a methodologist, who has to figure out the best available strategies to co-construct meaning from the network of agents that surrounds the design process. This role, therefore, delineates the design process not as "subject-to-the-subject" (Chomsky & Foucault, 2011; Foucault, 1969), but as a relational product, which is a glare and a response to a complex socio-environmental network.

In our case, therefore, assuming this perspective offered relevant benefits both improving our methodological approach as well as in relation to the design outcomes. Furthermore, by offering a

[3] The concept of Choral narration refers to a narrative technique employed to narrate an event from the perspectives of the multiple characters, giving the same importance to all viewpoints; an example of it can be found in the novel "I Malavoglia" (Verga, 1881)

standpoint that is situated in a close contact with the real world context, it avoided the risk of designing from “a god-eye view”. Finally, from a critical and ethical perspective, it allowed reformulating and questioning who is speaking (and in the behalf of whom) during the design process.

8.1.3 Design for Embodied Learning Processes

The proposed inclusive design approach (Section 5.1) allowed setting the basis to formulate a design proposal that includes end-users in the design process. Nonetheless, some limitations were still present. As pointed out in the systematic review of Chapter 3, none of the analyzed FUBILEs directly considered embodiment as a source of knowledge in the design process. Starting from this gap, our subsequent research aimed at more directly taking into account the specificities of experiential learning process and the features of Full-Body interaction experiences. To address these issues, we proposed two main complementary methodological approaches: the Evaluation-Driven Approach (Section 5.2) and the use of a multimodal analytical framework to guide design (Chapter 6).

The Evaluation-Driven approach, employed in the projects Eco-System (Section 5.2) and BetweenBodies (Section 6.2.2), addresses the effort of including requirements from multiple stakeholders within an iterative design process. At a procedural level, this approach derives from the principles of Design-Based research (Barab & Squire, 2004). Specifically, it proposes the use of a methodological workflow based on an iterative design and assessment cycle in order to constantly evaluate how the designed environment acquires meaning through user interpretations. At a conceptual level, it aims at emulating the process of experiential learning (Kolb et al., 2001), understood as the way in which learners get engaged with the experience by connecting it with previous knowledge and personal interests, experiment with it and reflect upon it.

For this purpose, the Evaluation-Driven approach proposes the employment of the meanings generated by the users as central instruments to guide the design process. In its unfolding, this approach is structured according to two main stages: a first *ideation stage* and a subsequent *experimentation stage*.

The *ideation stage* aims at setting the basis of the experience, by defining its educational goals and features through the collaboration with experts and children. In particular, in order to guide the collaborative process with children, we proposed a set of PD activities (described in Section 8.1.3) to elicit children's previous knowledge and interests. The outcomes of these activities were analyzed by focusing on core meanings (i.e. what children consider relevant to select, remember and recall), misconceptions and cultural and embodied representations around specific ideas (e.g. group's dynamics). The analysis of these aspects showed to be useful to frame the educational needs and to identify concepts that can be familiar enough to help children bridging between the novelty of the experience and their previous knowledge. From this perspective, we thus suggest that analyzing these aspects may constitute a relevant starting point to help designers in properly defining educational experience aimed at addressing conceptual knowledge.

On the other hand, the *experimentation stage* aims at analyzing the situated sense-making of the experience and the core meanings, representations and misconceptions that arise through the interaction with the system. Its goal is, therefore, to observe how the users signify the designed experience both in the process of interacting with it as well as in posterior reflections. To this end, we proposed the use of a PD approach, based on the users-as-informants model, to combine the observation of in situ interaction with the analysis of their post-task understanding through the use of participatory design activities (Chapter 6). In particular, in this context, we proposed the use of a multimodal analytical framework (for a detailed description see Section 8.2) and of Redesign activities to evaluate the role of embodied and spatial resources in shaping and expressing meanings. This methodological approach, besides contributing to the definition of appropriate evaluation methods for FUBILEs, also permitted to properly taking into account the specific features of this medium, hence offering robust empirical data upon which designers can define future improvements and refinements.

To sum up, in the context of FUBILEs, the presented methodological approach allowed addressing the limits of design approaches that are only based on designers' intuitions. To conclude we, therefore, offer the following suggestions to designers involved in the development of learning experiences based on Full-Body interaction:

- Carefully listening and observing the requirements and the interests of the multiple stakeholders in order to orchestrate their contributions in a coherent experience and critically analyzing how the different standpoints influence the design process. For this purpose, we suggest that structures, models and metaphors (e.g. the "building construction metaphor" or the use of an underlying narrative) that help tracking this process can serve as meaningful instruments to help designers navigate and combine the different perspectives.

- Carefully analyzing children's previous knowledge, interests, core meanings, embodied representations and misconceptions in order to set the basis of a proper communicational flow between designers and users. To this end, grounding on the PD tradition, we suggest that playful design activities may be particularly helpful both for defining educational needs as well as for spotting out concepts that can help children bridging between the novelty of the experience and their own worldviews.

