Combining participatory design methods and formative assessment strategies to improve design and evaluation of Full-Body Interaction Learning Environments

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MASTER THESIS UPF / 2014

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Acknowledgment

I would like to thank my thesis supervisor Laura Malinverni and thesis coordinator Prof. Narcís Parés for their support, valuable information and guidance which helped me in completing this project through various stages.

I also take this opportunity to express my gratitude to the other members of the CMTech research group, Joan Mora and Pascal Landry, for their cordial support and advice.

I wish to thank all of the participants in this study: children, teachers from the schools Escola IPSI and Pere IV in Barcelona and Local Education Authorities, for their time and motivation during the participatory workshops.

Lastly, I am obliged to Fàbrica del Sol, Ecoserveis, Aula Ambiental de la Sagrada Família, Societat Catalana d'Educació Ambiental (SCED) and Centre de Suport a la Innovació i la Recerca Educativa (CESIRE) for the valuable information and materials provided by them in environmental education. I am very grateful for their cooperation during the period of my thesis project.

Abstract

Recently, there has been an increasing interest in the potential of Full-Body Interaction Learning Environments as mediator for learning processes. However, previous research in this field has failed to develop robust design and assessment methods to foster proposed learning goals. In this master project, we present a participatory design study with children analyzing user's needs and mental models towards environmental education. The study was conducted over three workshops: 1. *Exploratory Study*, 2. *Children as Informants*, 3. *Children as Testers*. Based on formative assessment methods we incorporate children's feedback about the design and investigate how users' contributions can be integrated in the design process. Testing the prototype shows a significantly higher level of understanding and involvement with the proposed topic in the Full-Body Interaction than in the Traditional Learning Environment condition. Outlining future work we propose a final design of the Full-Body Interaction Environment.

Keywords: *Full-Body Interaction; Embodied Cognition; Participatory Design; Formative Assessment; Game Design*

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1. INTRODUCTION

In recent years, there has been a great deal of interest in research about the potential of learning through new digital technologies such as Full-Body Interaction Learning Environments. A central question that needs to be addressed in this context is how to effectively design and evaluate such digital applications. Thus, their design and assessment methods require a fundamental rethink of learning and educational approaches and the ideas how new technologies are able to support them (Resnick, 2002; Quellmalz et al., 2009).

Learning is particularly important during childhood, being one of the most creative chapters in everyone's life. Hence, it is a great importance to ensure that children are sufficiently supported during this period to develop their skills and abilities. They may benefit from new education approaches such as kinesthetic learning involving physical activity instead of focusing on traditional learning methods. Previous studies have demonstrated that the involvement of new technologies fosters learning better than traditional strategies (Papert, 1980; Zuckerman et al., 2005). Drawing on earlier work by Resnick (2002) it is apparent that in the past some topics such as the function of working systems and its elements could not be effectively enhanced by school children using traditional education tools. The introduction of new digital technologies into schools opened a new dimension of learning, e.g. through computer simulations, such as a concrete ecosystem, children were able to access contents and knowledge which were previously only dedicated to university students. On the other hand, it is noteworthy to mention that the use of new technologies has to be justified. Traditional tools can also be very effective. The first step, before selecting the learning approach, has to be a deep analysis of the topic and its requirements. A latter step would be to find the appropriate technology. In this context, we have to be careful with kinesthetic learning approaches such as Full-Body Interaction and ask ourselves first what exactly this technology may contribute to learning. This is because it is not only a matter of implementing existing educational games to new sensor-based technologies. Full-Body Interaction Learning Environments require a rethink in the very beginning of the design process. However, since Full-Body Interaction is a relatively recent research field, currently little information is available about its effectiveness which does not derive satisfactory conclusions about related design methods.

Hence, the main emphasis of this master project is the proposal of the evaluation of suitable design methods to develop an effective Full-Body Interaction Learning Environment. Therefore, we conducted a design study with children from 10 to 12 years old. The subjects were involved through participatory design approaches at different stages of the design process. Through this, the prototype was tested and evaluated under the aspect of its capability to foster the understanding and involvement with a specific topic.

This chapter is divided into four parts: the first part highlights the aspects of learning through Full-Body Interaction Learning Environments. This is followed by a somewhat more detailed discussion of the problem in design and evaluation of Full-Body Interaction Learning Environments in part 2. Next, part 3 covers the functions and uses of different Participatory Design methods in context with this study. Finally, this leads to a general overview of suitable assessment methods reported in part 4 of this chapter.

In the second chapter of this master thesis, we present our study including evaluation methods, results and conclusions of each design process stage. In the third chapter we propose a final design for the proposed Full-Body Interaction Learning Environment. Finally, this work will be completed with a final conclusion reflecting the effectiveness of the used assessment and evaluation methods during the process and suggestions about future work to design a robust Full-Body Interaction Learning Environment.

1.1 Learning and Full-Body Interaction

Learning through Full-Body Interaction offers a new dimension of interaction combining research fields such as computer science, cognitive science and digital arts. Current studies focus on Full-Body Interaction as mediator for learning processes. Their research is based on embodied learning studies promoting the idea that physical activity and specific gestures may facilitate learning of abstract concepts through concrete experiences (Glenberg, 2010; Goldin-Meadow, 2011; Freiler, 2008).

Such theoretical approaches are supported in the field of cognitive science, for instance by Barsalou's grounded cognition approach (Barsalou, 2008). In his simulation theory, he suggests that mental representation have their origin in motor areas of the cortex. Thus, when previous experienced knowledge is required, the same neural patterns of perceptual and motor states involved during the particular experience are reactivated through multi-modal simulation. It is noteworthy to mention, that this occurs even when the person is inactive, i.e. no physical simulation is required to recall the experience.

At the same time, many experts in pedagogy such as psychologists have oriented their educational concepts on the framework of Jean Piaget (Ackermann, 2004). In the middle of last century, he stated in his theory that learning does not only consists of information transmission but it is an active process partly based on the expansion of concrete physical patterns. Moreover, he emphasized on the fact that children understand and learn in a completely different way to adults. Their cognitive abilities "jump" according to the ages, rather than having a gradual learning process. Seymour Papert extended Piaget's work to new technologies. In his opinion it was important to provide the children with material or sources to construct new things. He believed in the necessity of "learning by doing" and "diving into the situation rather than looking from a distance" (Papert, 1980). In this context, he created the programming language Logo, a tool with the aim to improve children's cognitive abilities such as problem solving. To sum up, taking Piaget's and Papert's work together, it becomes clear that the cognitive development of children in terms of knowledge and conceptual changes are influenced by their living experience as result of people's action-in-the-world (Ackermann, 2004).
This idea connects with the theory of Lev Vygotsky (1978) who assumed that learning emerges from the socialization between people.

The presented frameworks are consistent with findings in studies on the use of Full-Body Interaction Learning Environments. Antle et al. (2013) argues that Full-Body

Interaction enhances the impact of the experience in terms of awareness about the topic and willingness to take action. By using an embodied metaphor approach, they created an interactive environment based on a springboard system which enabled the users to explore images and to personally rate those related to the issue of social justice. The mechanism of the rating was carried out by balancing or unbalancing the board. Lyons et al. (2012) followed a similar approach by using physical exercises as metaphor for the notion of effort. In the presented Learning Environment the users had to race each other on bikes while they were immersed as polar bears in the virtual Arctic Ocean. The resistance of the bikes changed according to the differences of sea ice cover between 1970 and 2010.

Other Full-Body Learning Environments are based on existing physical games, educational material or existing desktop-applications and they were simply translated to the technology of Full-Body Interaction by adapting existing materials (Malinverni & Parés, 2014).

Many applications following these kinds of design strategies show deficiency in understanding of child development and the role of the body in cognition. Therefore, the learning goals are often not achieved or the content focus remains incomprehensible.