- Considering each design choice as a sort of hypothesis that needs to be evaluated in a participatory way. To this end, we suggest employing raw versions of the system to evaluate the design proposals by observing children's interaction with it and by allowing children to anchor their design contributions on a concrete experience.

- Deeply analyzing children's in situ interaction with the system and their retrospective interpretations of it in order to better understand the role of embodiment in shaping and expressing meanings, hence allowing to properly framing design refinement for Full-Body interaction. For this purpose, we suggest that both PD techniques and multimodal analysis can constitute helpful and appropriate instruments.

In our case, these guidelines showed to be effective in guiding the development of FUBILEs capable of supporting learning (see Chapter 5 and 6). We, therefore, consider that their application can constitute a relevant methodological contribution to practitioners in this area.

8.1.4 Participatory Design Techniques

In the different studies, we proposed several Participatory Design techniques to involve children in the different stage of the design process. In order to provide an overview of the adopted approaches, we will briefly summarize the main features of all of them and describe their potential to be implemented in the different stage of the design process.

The Pictionary activity

The Pictionary activity was mainly applied during the *ideation stage* of the design process of the studies described in Section 5.2 (the EcoSystem project) and 6.2.2 (the BetweenBodies project). Its goal was to evaluate which concepts children were already familiar with and explore their embodied representations of those specific concepts. For this purpose, we conducted a game based on the mechanics of the board game *Pictionary* using terms related to the addressed learning goals (e.g. environmental education, group dynamics). One child per time was asked to pick-up one of the terms and to represent it through drawings on a whiteboard. The other children have one minute to guess it.

In both studies, this activity showed to offer relevant affordances to grasp children's representations across different modes, in particular when associated with a careful analysis of the specific formal features of their drawings and their embodiment during the task (e.g. gestures, facial expression). Furthermore, its playful nature was engaging and motivated children to participate in the activity. Moreover, its time-based structure avoided that they focusing too much on surface details. As a consequence, we suggest that this technique may represent a useful tool to grasp children's conceptions around a specific topic in a playful and "quick-and-dirty" way.

Combining narrative and game design

In the studies described in Section 5.1, 5.2 and 6.2.2 we combined the use of narrative with activities related to game design. This approach was employed both during the *ideation stage* and during the *experimentation stage*. Its goal was not to produce workable games. Instead, it worked as a strategy to deepen into children's understandings about the defined topics or the proposed experience, hence allowing to framing or refining design.

In the different cases, the activity was introduced through the use of a short fictional narrative that was either presented by the researcher or through the use of a letter. Subsequently, children were asked to shortly reflect in groups on the main issues presented by the narrative and to collaboratively design a game to address these issues. This approach confirmed the effectiveness of narratives in guiding design practices (Dindler & Iversen, 2007; Dindler et al., 2005). Furthermore, it showed to be particularly effective to delve into the analysis of children's previous knowledge, representations and misconceptions (see Sections 5.2 and 6.2.2, where this technique was applied to inform the design of the EcoSystem and the BetweenBodies projects). This outcome can be related to the fact that the task of designing a game is an activity that is meaningful and engaging by itself. Hence, it facilitates children's involvement and, at the same time, it offers affordances to allow them projecting and materializing their own ideas in the creation of an artifact. We, thus, suggest that this technique may constitute a useful approach to facilitate designers grounding their proposals on children's interests and previous knowledge (M. Nathan & Robinson, 2001) as well as to properly understand how children interpreted the proposed experience after playing with it.

Transmodal Translation

In the study presented in Section 6.1, we proposed an initial methodological exploration of the use of *transmodal translation,* understood as requiring participants to translate the same idea across different modal resources, in a PD workshop with ASD children. Specifically, in that case, we asked children both to verbally report their "detective investigation" of the proposed environment as well as to draw it. This approach allowed tapping into different shades of children understandings around the experience. Even if future research on this technique is still needed, we suggest that this approach can offer relevant contributions to delve into the different shades of children's understanding of a phenomenon.

Experimentation stage: The Intuitive Actions activity

In the study presented in Section 5.2, we proposed the use of the "Intuitive Action activity" to understand the affordances of the proposed interface and children's sense-making of the experience. In this activity, children did not receive any explicit instruction on the physical action that they had to perform to interact with the system before interacting with it. As a consequence, they need to improvise according to their own understandings of the affordances of the interface. Subsequently, at the end of the activity, children were asked to report on their experience.

The analysis of children's intuitive interaction with the system offered relevant insights to guide the design of specific physical actions. Furthermore, from the perspective of involving children in the design of embodied interaction, this approach offered relevant contributions for participatory processes. From our experience (Schaper, Malinverni & Pares, 2015), we noticed that addressing aspects related to embodied interaction during the ideation stage might represent a particularly challenging task for children. This difficulty can be due to the decontextualized nature of the task and to the novelty of the proposed interaction paradigm. As a consequence, children may tend either to reproduce traditional interaction modalities or to interpret the task as a sort of theatrical representation.

Instead, we suggest that the Intuitive Actions activity can represent a more fruitful approach to incorporating embodiment in the PD process. This approach, by framing PD around the situated experience that children have with a raw prototype, can help them in properly ground their contributions. Furthermore, it permits to observe the specific affordances of the designed experience and grasping behavioral aspects that cannot be expressed by words.

8.2 Evaluation Methods

The goal of this thesis was to explore evaluation methods that can allow a deeper understanding of meaning construction and learning in FUBILEs in order to inform design. From this perspective, therefore, we did not understand evaluation as a way of testing the effectiveness of a specific system but as an instrument to produce knowledge for guiding practitioners.

As pointed out in the critical analysis reported in Section 3.2, often the employed evaluation methods for FUBILEs end up employing instruments that only offer a limited and insufficient perspective to properly grasp phenomena related to embodied learning (and, hence, to inform design). The outcomes of this critical analysis were faithfully mirrored in the shortcomings of the study we reported in Chapter 4 (the experimental evaluation of the Archimedes and PhyGame projects). In particular, in that case, the poor consistency of the employed assessment instruments required of a radical epistemological shift in our approach to evaluation.

These issues highlighted the need of researching evaluation methods capable of coherently fitting with the embodied cognition framework (Sara Price & Jewitt, 2013a, 2013b) and with the intended learning goals in order to offer a deeper understanding of FUBILEs. Within this context, we identified the need for methods capable of being sensitive to analyze and interpret how learning is embodied in the situated lived experience and proposed a methodological exploration on appropriate approaches to evaluate FUBILEs. Through the experience and reflections on the different studies described in Chapter 5, 6 and 7, we therefore elaborated an initial methodological framework to evaluate FUBILEs.

8.2.1 A Methodological Framework for Evaluating FUBILEs

The proposed methodological framework aims at evaluating learning and meaning construction in

FUBILEs in order to inform design. At a theoretical level, it derives from multimodal analytical approaches (Kress, 2010) and grounds itself on conceptualizing learning and meaning-making as processes that are constructed by the users in the iterative connection between the meaning potential of an artifact, the user's previous knowledge and the features of socio-cultural context (Jewitt, 2013). Consequently, it aims at taking into account both the affordances offered by the system as well as users' appropriations (E. K. Ackermann, 2007). Its main goals are: 1) to research on *users' sense-making of the experience*, understood as the way in which the users give meaning to the experience and 2) to identify *indicators of learning*, understood as signals of constructive learning processes.

In order to research on these aspects, the proposed framework combines the analysis of children's *in situ interaction* with the system with their *retrospective reflections* on the experience. It, thus, encompasses both the observation of *reflection-in-action* and of *reflection-on-action* (Schon, 1983). For this purpose, the proposed framework structures itself following the model of experiential learning processes (Kolb et al., 2001), understood as the iterative cycle of getting engaged and interested with the experience, experimenting with it and reflecting upon it. Hence, it focuses on the following aspects:

- *Ways of engaging:* understood as the ways in which users get engaged with the experience, what capture their attention and what they consider relevant or salient.
- *Ways of exploring*: understood as the ways in which users explore the system, experiment with it and make it works according to their own purposes.
- *Ways of transforming:* understood as the ways in which users 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.

For the purpose of evaluating these aspects, we proposed the observation, analysis, integration and interpretation of a wide range of multimodal resources that humans employ to make and express meaning (Streeck et al., 2011). Specifically, the following resources were analyzed:

1. *Sensorimotor exploration,* understood as the ways in which users physically get engage, explore and use the physical-digital environment to build their own understanding during in situ interaction. For this purpose, we proposed the analysis of their *paths of exploration*,

their *usage of the space*, the *variations* in their sensorimotor enactments, their *focus of attention* (either through the analysis of gaze directionality or by asking them to take pictures) and their *proxemics relations*. This analysis (combined with the other resources) allowed identifying what kind of play does the physical-digital environment evokes, what children consider interesting to be explored, how they employ specific qualities of the environment to build their understandings and how different affordances shape their sense-making and behavior.

2. *Verbal interaction,* understood as the analysis of children's spontaneous or elicited speech acts (J. R. Searle, 1969) both during in situ interaction and after the experience. This analysis allowed: a) identifying the meanings that children attribute to their actions, b) tracking what they consider relevant to be remembered or shared with somebody else, c) grasping relevant indicators of learning such as the ability to connect the experience with previous knowledge or to plan a specific strategy to solve a task.

3. *Children's productions,* understood as the analysis of children's productions (e.g. drawings, written reports) that are created during post-tasks activities aimed at reflecting on the experience. The analysis of these artifacts allowed spotting out how children connect the experience within their previous knowledge, their core meanings, their misconceptions and their contributions on potential design refinements.