In this context, the next part of this chapter gives a more detailed overview of the problems in the design and evaluation of Full-Body Interaction Learning Environments.

1.2 Problem of Design and Evaluation of Full-Body Interaction Learning Environments

Full-Body Interaction has the potential to embed information into the physical interaction of the system due to its feature to integrate control and content at an equal level. The origin of this idea goes back to the research of tangible interfaces. Ishii & Ullmer (1997) stated that the benefits of tangibles are related to *embedding information in the control* of the interface instead of treating content and interaction as separated instances such as traditional interfaces. Hence, this concept can be extended to Full-Body Interaction. Representing a relevant potential for Technology Enhanced Learning, in recent years an increasing number of studies (see chapter 1.1) focused on the exploration of possibilities of creating Full-Body Interaction Learning Environments. However, since Full-Body Interaction is a relatively recent research field, currently little information is available about its effectiveness which does not derive satisfactory conclusions about related design methods.

In this context, we start presenting an explicit method aimed towards improving the design and evaluation of Full-Body Interaction Learning Environments: *Conceptual mapping by embedding meaning in the physical interaction.*

Drawing on research related to the concept of mapping has been widely discussed in HCI. However, since these studies basically focus on functional aspects such as usability and facilitating the understanding of the interface (Norman, 1988), they are not sufficient to evaluate Full-Body Learning Environments. To overcome this issue, it is necessary to consider aspects beyond usability and to conceive mapping as a holistic design strategy. In detail, this refers to the idea that the interaction experience additionally should stimulate mental models of the learning concepts. In particular, those concepts dealing with the understanding of abstract content and meaning should be embedded in the user interaction with the system.

Starting from this perspective demonstrates the necessity of the research in Full-Body Interaction to promote design methods leading to design effectively physical interaction capable of evoking the user's mental models about the defined learning goals. First approaches have been carried out, for instance by Antle et al. (2009) focusing on design perspectives based on *embodied metaphors*. That means the designer needs to define and conceptualize the physical interaction with the system, by relating concrete actions or the experience to a pre-defined meaning. That can be done by using embodied metaphors as previously reviewed in the Springboard example (Antle et al., 2013). Other more traditional approaches are based on Peirce's sign theory or *semiotics* (Dewey 1946) referring to the meaning and representation of signs. The form the sign takes (signifier) becomes to the concept it represents (signified).Van Leeuwen (2004) argues in this context that the interpretation of physical activity constitutes a semiotic resource which makes it possible to describe its semiotic potential or meaning. The interpretation of physical activity as signs occurs unconsciously by associating them to pre-established mental concepts. Research based on the reviewed design approaches have often neglected a proper communication of the content to the user and thus do not mediate the desired learning goals. The following example perfectly illustrates this issue: the installation Wobble (Kynigos et al., 2010) required a collaborative task between different users controlling the virtual board by displacement. The goal of the installation was to foster concepts of several physical properties such as force, balance, weight, location and direction. Despite the defined learning goals, the users did not understand what the installation was supposed to mediate.

Such methods have one basic aspect in common: the meanings of the actions are determined by the designer. However, the pre-established meaning may enter into conflict with the user's mental models influenced e.g. by his/her cultural or social background and this may lead to completely different interpretations of the system by the user. In contrary to the research field linguistics, where a word is normally related to a limited number of meanings, gestures can be interpreted in many different ways (Beattie, 2004). In relation to this Umberto Eco (1989) claimed that each experience provides a multiplication of meaning in its interpretation process.

This key issue affects in particular the research field of Full-Body Interaction due to its polysemic nature of physicality and the lack of pre-established and shared cultural conventions. Therefore, to prevent misconceptions of the proposed experience or other shortcomings caused by the *pre-given* meaning approach, we propose in our method the necessity of incorporating the analysis of user's mental models and interpretation directly into the design strategy.

The topic of user experience testing has increasingly attracted the attention of designers and HCI experts around the world. It involves the user's behaviors related to interpretations of the system. The users' mental concepts about the system emerge in relation between the system and the intrapersonal and interpersonal meaning that the user possesses. In this context, we can conclude that the design and assessment of the system by the user are inseparable from the design process. However, this often remains only a theory; the user is very poorly included a methodological tool of the design strategy.

First attempts can be found in Participatory Design methods but these approaches often concentrate on the assessment of user's needs and preferences rather than analyzing the user´s interpretations of his/her interaction with the system. Hence, this shows the necessity of the interpretative process to be included into the design strategy and a careful analysis of *user-generated meanings* emerging from the interaction with the system. The interpretation of the system by the user may be influenced by many factors such as previous knowledge or experience, socio-cultural context, emotional states and perceptual and physiological aspects.

In the next section, we present different Participatory Design stages and methods. Furthermore, we explain how they may be adapted to workshops of children taking into account the analysis of the user's mental models and interpretation with the system.

1.3 Participatory Design

The origin of Participatory Design goes back to the Scandinavian countries where from the 1970s onwards a new design approach was developed consisting of the active involvement of all stakeholders, such as researchers, designers, developers and end users, in the design process. This method resulted from the need to gain insights about mental models, language and references of the end user in order to ensure their needs and interests.

Participatory Design methods are often criticized as time-consuming (Bossen, 2002) because they have to be carried out over several hours or days and large amounts of data must be processed in order to qualify the material suitable for the design process. Despite these disadvantages an increasing number of companies have recognized that the incorporation of the end user prevents them from making incorrect design decisions which might have caused a failing of the product or service on the customer market. Therefore, considering the long-term perspective, it is assumed that the use of Participatory Design methods save costs because they explicitly analyze users' needs and mental concepts.

The participation can take place at several stages of an innovation process. Firstly, in an exploratory study users can be observed while interacting with the prototype to elicit relevant information such as defining problems and focusing ideas for solution. The study which may be carried out at the beginning, during or at the end of the design process, is assessed through ethnographic methods such as videotaping and annotations. Secondly, in case of the users as informants, they are considered as experts informing the design team of key issues related to their experience, helping to develop early design ideas and testing prototypes in the development process. Thirdly, as testers the users provide feedback through interviews or questionnaires after testing the prototype. This method is commonly used at the end of each development phase. And lastly, the role of the users as design partners where they get equally involved as members of the design team helping to identify problems and solutions to improve the prototype (Kelly et al., 2006).

In the 1990s Participatory Design methods were also adapted to children. Under the claim “Telling us what we didn’t know or confirming what we knew already” (Scaife & Rogers, 1998) focus groups were conducted asking children their opinion related to certain topics. In many different workshops it was confirmed that children perceive the world differently to adults. In this context, Druin (2002) stated that especially for the communication of abstract concepts, children should be involved in the design process to guarantee a high degree of comprehension and to achieve proposed learning goals. Hence, there has been a growing interest in the participation of children in the design process.

Another important aspect is learning through collaboration. In this context, the psychologist Vygotsky (1978) brought up the question of how much a child develops on his/her own. He observed that when children are exploring something, they naturally turn to someone who knows about it, such as their parents, other family members or the teacher. Hence, in his learning theory, he argues that children are Independently capable of solving a problem. However, their level of potential cognitive development requires guidance through an adult (Vygotsky, 1978).

Nowadays, children have been incorporated mainly in the design process in exploratory studies, as informants or as testers. Their role as design partner is highly questionable because children still do not have the capability to make design decisions or to understand technological aspects of the prototype. However, Druin (1999) claims in her study that children became equal and active partners of the research design. We agree to this suggestion only to some extent. Druin worked in a longitudinal study with the same children in regular sessions over a long-term period. Through the workshops the children were provided with extensive training on new technologies. Finally, they could be considered as capable design informants in this specific context because they obtained a different way of training in new technologies. Nevertheless, we should not jump to the conclusion to generalize the fact that children should have a voice as design partners because “ordinary” children may not be provided with the required previous knowledge. Furthermore, it is not realistic to believe that other research groups or the industry would have the possibility to train children for such a long-term period. For these reasons, in our approach we limited the role of the children to an exploratory study, as informants and as testers through a guided Participatory Design approach.

From this perspective, several assessment methods have been developed to involve children in the participatory design process. Hence, in the next section of this chapter we address the benefits of formative assessments and provide an overview of suitable assessment methods related to Participatory Design with children.

1.4 Assessment methods: formative assessment

Before presenting this topic it is important to define the concepts to be used in the paper.

Formative assessment is defined as the process of ongoing feedback provided by the children used to adapt learning material to the students needs. Through this method the instructor allows learners to become aware of shortcomings of their knowledge related to the required goal (Boston, 2002; Quellmalz et al., 2009). Children's feedback may be obtained for instance by drawing a conceptual map (Phye, 1996) to represent their understanding of a topic, open-ended questionnaire (Zaman, 2007) identifying the main purpose of a workshop or semi-structured discussion (Donker & Markopoulos, 2002; Price & Jewill, 2013) about a certain topic.

Addressing a specific concept to children requires different methods than to adults. Mazzone et al. (2012) suggests that a variation of activities, such as using audiovisual media, drawing or making physical objects help to obtain better outputs and keeps children's attention during the workshop.

For younger participants it is essential to use scenarios they are familiar with and to be creative in setting the scene (Kelly et al., 2006). It has been found that children pay more attention to issues presented by fictional or *narrative inquiry* methods rather than general descriptions of the topic. The fictional or *narrative inquiry* consists of a role play according to a story, movie plot or an actual topic. Dindler & Iverson (2007) engaged the participating children in a playful way to their workshop by introducing the topic through the Mission from Mars method. In this study the children were asked to participate in the design of an eBag. Instead of presenting their ideas directly to the adults, the presentation was done to the alien. The children could hear the alien's questions through speakers. At the same time the subjects were recorded by video camera allowing them to communicate with the Martian and simultaneously to show him their design ideas. This method helped to engage and to motivate the children for the workshop. The children play themselves but in fictional circumstances. Additionally, it loosened up the boundaries between children and design team and made the children more free to express their ideas. Otherwise, their actions might have been restricted by the thoughts to fulfill the expectations of the adults. Another example of *narrative inquiry* is the study of Bekker et al. (2002) encouraged children to act as reporters and invent stories about a certain topic. The aim was to make the children concentrate on issues which are meaningful to them. According to Dindler & Iverson (2007) this specific method brings the children closer to the ideal of a design partner because children and adults are equally involved in the design process and the ideas are handled democratically. However, it is recommendable that the final selection of the results is carried out by adults due to the children's shortcomings of technological understanding (see chapter 1.3).

Another important aspect during Participatory Design workshops with children is to take into account that they are not used to express their thoughts and opinions verbally or written as adults would do. Thus, they should be given the possibility to produce drawings or paintings with their ideas (Kelly et al., 2006).

These concepts can be extended to different collage techniques such as *pictorial flowcharts* combining drawings with small amounts of text to create cartoon-like flow charts (Druin, 2002). Another approach is using laminated cut-outs which the children manipulate against a pre-defined background simulating interactions of a game. Scaife & Rogers (1998) emphasize on the time saving aspect and the facilitation of the observation of interaction behavior of this technique. They point out that usually children between 9 and 14 years old concentrate on defining details of their drawings rather than paying attention on the proposed activity. Another interesting co-design technique to define the content and narrative of a game is the *layered elaboration* approach presented by Walsh et al. (2009). The approach consists of adding tracing paper on top of the original storyboard through which the initial ideas easily can be modified. This technique also enables the interchange of several groups working on the same storyboard. Facilitating the collaboration between different participants is also the intention of the co-design approach of Giaccardi et al. (2012) where children develop a storyboard with self-taken polaroid pictures using a role play.

In a further step, these drawings and ideas can be expressed through 3D modeling with carton or clay (Nesset & Large, 2004). The possibility of interactive low-tech prototyping provides the children a concrete way to discuss and develop their ideas (Druin, 1999; Scaife et al., 1997). 3D modeling may be particularly interesting for the design of Full-Body Interaction Learning Environments because the interaction between the elements incorporates the configuration of spatial needs.

Traditional methods such as interviews and questionnaires are used both with adults and children. For the latter target group, they need to be adapted to “infantile language”. In terms of the assessment of attitudes and emotions, there have been several approaches to use smileys or other drawings with facial expressions (Donker & Markopoulos, 2002). The use of multiple-choice questionnaires should be avoided because children usually find this activity boring and due to the lack of motivation, they do not lead to valid outcomes (Druin, 2002; Nesset & Large, 2004). In general, if questionnaires are used the content should be as short as possible, limited to only one page.

Another challenge refers to the need to develop methods that facilitate designing for and with the body. Most Participatory Design methods have been mainly developed to design desktop-based applications or similar products. However, for the design of Full-Body Interaction Learning Environments some of these methods are not suitable since they do not take into account the specific features of body-based interaction or the configuration of spatial needs. Little information is available on the enquiry of bodily-based activities such as bodystorming to simulate interaction for games (Hemmert et al., 2010).

Hence, the primary aim of this master project is to develop and to verify new methods to develop Full-Body Interaction Learning Environments for children which effectively foster proposed learning goals.

2. PARTICIPATORY DESIGN WORKSHOPS

This chapter presents a novel design and evaluation approach to improve Full-Body Interaction Learning Environments for children. We used a mixed method of qualitative and quantitative analysis. On the one hand, the research goal of the users qualitative analysis was to understand previous knowledge and to analyze how user interpret and understand the system. On the other hand, the quantitative analysis focused on the evaluation of the effectiveness of proposed methods and the Learning Environment.

This method was based on Participatory Design methods (Druin, 1999), formative assessment methods (Quellmalz et al., 2009), agile methods as on-going feedback loop between design and assessment (Beyer, 2010) and guided participation, i.e. to provide bridges between previous and novel knowledge of the children (Rogoff, 1990).

Participatory Design and formative assessment methods have been reviewed in detail in the previous chapter. Apart from that, incorporating agile methods in the interpretative process of the design strategy is necessary since design and assessment has to be considered as inseparable instances mutually reinforcing and informing each other. To implement this participatory design method we propose a four-step procedure aimed at designing Full-Body Interaction Learning Environments and based on creating continuous iterations and an ongoing feedback loop between design and assessment. In the design procedure we concentrate on the following main research question:

Main Research Question: How can users' contributions be integrated in the design of Full-Body Interaction Learning Environments?

Therefore, we analyze children's previous knowledge, misconceptions and interpretations evoked during their interaction with the system. The aim of such method is to determine educational requirements and strategies to create bridges between what the children already know and obtained novel knowledge (Rogoff, 1990). This approach involves the necessity of using intuitive actions or *user generated meanings* during the interaction as a source to inform and improve design.