In order to analyze and interpret these aspects, we structured the research by first proposing children to interact with the prototype and subsequently involve them in participatory Redesign activities. The analysis was carried out mainly through the use of techniques for multimodal transcriptions (Flewitt et al., 2009) and for content analysis. Specifically, the multimodal transcriptions were based on creating annotated maps of children's behavior during in situ interaction. On the other hand, content analysis was mainly based on a grounded approach (Corbin & Strauss, 1990) aimed at spotting out core meanings, representations, interests, misconceptions and indicators of learning (e.g. connect with previous knowledge, metacognitive skills).

The application of this approach (in its different variations) in the studies reported in Chapter 6 and 7 allowed gaining knowledge to inform research on embodied learning and to guide Design-Based Research. In particular, in the presented cases, the proposed approach showed to be particularly useful to: 1) understand the affordances of the system and how users interact with it (Section 6.1 and 6.2.2), 2) analyze what is relevant and interesting for them (Section 6.1), 3) compare different interfaces, 4) analyze how their specific affordances shape children's understanding and sense-making (Section 6.2.2), 5) understand how users employ embodied and spatial resources to support their learning process (Section 7.1).

To sum up, we therefore consider that the proposed methodological approach offer relevant contributions to research in FUBILEs. First, it allows overcoming the identified limits and shortcoming of the existing evaluation approaches (Chapter 3) by proposing a framework that is consistent both with embodiment theories and with experiential learning. Second, it provides tools and interpretative instruments to take into account the relational and temporal dimensions of meaning construction. It, therefore, allowed analyzing the role of contextual elements in shaping meaning construction and the way in which this process unfolds in time. Third, it allows researchers to construct knowledge that informs both the understanding of the phenomenon and the eventual design refinements. Nonetheless, as Polkinghorne (1983) pointed out, the quest for methodological appropriateness in human science needs to remain in a state of crisis, where methods and assumptions are continuously questioned. As a consequence, 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.

8.3 Design Qualities

Through the present research, we identified a set of qualities that we considered to be relevant to guide the design of FUBILEs. The definition of these qualities has been informed by the theoretical background, the knowledge gained in the different studies and the self-reflection on our own practice.

The goal of the proposed qualities is not to offer a prescriptive approach to design FUBILEs. Instead, they should work as generative tools, aimed at providing designers with concepts to stimulate reflection on their own practice and to facilitate making distinctions and asking relevant questions. At the same time, the proposed qualities do not aim at being an exhaustive and complete panorama, but, as all taxonomies, they offer a view that is always partial and incomplete (Van Leeuwen, 2004).

In the next sections, we will present the following qualities: *expressiveness, consistency, relationality, salience* and *reflexivity*. Each quality is structured according to the following format:

1) An initial descriptive section aimed at proposing a short definition and description of the addressed quality and a set of questions that may be referred both to the analysis of one's own product as well as to critically analyze related works.

2) A general analysis of potential design risks and opportunities aimed at proposing examples of the application of the defined quality in guiding design decisions.

These described qualities should not be considered as related only to the features of the environment or of the users. Instead, they emerge in the reciprocal relation between the users and the environment.

8.3.1 Expressiveness

In Chapter 3, we introduced the need for a careful analysis of the concepts and experiences can be easily expressed through Full-Body interaction or what are less straightforward or inadequate for this medium. Starting from this perspective, we proposed the notion of "expressiveness", understood as *"the definition of what is understood through the embodied experience and that which can be expressed through the available resources the definition of what is understood through embodied experience and what can be expressed through the resources available*. Furthermore, we suggested that addressing this notion implies to ask ourselves some questions related to the expressive potential of Full-Body interaction: *What concepts can be expressed through embodied and spatial experiences? And consequently, which are the meanings that can best fit this kind of experiences? Is Full-Body interaction the best medium to convey this idea? Why? How? Can you find a way to explore this concept in an equally interesting way without using technology or using a different technological solution? What kind of added value Full-Body interaction is providing?* In order to dig deeper into this idea, in the next section, we will expand it by taking into account the knowledge gained through this research.

8.3.1.1 Design for Expressiveness: Risks and opportunities

The notion of expressiveness, in the context of FUBILEs, deals with researching the areas of knowledge where embodiment becomes the privileged channel for understanding. The overview presented in Chapter 2 allowed pointing out some potential areas such as: socio-emotional aspects, esthetic experiences, artifacts and different abstract concepts (e.g. mathematics, metaphors, etc.).

On the other hand, in Section 4.1, we reported the shortcomings related to ignoring the polysemy intrinsic to embodied experience and trying to apply strictly codified logocentric approach to communicating a very precise and univocal concept (e.g. Newton's Laws of motion). This issue warned against the risk of adopting the naïve position according to which "the action X means Y" and pointed out the need of properly taking into account the role of users' interpretations. Furthermore, it highlighted the necessity of carefully considering the *meaning potentials* of Full-Body interaction, understood as the potential that this medium has for expressing meaning (Leeuwen, 2004).

In order to delve into the analysis of the meaning potentials of Full-Body interaction, possible research can address the analysis of how the body has been employed in traditional educational practices and on how it is used to construct understanding in everyday life. The goal of this thesis was not to provide an exhaustive panorama on these aspects. However, the projects presented in Section 5.2 and Section 6.2.2 showed how deriving knowledge from embodied practices such as role-play (e.g. the use of role play to understand system dynamics or group dynamics) can constitute a relevant entry path to explore the potential of Full-Body interaction. On the other hand, in order to proper understand the meaning potential of this medium, researchers should pay a careful attention to users' interpretations.

8.3.2 Embodied Consistency

In Chapter 4, 5 and 6 we pointed out the importance of designing a consistent relation between the sensorimotor experience, the physical-digital environment and the goals of the experience. To address this issue, we proposed the notion of *embodied consistency* as a relevant quality for guiding the design of the specific features of FUBILEs (e.g. embodied interaction, the configuration of the physical-digital environment, etc.). Specifically, we defined *embodied consistency* as *the degree to* *which the embodied experience is compatible with what we want to express and the degree to which technology can strengthen this relation.*

This notion, thus, implies an effort to design experiences capable of coherently bond content, sensorimotor experience, spatial features and digital technology. It, therefore, requires designers to ask themselves questions about specific design choices, such as: *What physical interface will be used? Why? What are its spatial qualities and affordances? What kind of sensorimotor experience does it promote? How and why these spatial qualities and sensorimotor experience are particularly suitable to address the defined content or ideas? How the actions of the users are operationalized? How the embodied experience relates to what we want to express? In which way embodied experience may offer an additional entry path to facilitate understanding? How can technology augment or enhance embodied experience? How can technology provide an additional value and make the learning goal more understandable and accessible to perception?*

8.3.2.1 Design for Embodied Consistency: Risks and opportunities

From a pragmatic perspective, the notion of *embodied consistency* deals with making concrete design decisions about which physical interface will be used, how the users will interact with it, how technology will augment their embodied experience and how the sum of these parts would allow a better understanding of a certain learning goals or experiences. In order to disentangle these tasks, we propose to consider them in relation to two main aspects:

1. The *embodied and embedded experience*, understood as the actions that are physically enacted by the users and the specific qualities of the physical interface.
2. The *digital augmentation*, understood as the way in which technology responds to users interactions and the feedbacks that it provides.

Design the embodied and embedded experience

The research reported in Section 4.1 and 5.2 suggested the importance of designing embodied interactions that are consistent with the addressed learning contents and with the proposed task. Specifically, we showed that a close analogy between the sensorimotor experience, the learning goals (Section 4.1) and the task features (Section 5.2) could be beneficial both to support learning and to facilitate the understanding of the system. This outcome is consistent with findings in cognitive science, which pointed out that embodied learning is more fruitful when the physical enactment consistently relates with the proposed learning goals (Kontra et al., 2012). On the other hand, the research reported in Section 6.2 showed the role of the physical interface in shaping children sense-making of the experience.

These findings suggest how both embodied interaction and spatial configuration should coherently relate to the defined contents or goals of the experience. As a consequence, we suggest that to properly take advantage of embodied experience, relevant opportunities can be found in designing actions and affordances that maintain some affinities with the ideas that we want to express. For this purpose, a careful observation of users' embodied representations of certain concepts (e.g. the proposed Pictionary activity, see Section 8.1) and of their in situ interaction (see Section 8.2) can provide useful insights.

On the other hand, potential risks can be identified in approaches that mold embodied experience according to existing paradigms such as mouse-based interaction (e.g. they body is employed just as a sort of "extended pointer") or that employ embodiment only as a strategy to sugarcoat certain tasks (e.g. the user has to run to answer some questions about unrelated topics). We, thus, suggest that, in order to deeply exploit the potential of embodied experience, designers should carefully analyze how the qualities of physicality and space may be configured to provide compatible entry paths to the addressed concepts. This analysis should be carefully informed both by theory as well as by empirical observation.

Design the digital augmentation

The project presented in Section 4.1 (Archimedes game) and the research reported in Section 6.2.2 (the "BetweenBodies" projects) pointed out relevant shortcomings in designing the relation between the sensorimotor experience and the digital augmentation. In the first case, the learning content was mainly embedded in the digital augmentation (the game projected on the Slide surface), nonetheless, the related embodied interaction was poorly consistent with it. This issue may constitute an explanatory factor of the case study reported in Section 7.1, where one child playing with Archimedes just focused on the sensorimotor exploration, without paying attention to the digital layer. On the other hand, in Section 6.2.2, we highlighted how the features of the sensorimotor experience were poorly consistent with the motor control required to interact with the digital augmentation.

These shortcomings, therefore, point out how the digital augmentation should be consistent with the features of the physical environment and of sensorimotor exploration. To guide this design process, relevant opportunities can be found in design solutions capable of using the digital augmentation as a layer capable of making some qualities of the embodied experience more salient or accessible to perception. In this context, we therefore suggest that a careful observation of users' sensorimotor interaction may provide useful hints to augment it with digital contents capable of consistently "go along" with the embodied experience.