The procedure of the design process is structured as follows:

1. Definition of the educational needs:
   analyzing previous knowledge and misconceptions
2. First design iteration: analyzing the interpretation
3. Second design iteration:
   analyzing the effectiveness in terms of learning gains
4. Third design iteration: design proposal

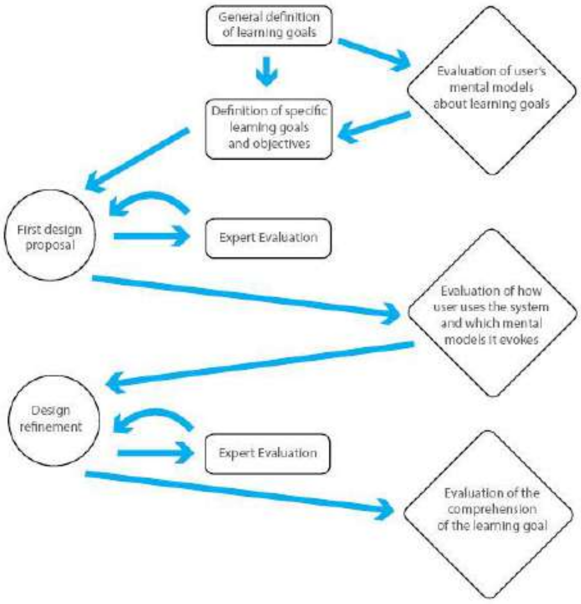

Fig 01: Research and design process

1. *General definition of learning goals*
2. *Evaluation of the already existing users' mental models about the defined learning goals*
3. *Definition of specific learning goals and objectives*
4. *First design proposal*
5. *Expert evaluation of the first design proposal*
6. *First study of the system: evaluate how children use it and which mental models it evokes*
7. *Design refinement*
8. *Expert evaluation*
9. *Evaluate whether the system facilitates an appropriate comprehension of the learning goals.*

The different design stages were carried out with children between 10 and 12 years old in three consecutive workshops. The methodology of the designed workshop was based on literature focusing on Participatory Design methods, formative assessment methods, agile methods and guided participation. The methods and design of each experiment was adapted according to the main findings of the previous workshops.

Thus, in this study we concentrated on the following main hypothesis:

H1 Comprehension: The use of this method will guarantee the effectiveness of the Full-Body Interaction Learning Environments in terms of learning gains.

Each reviewed workshop is divided into five parts: the first part presents the definition of the research goals and the present state of the design process. The second describes the methods and procedure of the experiment. The third part gives detailed information about the evaluation process. Then, in the fourth part we present an overview of main findings and in the last part we discuss what consequences these findings have for the following workshop.

Tab. 01: Overview workshops and methods

Phase A: Requirements and defining of methods	**Phase B:** Preliminary Design	**Phase C:** Improvement of first design iteration and testing of prototype
- Contact Experts: Consultation guidelines, methods, materials - Workshop Part 1: Exploratory Study	Workshop Part 2: User as Informants	Workshop Part 3: User as Testers
Aim: 1. Identification of requirements and mental models for target group in environmental education 2. Exploration of how to adapt Participatory Design methods to Full-Body Interaction	*Aim:* 1. Analysis of how children understand and interpret the system 2. Exploration of the role of physical interaction	*Aim:* 1. Assessment of game effectiveness towards the set of learning goals 2. Evaluation if specific gestures can enhance learning

2.1 Workshop Part 1: Exploratory study

The exploratory study was oriented towards defining appropriate learning goals and exploring methods for integration Participatory Design and Full-Body Interaction. The aim of the workshop was to analyze children's previous knowledge in order to identify misconceptions that need to be addressed as educational requirements and concepts that can bridge between what the children already know and novel knowledge to be acquired by them (Rogoff, 1990) around environmental education. Furthermore, we explored how to adapt Participatory Design methods for the development of Full-Body Interaction Learning Environments. Therefore, we focused in particular on bodily-based techniques during the warm up activity in order to evaluate its effectiveness in facilitating design for Full-Body Interaction. In order to properly define learning goals, the study was divided into two main parts: firstly, the identification of requirements by consulting experts in environmental education; secondly, the organization of a participatory workshop with children.

a) Definition of Learning Goals

The design process began with an activity which resulted in the identification of the requirements and constraints of the project where we formulated the purpose of the project and the research structure. We decided to focus on environmental education in the workshops because related topics required perspective emotional engagement and empathy. Furthermore, it is a topic of high importance affecting everyday life of the children and their future. Schools and family deal only briefly with these issues giving home practice advice rather than a general or global view on causes and effects.

Hence, we contacted several experts in environmental education in Barcelona, among others, Fàbrica del Sol, Ecoserveis, Aula Ambiental de la Sagrada Família, Societat Catalana d'Educació Ambiental (SCED) and Centre de Suport a la Innovació i la Recerca Educativa (CESIRE) who provided us with guidelines, methods and materials appropriate for children from 10 to 12 years old.

With this first set of constraints in account, we started to gather user requirements involving children in a series of activities. In order to examine children's mental models, we focused our study towards the analysis of their current knowledge. We embrace this by examining their misconceptions and their core perceptions about the environment (i.e. what children consider to be relevant, what they select and remember). Such an approach was aimed at identifying knowledge gaps that needed to be addressed as learning goals. Furthermore, the analysis was oriented towards defining concepts that can bridge between what children already know and novel knowledge, according to the method of guided participation proposed by Rogoff. In this instructional technique the author suggests the fundamental importance of using children's previous knowledge as an entry path for the comprehension of novel concepts (Rogoff, 1990). The findings gave us a starting point for the first design iteration. In this context, we focused in the *Exploratory Study* on the following research question:

RQ: What is children's previous knowledge about environmental education?

Moreover, to explore the possibilities of including bodily-based techniques that facilitate the design of experiences fitting within the features of Full-Body Interaction, we hypothesized that the inclusion of bodily-based training would be beneficial. For this purpose, in the workshop we conducted a warm up activity based on two different conditions: verbal- and bodily-based training. Our hypothesis was that children assigned to bodily-based training would enjoy the Participatory Design more and would propose design solutions which would be more appropriate for the features of Full-Body Interaction.

The concrete formulation of the hypothesis was as follows:

H: The inclusion of bodily-based training will facilitate the suitability of the activity and capability of the children to produce bodily-based games.

The term *suitability* refers to the likeability of the activities and how much the children felt engaged and involved as active participants in the design process. The notion of engagement is important because it enables the children to participate actively. That can be achieved by proposing activities that inspire them and understanding the type of tasks which encourage their imagination. On the other hand, *capability* represents the extent to which the activities can produce useful results for the design (Mazzone et al., 2012).

The methods used included observations through video recording during the activities, annotations and surveys of the enjoyment of the activities at the end of each workshop. Furthermore, we involved experts in Full-Body Interaction Learning Environments in the evaluation of the workshop outputs.

In the next sections we describe the methodology and experimental procedure of the study; followed by a review of the results and a discussion of the main findings in context of the design process.

b) Methods and Procedure

The *Exploratory Study* was carried out on three consecutive days in our Full-Body Interaction laboratory. A total of 68 children between 10 and 12 years old participated. Each session had a duration of approximately 45 minutes. Children were divided in groups of 4 to 5 members and the groups were randomly assigned to one of the two conditions (bodily- and verbal-based training). All groupings knew each other before the workshop because they came from the same school

We used a between groups design, i.e. two conditions were randomized: bodily- and verbal-based training. Both conditions mainly differed in the warm up activities and were derived from theatrical practices. The bodily-based activity (Boal, 2002) consisted of corporal exploration of the space by running around and distributing uniformly when indicated by the researchers. Then, the children had to pass gestures to their peers which were first introduced by the design team and later invented by the children themselves. Whereas, in the verbal-based activity (Boal, 2002) the children were asked to say first their own name, in the next round only the vocals and then only the consonants. In the last round, we introduced the children to the workshop topic by asking them to think of a true or false statement related to environmental issues, such as "you should turn all lights off when you leave home" (true) or "making a fire in the forest is not dangerous" (false). When the statement was false, their peers had to respond accordingly with hand claps (bodily-based) or shout a word (verbal-based).

In the next step, we conducted a game based on the mechanics of the Pictionary game in both conditions where the children randomly selected a word related to environmental issues, such as solar energy or ecological footprint. The selected term had to be drawn on a flip-board and the other children tried to guess the meaning in a limited period of time. The goal of the activity was twofold. On the one hand, we wanted to evaluate which terms the children were familiar with and their previous knowledge, knowledge gaps and misconceptions on environmental topics. Hence, we were able to receive insights into the children's perceptions of the concept. On the other hand, the activity was useful to explore their representation of concrete concepts and helped to prepare the children in terms of the topic for the next activity.