8.3.3 Relationality

In the theoretical framework delineated in Chapter 2, we pointed out the fundamental role of the social environment in supporting the construction of meaning and learning (Vygotsky, 1979). These ideas have been explored in details in Chapter 6, where we analyzed the role of different interfaces in shaping the socio-emotional aspects of collaboration and collaborative behaviors.

Starting from this perspective, we propose the notion of *relationality* understood as *the degree to which the system affords conditions for co-construction of meaning and collaborative learning.* This definition requires designers to carefully scrutinize the relational affordances of the designed environment and ask themselves a series of questions related to: *How do we conceptualize collaboration? What kind of collaborative behavior does the employed interface afford? How the relations between multiple users are conceptualized? Does the system allow offloading cognition into others?*

8.3.3.1 Designing for Relationality: Risks and opportunities

As Dillenbourg et al. (2009) point out, collaborative learning does not occur "per se" but needs of proper conditions. Thus, paraphrasing the famous feminist quote "you can't just add women and stir" (Bunch, 1987), design for collaborative learning does not only means to "put multiple users together and stir".

As pointed out in Section 6.2, Full-Body interaction had a more positive impact than traditional interfaces on children's perceived collaboration and on how group members feel about each other. A possible reason behind this finding was identified in the affordance that this medium offer to support the use of different spatial and bodily resources that are fundamental to social understanding (L. W. Barsalou et al., 2003). However, the study reported in Section 6.2.2 (the BetweenBodies project) showed how the different affordances of the system (e.g. Vertical Screen vs. Floor Projection), by shaping the way of physically interacting with it, may shape users' sense-making of the collaborative tasks and socio-affective aspects of collaboration.

These findings point the potential benefits of Full-Body interaction to afford conditions for collaborative learning. Nonetheless, they also highlight the role of relation that unfolds between the configuration of the environment and the kind of collaboration that is promoted. Hence, designers should carefully reflect on the implications and pedagogical value that different collaborative models may carry and how the system is shaping them.

Within this context, in the study presented in Chapter 7, we also identified other relevant opportunities related to the relational qualities of the system. Specifically, in one of the described case studies, we showed how conditions that allow children to observe their peers' interaction with the system can facilitate them reflecting and elaborating the experience. This finding brings into question the limits of embodiment delineated in Chapter 2: if I may learn also through the body of other people, does it make any sense to consider embodiment as a notion enclosed to the limits of my physical body or it should be extended to encompass my relation with the world? Addressing this question in the design of FUBILEs suggests the need of considering the opportunities that allow users offloading cognition into the other and learning and understanding through the bodies of others.

To sum up, even if Full-Body interaction may offer relevant affordances for collaboration, nonetheless, its specific configuration should be carefully scrutinized in order to spot out its implicit models. Furthermore, designers should avoid the risk of considering collaboration just as the sum of a group of isolated bodies.

8.3.4 Salience

In the studies reported in Section 5.2 and 7, we pointed out the importance of carefully framing the configuration of the system in order to facilitate conditions to allow children focusing on what matter of the experience and minimize eventual distractors. This requirement implies designers to clearly define "what matter of the experience" and find strategies to make it relevant and salient. Starting from this perspective, we, thus, propose the notion of *salience,* understood as *the degree to which the system promote getting immersed in the experience and focused on what matter of it.* This definition requires designers to ask themselves a series of questions related to: *What are the most relevant aspects of the experience? How can they be meaningfully enhanced to be enough interesting to the users? How their interest can be sustained? Which are the affordances of the space and physical interaction that might promote being aware and focused?*

8.3.4.1 Design for Salience: Risks and Opportunities

FUBILEs are characterized by a plethora of stimuli that can potentially attract (or not) the interests of the users, hence determining the way in which they will engage with the system. As a consequence, users may engage with aspects that can be relevant (or not) for the addressed learning goals (e.g. get engaged with just making points or with some specific interactive element).

In this context, the studies reported in Section 5.2 and 7.1 showed how certain design elements may help or hinder children's possibilities to focus on what matter of the experience. In the first case, for instance, the spatial layout of the waste in the first prototype of the EcoSystem project diverted children's attention from focusing on the global relationships between the different interactive elements. In the second case, instead, we showed how the poor consistency between the sensorimotor experience and the digital augmentation diverted the attention of a child from focusing on the goals of the task to focusing only on the sensorimotor exploration (Section 7.1). These shortcomings pointed out the need of carefully analyzing what matter to the users in order to either enhance it or using it to guide design refinements (as in the Ecosystem case).

Furthermore, in the context of FUBILEs, additional considerations should address the relation between the notion of *salience* and the specificities of this medium. Building on the idea that *"the medium is the message"* (McLuhan, 1994), if we take seriously the specificities of FUBILEs with respect to other media, our focus of attention - both as designers and as users - should be directed toward the situated and embodied nature of the experience. As a consequence, designers should figure out strategies to make embodied experience enough salient and interesting to facilitate users focusing on it. Within this context, in Section 6.2, we proposed the use of an unusual bodily experience (the shared bodily control of a drawing tool) to facilitate users focusing on their reciprocal embodiment. Nonetheless, the ambiguous results related to this approach, suggest the need for further research aimed at exploring this strategy more deeply.

8.3.5 Reflexivity

In the study reported in Chapter 7, we highlighted the importance of facilitating conditions to allow children's reflection-in-action (Schon, 1983). This suggestion is consistent with research in developmental psychology (E. K. Ackermann, 2004; Karmiloff-Smith, 1995) and experiential pedagogies (Kolb et al., 2001), which suggests that concrete experience needs to be transformed in order to meaningfully bridge with explicit forms of knowledge. From an applied perspective, these studies suggest that, when designing for FUBILEs, it becomes necessary to consider how certain design choices may facilitate conditions to transform concrete experience into an object of thought through reflection and observation.

In this context, we thus suggest the notion of *reflexivity*, understood as *the degree to which the system enables space for reflection and observation* or, in other words, how it can facilitate users to dwell between getting immersed in the experience and reflect upon it. From a designers' perspective, this concept requires addressing questions related to: *Which features of the experience can facilitate users to assume a reflexive standpoint? How can we design spaces and physical interaction that offer affordances to facilitate users to step back and reflect on the experience? How can we facilitate users go through different stages of knowledge construction?*

8.3.5.1 Design for Reflexivity: Risks and opportunities

In the context of FUBILEs, the notion of *reflexivity* requires enabling conditions to allow users going back and forth between get immersed and focused in the experience (*salience*) and reflect upon it. Faced with the notion of *salience*, the concept of *reflexivity* represents its complementary dimension. Using a theatrical metaphor, *reflexivity*, may correspond to the notion of "distancing effect" proposed by Bertolt Brecht as a form of breaking the theatrical illusion and hinder the audience from simply identifying themselves with the characters in the play (Willett, 1964).

Nonetheless, as pointed out in Chapter 7, design for reflexivity does not mean to fall into the dualistic trap of designing a "*space for thinking and a space for doing*", but instead it implies to conceive experiences that can be lived in a flexible way, or, in other words, that offer a place for reflection but do not delimitate it. In order to offer some cues for designers, we suggest some potential research directions oriented toward exploring which affordances of FUBILEs may enable time for reflection and observation.

Enabling multiple perspectives

In Chapter 7 we showed how children's change in their physical standpoint, offers an embodied instantiation of Ackermann's (2004) model of framing and reframing experience. This finding confirmed the crucial role of adopting different viewpoints to build understanding and suggested the importance of enabling conditions for framing and reframing the experience by looking at it from different perspectives.

In the context of Full-Body interaction, relevant opportunities can be found in grounding the practice of perspective-taking in its specifically embodied and spatial nature. Research in social cognition has shown that even simple exercises such as making children stand in the location previously taken by somebody else can facilitate their understanding of the other person's standpoint (Perinat & Lalueza, 2007). At the same time, studies related to asking people to physically enact metaphorical concepts of perspective-taking (e.g. "on one hand, on the other hand"), showed how this simple action can foster creative problem solving (Leung et al., 2012).

From an applied perspective, therefore, possible research directions can explore how bodily interaction and the physical configuration of the environment can allow users to embody or inhabit different standpoints during the interaction with the system, hence enable them to assume a different perspective (e.g. go in an "observer position").

Enabling conditions for the co-construction of meaning

Alongside with the spatial and embodied features that may facilitate perspective-taking, another fundamental aspect to support reflection on the experience is represented by instances for co-constructing meaning. As highlighted in the study presented in Chapter 7, looking at other users' behavior and sharing our thoughts with them allowed children to reflect on the experience and derive implications for action. We, thus, suggest that, in the field of FUBILE, potential research should address the analysis of the conditions that can enable users to share their knowledge and take advantage of the experience of the others. In this context, potential design directions may address the exchange between different roles (both in terms of spatial positioning or in relation to specific game mechanics), spatial configurations for observing peers' actions or affordances to allow users identifying themselves with their peers' experience.

The temporal qualities of reflexivity

As pointed out in Chapter 7, the dwelling between immersion and reflection may unfold according to different temporalities, depending on the specific strategies adopted by each user. This aspect requires designers to take diversity into account, instead of adopting a prescriptive approach where they define a specific modulation of the time for action and for reflection. As a consequence, it becomes necessary to consider how the pace of the experience can afford the self-regulation of different moments such as experimentation and reflection, dive in and step out. Hence, relevant research opportunities can address the analysis of the temporalities that users employ to go (or not) through these different stages. Furthermore, additional research should explore learning-appropriate pace, analyzing the possible risks of paces that do not allow time for assimilation, reflection or observation. In this context, possible risks may be found in experiences that require a constant immersion, fast paced actions or an excessive physical workload (e.g. time-based games, where the user need to be constantly attentive and focused on a repetitive task).