In the last part of the workshop, the children were asked to sit down at tables prepared with colored-pencils and paper. First, the children were asked to produce two lists of actions related to environmental issues classifying in positive or negative. After the brainstorming phase, the children were introduced to the next activity aimed towards facilitating the design of a Full-Body Interaction Learning Environment. The instructions were provided by incorporating a *narrative inquiry*. (Dindler & Iverson, 2007) activity where we handed out a fictive letter of a boy called Ted writing from the future (see Fig. 02). The story was inspired by the Walt Disney cartoon *Lorax*. Then, the children were asked to choose one of their group

Fig. 02: Letter narrative inquiry method

members to read the letter aloud. Thus, the children were informed about the critical situation of the environment in 100 years time.

Starting from this letter, they were asked to invent a game based on body movements. The aim of this game was to make other people aware of strategies to avoid further degradation of the nature and to improve our habits in relation to environmental issues. The narrative inquiry activity strongly helped to engage the children to the context and to minimize the skill and knowledge differential between adult and children (Kelly et al., 2006). However, the children were aware that the letter was not real. Further goals of this novel approach were to get more value out of each session and to improve the usefulness of the outputs.

After a short explanation, the children produced drawings and written game descriptions (Millen et al., 2010). The research team supported the groups in the design process through advice. Then, each team presented their design ideas to the entire group. The children were asked to grade the work of their peers from 1 to 3.

To test the likeability of the activities, the children were asked to fill out two different questionnaires rating the activities.

Tab. 02: Comparison bodily-based and verbal-based condition during Exploratory Study

bodily-based	**verbal-based**
Corporal exploration of space and passing gestures	Verbal exploration "names"
Pictionary with environmental expressions	*Pictionary* with environmental expressions
Brainstorming "positive" and "negative"	Brainstorming "positive" and "negative"
Invention game through *narrative inquiry*	Invention game through *narrative inquiry*
Presentation of games	Presentation of games

c) Evaluation Methods

The results were obtained by quantitative analysis through two different questionnaires and qualitative analysis by video recordings of the sessions, drawings and annotation during the sessions. The evaluation was oriented towards analyzing children's mental models and assessing the effects of the warm up activity on the unfolding workshop. Then, we presented in our analysis how the defined methods enabled us to follow the design process.

Quantitative analysis

The evaluation of the effect of the warm up activity was based on two measures: *suitability* and *capability* (Mazzone et al., 2012). The term *suitability* refers to the likeability of the activities and how much the children felt engaged and involved as active participants in the design process. On the other hand, *capability* represents the extent to which the activities can produce useful results for the design.

To access suitability children were asked to rate the likeability of the attended activities through two different types of questionnaires. The first questionnaire was a Likert-scale rating from 1 to 10 based on the local grading system with the value 10 as highest achievable grade. The second one was divided in five verbal ratings in appropriate infantile language: “very much fun”, “much fun”, “okay”, “boring” and “very boring”.

Firstly, this procedure was carried out to investigate the effectiveness of the two assessment approaches and the validity of the answers of the children. Secondly, the questionnaires were designed to elicit if the two different approaches of warm up activity through bodily-based and verbal-based training had an effect on children’s performance and likeability of the *narrative inquiry* activity where they were asked to invent a game incorporating Full-Body Interaction.

On the other hand, to evaluate capability, a transcription of the 26 proposed games was rated on a Likert-scale rating from 1 to 5 points by three experts blind to conditions in order to estimate the degree to which the proposed games fit with the specificities of Full-Body Interaction. Before the evaluation, the game descriptions were literally transcripted from recorded videos of the sessions.

Qualitative Analysis

The analysis was carried out using qualitative methods based on the analysis of the video recordings of the sessions, children’s productions (i.e. drawing, lists, and written descriptions) and annotations. The evaluation of the materials concentrated on suitability and capability of the proposed activities. Moreover, the material had a great inspirational value, not only in terms of new approaches of design solutions but particularly to get insights about the children’s mental models.

After the workshop sessions, we examined the outputs from each activity which had ended with a huge amount of papers, words, drawings and ideas and video material. The analysis was oriented toward identifying children’s previous knowledge, misconceptions and core meaning related to environmental education.
Data from the workshop sessions were analyzed as follows. First, the video transcription of the proposed games and text from the list were analyzed using the NVivo10 software. Video transcriptions were coded according to a grounded theory approach. From the data collected, the key points were marked with a series of codes, which were extracted from the text. The codes were grouped into similar concepts in order to make them more workable and finally categories were formed (compare Tab. 03). Additionally, we analyzed our observations and annotations of the activities individually.

Tab. 03: Used codes and categories during qualitative analysis

Topic	Game Elements
• environment ○ domestic environment ○ urban environment ○ natural environment • elements ○ rubbish ○ natural elements • misconceptions ○ accumulation	• reward a behavior • punishment

d) Results

In the following part we present the obtained results of quantitative and qualitative analysis.

Quantitative analysis

Starting with evaluation of the effectiveness and validity of the assessment methods, we performed a correlation between the two questionnaire approaches. The results showed with $p < .001$ a correlation between both approaches.

Then, to analyze children's answers to the likeability questionnaires an Independent t-test was performed between the two conditions: bodily-based and verbal-based activity. As we detected a great standard deviation in one of the groups (see Fig. 03 (left)), we had to eliminate five outliers from the bodily-based condition (25, 26, 68, 69, 70). Children who started the workshop with bodily-based activities ($M = 8.75$, $SD = 1.554$) rated the activities significantly more positive than those with verbal-based activities ($M = 7.10$, $SD = 3.986$), t (32,794) = 2.081, $p = .045$ (see Fig. 03; right). That means although the narrative inquiry was the same in both conditions, children assigned to the bodily-based training liked it more than those assigned to the verbal-based training. Thus, we can conclude that the bodily-based training primed the children's perceptions of the workshop activities.

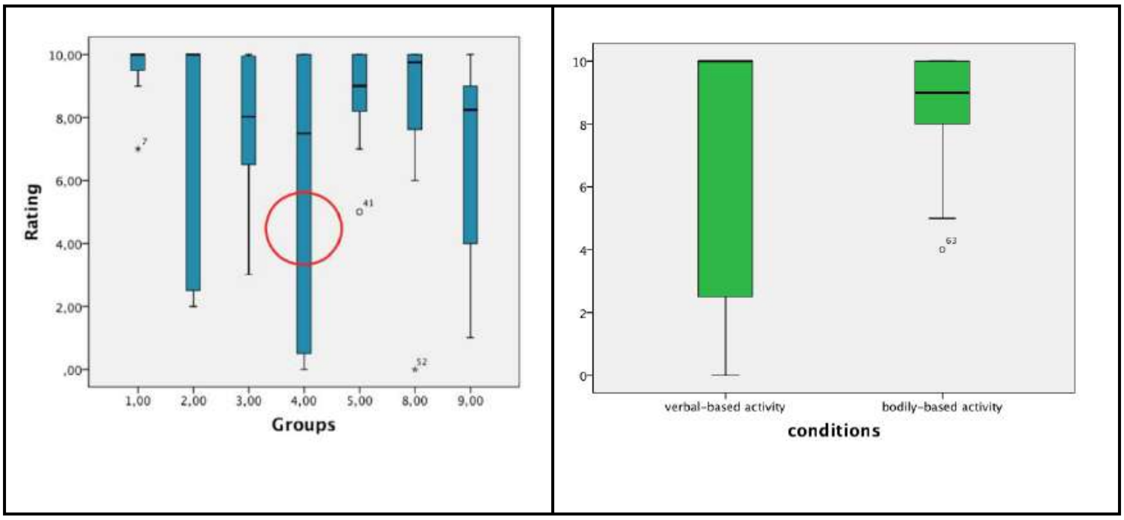

Fig. 03: Box plots of questionnaire results*; left distributions of rating results between the groups; right comparison of distribution of rating results between two conditions (verbal-based vs. bodily-based) after eliminating outliers.*

By contrast, no significant differences between groups were found.

Therefore, as hypothesized we conclude that the children assigned to bodily-based training enjoyed the Participatory Design more. The great standard deviation and the obtained results might be influenced by the different personalities of the children, their interest in the topic, previous activities and at which time of the day they started the workshop.

In order to assess the extent to which the proposed games fit with the specifications of Full-Body Interaction we firstly calculated the average between raters for each game. Therefore, we compared the results of both conditions, verbal-based and bodily-based training, and we conducted an additional analysis taking into account previous experience with Full-Body Interaction Learning Environments in other experiments during the day. Subsequently a Wilcoxon-test was performed between the two conditions. No significant difference was found between the two conditions.

Furthermore, we realized that the method of individual grading of the game ideas from 1 to 3 points between the children (Kuiper-hoyng, 2011) was not very effective because it seemed that they mainly gave high ratings for sympathy, that means to their closer friends. Lower points were given for reasons of revenge, e.g. when one child had received only one point from the other group, s/he tended to give only one to them as well. Therefore, we propose to evaluate children individually in a separate room so that they cannot influence each other's decisions.

Qualitative analysis

By analyzing video recordings of the sessions, children's drawings and our annotations during the sessions, we obtained a better understanding of the previous knowledge and misconceptions of the children related to environmental issues.

Using the grounded theory approach we identified that 14 out of 26 proposed games were related to the topic recycling or waste (see Fig. 04; right) and 8 out of 26 referred to plants or trees. Examining the more frequent environmental location of the proposed games, we found out that 11 were related to natural setting, 4 with domestic and other 4 with urban settings.

Furthermore, this method gave us insights about the following misconceptions. Firstly, 9 out of 26 games wrongly applied the idea of "accumulation" to environmental aspects such as waste or watering plants. A typical game's structure of rewarding who obtains more items was therefore translated to "whoever obtains more waste or whoever gives more water to the plants, wins". Such proposals reveal an inadequate model, which does not take into account that reducing waste is a priority over recycling large amount of waste. Also, many children believed that the player needs reward for activities, which are good for the environment. Some also proposed positive actions (e.g. recycling, planting trees) as punishment activities for players who lose in the game (e.g. "if you lose, you have to go to plant trees".)

By analyzing observations and annotations, we could detect more misconceptions. The concept of "light pollution" was incomprehensible; some children related it to the sun and they did not understand its effects on nature. The same occurred with the rather abstract concept of "contamination". Many children did not understand its meaning or related it only to rubbish. Although contamination caused by petroleum seemed to be at first more concrete to them, further observations showed that they understood that petroleum can cause contamination of the ocean but they had difficulties to determine how the petroleum reaches the ocean and how it can be eliminated when it is already there (see Fig. 04; left).

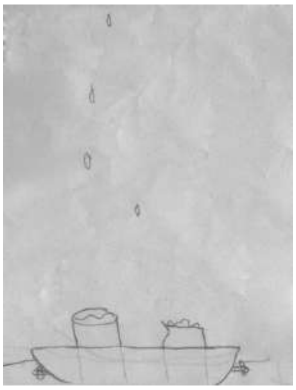
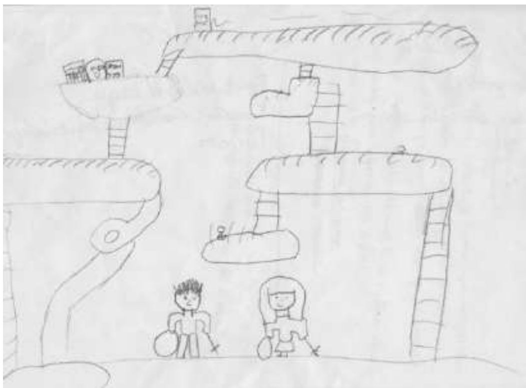

Fig. 04: Children's drawings of proposed games; *contamination caused by petroleum (left); game based on collecting waste (right).*

Interesting for a further game design may be the proposal of one child to use the sun as timer for the game. According to him the player had time to solve the situation until sun set. The idea would enable to introduce a rather artificial game element (the time) in a natural context.

e) Discussion

The method used to analyze children's mental models by focusing on core meanings and misconceptions showed to be highly effective to extract aspects to be taken into account for further steps in our next workshop and for the general design process of the project.

Main insights were related to the definition of area of knowledge that need to be addressed and to the identification of bridging concepts. Children have a quite clear idea about the local system of recycling and home practices related to saving energy or water. These topics should not be addressed directly since they already know them. However, these topics can be used to evoke some new concepts.

Balance, equilibrium and rhythm of the nature is an important topic because 9 out of 26 games presented misconceptions related to the notion of "the more the better", e.g. the children had difficulties to understand that reducing waste is more important than recycling. Potential topics to be addressed would: to reduce contamination or generate as little as possible; the balance of ecosystems related to equilibrium between resources; or the meaning of contamination, its origin and global effects. Many topics around environment and abstract concepts such as light pollution or contamination are related only to home practice. We detect a lack of knowledge on global processes around environmental topics, such as the role of industries or specific nations. The children were also not aware of their own responsibility in this process and how their actions have an impact on all living beings on the planet, including themselves.

In general, we observed that many children had difficulties to invent bodily-based games as they were more familiar with desktop applications and games based on the use of consoles. This is mostly reflected in the proposed games where they tried to introduce game mechanisms known from table top or traditional video games.

Then, results related to the effects of the warm up activity showed that although bodily-based training had fostered the overall engagement of the children during the workshop and primed their perception of the subsequent activities, it however did not facilitate the design of games which are more suitable for the features of Full-Body Interaction.

2.2 Workshop Part 2: Children as Informants

For the study *Children as Informants* we redefined the learning goals and developed a first prototype aimed towards countering the lack of knowledge by focusing on an abstract concept such as an eco-system and its elements. Furthermore, to incorporate bridging concepts, we inserted elements such as waste reduction and plant growing in the Learning Environment. The aim of this study was to analyze how children understand and interpreted the system of the first design iteration. Additionally, we explored the role of physical interaction within the proposed game. In the next sections, we present the preliminary design and the different steps of the design process of the workshop.

a) Preliminary Design

The *Exploratory Study* has shown that children are familiar with home practices related to environmental issues but do not seem to be outward-looking. Thus, we decided to focus on an eco-system and the relationship of its elements for the preliminary design. The aim of the Full-Body Learning Environment we propose is to confront children with the concept of air-pollution and to convey its origin and effects on its environment. The learning goals and the game design was reviewed and corrected with an expert of environmental education from Fàbrica del Sol in Barcelona.

These findings are concurrent with a study previously mentioned. According to Resnick (2002) the function of working systems and its elements could not be effectively enhanced by school children using traditional education tools. Digital technology, facilitating a great number of interaction possibilities, opens new approaches to teach particularly abstract concepts.

The game "Air-pollution and it affects our environment" is a Full-Body Interaction Learning Environment designed for primary school children at the age of 10 to 12 years old. Children at this age group start to understand more abstract concepts by considering multiple viewpoints such as their friends, siblings or parents and adjust their behavior accordingly (Bekker & Antle, 2011).