8.4 A Broader Perspective on the Current Research

This thesis allowed defining potential contributions to the quest for methodological appropriateness in the design and evaluation of FUBILEs. In this context, we proposed specific design guidelines, possible PD techniques and a framework for evaluation. Furthermore, we explored some potential qualities to help reflection during the design process. While this research was focused toward multi-users FUBILEs, nonetheless we considered that some of its contributions can also be extended to other research fields dedicated to the design of embodied interaction for learning contexts.

On the other hand, from a broader and overreaching perspective, this thesis allowed making visible how both the design process and the definition of appropriate methods are processes that are grounded on iterative and progressive approximations, where knowledge is constructed in the interplay between concrete experience and reflection on it. This affinity with experiential learning processes (Kolb et al., 2001) points out the need for paying closer attention to the often neglected practice of reflexive analysis in design practice (Sengers et al., 2005). We, thus, suggest that tools and form of reporting that promote a more careful attention to critical reflection could be highly beneficial especially in the context of Design-Based research and participatory practices.

8.5 Limitations and Future Works

This thesis had the goal of delineating an encompassing panorama on research and design methods for FUBILEs. We considered that this broad perspective was relevant for the field. Nonetheless, the choice of addressing a broad spectrum of research aspects presents some relevant counterparts. Specifically, the following research allowed opening relevant research directions related to the exploration of design methods, evaluations methods and qualities for FUBILEs. However, further research is needed in order to properly go in depth into these aspects.

8.5.1 Design Methods: Limitations and Future Works

The current research allowed defining methodological guidelines for the design of FUBILEs and proposed a set of PD techniques that may be employed during this process. The proposed methodological approach showed to be useful to guide the development of different projects, and its "flexible" nature makes it adaptable to future iterations and improvements. However, further research in this area is still needed in order to properly refine it.

First, the proposed inclusive approach allowed tracking and making visible the network of agents involved in the design process, hence permitting to merge and orchestrating their contributions.

Nonetheless, we suggest that in order to properly take advantage of this structural approach, further research should deepen in the analysis of the role, contributions, discourses and weights of different stakeholders. A fine-grain analysis of these aspects could allow researchers to properly tracking the relations of influence that unfold in PD processes, hence allowing to clearly situate design choices and address eventual ethical dilemmas. Possible methodological directions to carry out this analysis can be found in models derived from Actor Network Theory (Latour, 1996).

Second, even if the combination of an iterative design process with the fine grain analysis of users' embodiment showed to be highly informative to guide design, nonetheless its application mainly addressed the development of projects that were only tested in laboratory conditions. Thus, further research should address its suitability for designing FUBILEs based on more complex environments such as site-specific installations or school-based projects.

Third, in order to inform design we employed knowledge that was mainly derived from theoretical analysis and empirical observations. Even if this effort already enriched the panorama of design methods for FUBILEs, we suggest that future explorations could address a more radical involvement of embodiment in this research. Possible research opportunities can explore the role of researcher embodiment in the design process according to approaches such as Experience-Based Design (Buchenau & Suri, 2000) or autoethnographical design (Höök, 2010). At the same time, further research may address more deeply the employment of bodily-based techniques in design such as body-storming (Loke et al., 2013).

Finally, further research should explore, deepen and broaden the proposed PD techniques. In particular, relevant research directions should address the comparative studies of the affordances that different PD techniques may offer to properly inform design for Full-Body interaction.

8.5.2 Evaluation Methods: Limitations and Future Works

The proposed methodological framework for the evaluation of FUBILEs offered a coherent approach for researching this kind of environments. Nonetheless, further refinements are still needed in order to properly evaluate its suitability in different contexts.

First, a consistent research effort should be dedicated to developing tools and instruments that can make this approach more manageable in time-constrained projects. Within this context, we are currently developing a software to facilitate multimodal analysis and visualization of multimodal data. The aim of the software is to combine tool for multimodal transcription, with top-down and bottom-up video-coding instruments and with the analysis of data-log. Nonetheless, the specific definition of requirements and features represent a complex task that is currently under-development.

Second, relevant opportunities can be found in delineating strategies that can allow integrating this approach with participatory evaluation methods in order to take into account the role of the users also in the evaluation process. Finally, as our initial research suggest, further research should address more deeply the development of instruments, practices and tools-to-think-with aimed at fostering researcher's reflexive and critical practice on the employed design and assessment methods.

8.5.3 Design Qualities: Limitations and Future Works

The proposed design qualities offered a set on critical lenses through which researcher can look at their design proposals. Furthermore, each of them opened the paths for potential novel research. First, we suggest that further research should be dedicated to more deeply evaluating and expanding the understanding of the meaning potential of FUBILEs in order to offer a broad and robust panorama. Second, additional studies should explore the relation between the embodied experience and the physical-digital environment in order to spot out possible design solutions to address its consistency, the salience of the embodied experience and the conditions to foster reflexivity. Finally, the knowledge derived from this research should be summarized in a format that can make it more ""ready-to-use" in a design process (e.g. a set of cards). We performed an initial attempt in this direction and evaluated it with students. Nonetheless, the limitations our proposal (i.e. being too abstract) require further research in order to improve it.

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