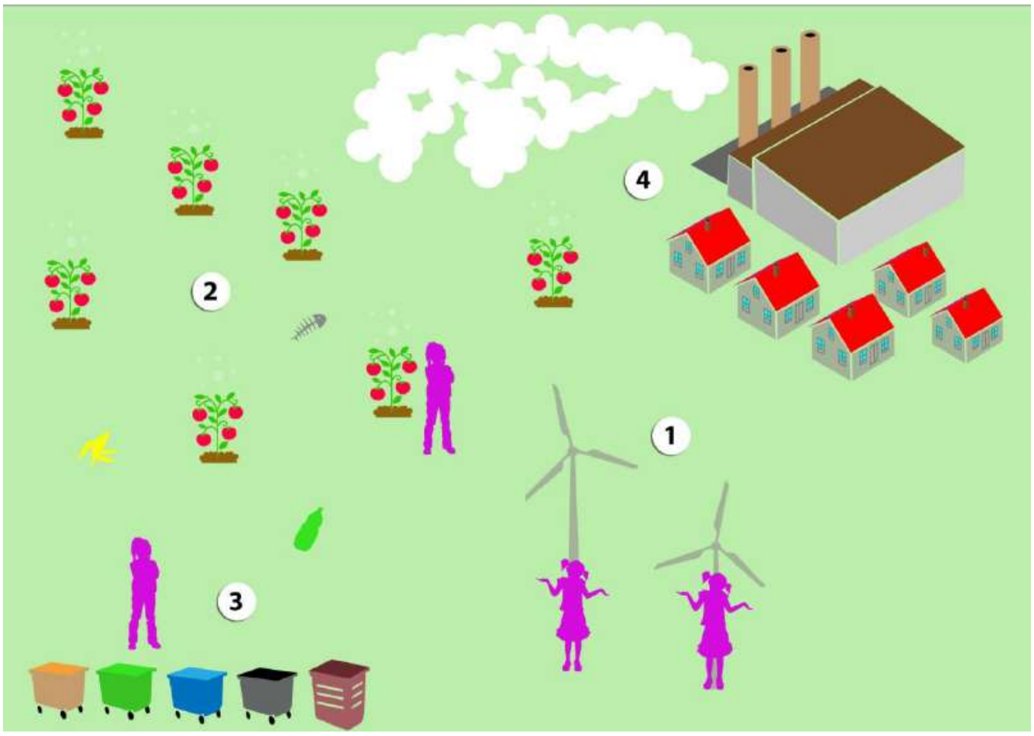

Fig. 05: Design Draft of game setup*: 1. Wind power, 2. Vegetable garden for planting plants, 3. Recycling area, 4. Air-pollution caused by steam power station*

Hence, the aim of the game was to promote and increase awareness of environmental issues related to the risk of air-pollution and the possible strategy to reduce it. The game is based on a floor projection. During the game children play in groups of 4 with a virtual simulation of a semi-urban landscape. Children have to collaborate with each other in order to reduce the amount of air-pollution in the environment by using different strategies. The main learning goals are to obtain a global and systemic vision of environmental issues. Therefore, the children are invited to experiment with the existing relationships between carbon dioxide emission and strategies for reduction and absorption. Additionally, the game should facilitate the children to distinguish which elements produce air-pollution and those which are affected by it. This novel awareness should help the children to make hypothesis about how air-pollution could be decreased or increased. The applied pedagogical model is based on models of learning by doing, i.e. through concrete experience and active involvement (Papert, 1980) and learning through inquiry (Vygotsky, 1978).

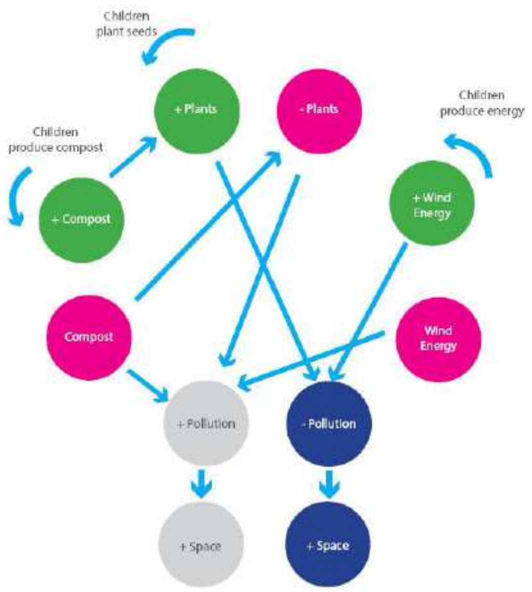

Fig 06: Behavior of the different game elements and their reciprocal relationships

The active involvement in the game was provided through the following three roles:

1. *Producing alternative energy:* by producing wind energy the children replace the amount of energy produced by the steam power station and reduce the air-pollution

2. *planting vegetables:* by planting plants the children facilitate CO2 absorption and contribute to the usage of local food, i.e. reduce the pollution provoked by food transportation

3. *recycling and producing compost:* by producing compost the children increase the growth of the plants

The air-pollution is visualized as a cloud covering the game ground. Thus, as the cloud increases the amount of space available for playing decreases. In order to make the cloud decrease children need to understand the behavior of the elements present in the game and properly collaborate between them.

The game only has one level based on a simulation of the landscape environment. The behavior of the different elements and their reciprocal relationships are the following:

In the following table the relationships between user's action and elements behavior is detailed (see Tab. 04).

Tab. 04: Relationships between user's action and elements behavior

	Yes	**No**
Producing alternative energy	● reduce consumption of energy from steam power station ● reduce pollution	● increase consumption of steam power station ● increase pollution
Planting vegetables	● plant growing ● absorption of pollution	● increase pollution
Recycling and producing compost	● plant growing ● reduce pollution	● increase pollution

Due to our findings in the *Exploratory Study,* we investigated in this workshop how the children understood and interpreted the preliminary design at a conceptual and physical level, i.e. the comprehension of the playing experience. This research goal leads to the following research question:

***RQ** Interpretation:* How does the user interpret the system?

To analyze how the children understand the playing experience and interpret the system, we identified previous knowledge, core meanings and misconceptions about the defined learning goals.

Furthermore, we explored the role of physical interaction within the proposed game conducting the experiment in two different conditions: *intuitive actions* and *designed actions*. In this context, we hypothesized as follows:

***H** intuitive action vs. designed actions:*
The design of different kind of action evokes different interpretations in children and leads to different outcomes in terms of learning.

In the next sections we describe the methodology and experimental procedure of the study; followed by a review of the results and a discussion of the main findings in context of the design process.

b) Methods and Procedure

The workshop *Children as Informants* was carried out in one day in our Full-Body Interaction laboratory. In total, 20 children from 11 to 12 years old participated. They were randomly separated into 5 groups. Each session had a duration of approximately 30 minutes. All groupings knew each other before the workshop because they came from the same school class.

For the experiment, we developed a low-tech prototype using the Wizard of Oz method; i. e. partly implemented in the programming language *Processing* and the other part directly manipulated with physical objects. Low-tech prototypes have the advantage as being rough sketches, to help the user concentrating on the main issues of the game such as interactions rather than low level issues such as colors or the appearance of the specific game elements (Wong, 1992). In our case, we used a camera to record the low-tech prototype during the manipulation process in real-time. The camera was connected to a projector projecting the final image on the floor. The dimensions of the floor projection were approximately 2 x 3 m.

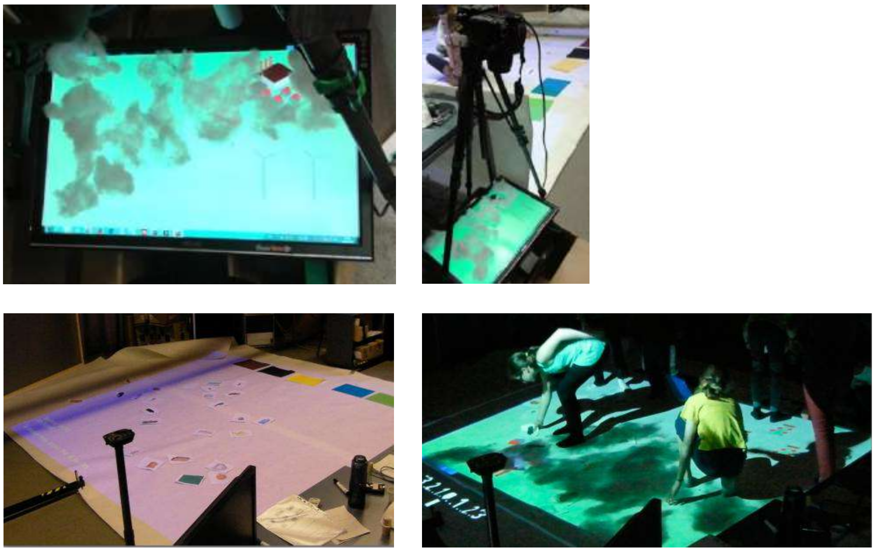

Fig. 07: ***Low-tech prototype using Wizard of Oz method.*** *A camera (top right) recorded the low-tech prototype during the manipulation process (top left). The camera was connected to a projector projecting the final image on the floor (bottom right). Paper sheets with different kind of waste was distributed over the play ground (bottom left).*

We used a between groups design, i.e. the children were divided into groups of 4 and the following two conditions were randomized: *designed actions and intuitive actions*.

C1 *designed actions:*	Children will receive explicit instructions on the physical action that they have to perform.
C2 *intuitive actions:*	Children will not receive any explicit instruction on the physical action that they have to perform.

Tab. 05: ***Instructions for conditions designed actions and intuitive actions***

C1 (designed actions)	C2 (intuitive actions)
• to make the wind power run you have to turn your arms in circles in the air • to recycle you have to pick up the waste from the ground and put it in the corresponding bin • to plant plants in the vegetable garden you have to remain still for 3 seconds in this area	• to make the wind power run you can make a movement of your choice • to recycle you have to pick up the waste from the ground and put it in the corresponding bin • to plant plants in the vegetable garden you can make a movement of your choice

The idea behind this analysis was to investigate how children understand the system. Through conducting the experiment with two different conditions, we tried to analyze if explicit instructions by researchers or rather *user generated meanings* on the physical action they performed helped to enhance better proposed learning goals. Additionally, we wanted to find out if the explicit instruction by researchers were coherent with the performed action or if there was a better solution.

Before the workshop started, the children were briefed about the session structure and the topic. To ground their expectations, we informed them that we would use a low-tech prototype (Hanna et al., 1997) and asked them to take part in the improvement process. Using role cards (see Fig. 08) we introduced the common goal and the three different interaction roles (wind power, plants and recycling) during the game to the children. We chose cards over other formats such as posters, PowerPoint presentations or handouts because consulting experts we found that the affordance of cards brought the content into the design process better than other formats (Lucero & Arrasvuori, 2010). The cards were read aloud by one child at the time. Before playing they were asked if there were any questions related to the game process. Then, the children played once. The pollution increased or decreased according to their actions. The appearance of the pollution clouds was manually manipulated applying cotton wool on the screen surface. Furthermore, the animation of the windmills was activated by keyboard command, whereas the plants were created by mouse-click at the location where children remained for at least 3 seconds.

Fig. 08: Role Cards: *plants (left), wind power (center), recycling (right)*

The assessment strategy was based on 3 main methods: Open-ended questionnaire and conceptual map after the playing sessions, semi-structured group discussion about the individual results and finally a short essay on that topic.

When the game finished, the children filled out an open-ended questionnaire about their comprehension of the played roles in relation with the common goal. Furthermore, they were asked to think individually of other possibilities, not presented in the game, to reduce the pollution. The latter question was picked up in the following semi-structured group discussion. We decided to use first individual questionnaire and then group discussions to get a diverse perspective on possible use of theoretical knowledge in designing for children and to reduce reciprocal influence. In the second trial, the game started presenting a greater amount of pollution than in the first game. Then, the participants individually filled out a conceptual map about the relationships between the different elements of the game. In a final semi-structured discussion the individual contributions were discussed and if necessary corrected. After the session, the children were brought to a different room where they finalized the last activity; children were asked to write a short essay explaining the game to a friend and describing whether they liked it or not. The aim of the last activity was to obtain additional information about their comprehension of the playing experience and identifying misconceptions. Furthermore, it allowed us to gain insights about the likeability of the game. In this activity the children were also given the opportunity to suggest design improvements for the game.

c) Evaluation Methods

The results were obtained by quantitative and qualitative analysis by video recordings of the sessions, annotations, semi-structured discussions and questionnaires and conceptual maps. In this section we present our assessment and evaluation methods of the different activities.

Quantitative Analysis

First, we conducted a qualitative analysis to identify the quality of understanding of the given answers. Thus, the open-ended questionnaire was independently evaluated by two different raters. The evaluation was carried out by a pre-established scale ranging from 0 to 3 points for each question or connection. The applied criteria were as follows:

3: correct comprehension of the relationships between elements
2: partial comprehension of the relationships between elements
1: correct idea of the element but lack of comprehension of the relationships between elements
0: misconceptions / no answer

Then, we evaluated the conceptual maps counting the number of correct answers (1 point per answer) of each child.

Both assessment methods were used to identify the difference of effectiveness of the Learning Environment or learned topics between the two conditions (designed actions vs. intuitive actions). Therefore, we compared first the individual score of the game elements (open-ended questionnaire) and the number amount of correct connections (conceptual map) between the conditions. From the open-ended questionnaire we also extracted the difference of proposed novel strategies to reduce pollution between both conditions.

Qualitative analysis

In the second study, we limited the qualitative analysis to the identification of knowledge and misconceptions related to the learned topic. Therefore, we extracted the corresponding information individually from the collected material which included an open-ended questionnaire, conceptual map and videos of group discussions. The analysis was based on the grounded theory approach dividing the transcripted material in the main categories "correct knowledge" and misconceptions and then in the subcategories air-pollution, plants, wind power and recycling. The results were compared between both conditions (designed actions vs. intuitive actions).

In addition, we gained insights about proposed novel solutions to reduce the air-pollution through the last part of the open-ended questionnaire.

By analyzing the short essay we were informed about the likeability of the game and obtained additional ideas about how the game may be improved.

The used assessment methods also provided us with information required to analyze our research question about how the users interpret the system in term of understanding of the relationships between action in the world and action in the system.

d) Results

In this section we present our results based on the described assessment and evaluation methods.

Quantitative Analysis

First, the three elements (plants, wind power recycling) of the open-ended questionnaire were tested for internal reliability using Cronbach's Alpha. The alpha coefficient for Cronbach's Alpha for the three items is .768, indicating that the items have relatively high internal consistency.

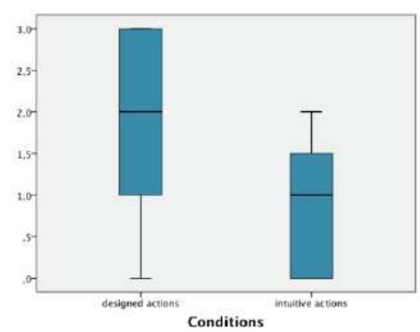

Fig. 09: *Box Plot of correct answers open-ended questionnaire related to the game topic.*

Starting with the comparison of the two conditions *designed actions* and *intuitive actions*; by performing an Independent t-test on the results of the open-ended questionnaire we identified a significant difference in the understanding of the game topic between the two conditions. Children performing under *designed actions* through the researchers (M = 1.92, SD = .966) had in total a higher score in the game than those performing by *intuitive actions* (M = .88, SD = .354), t (18) = 2.437, p = .025.

However, no significant difference was present in individual scores related to wind power, recycling and plants between the two conditions.

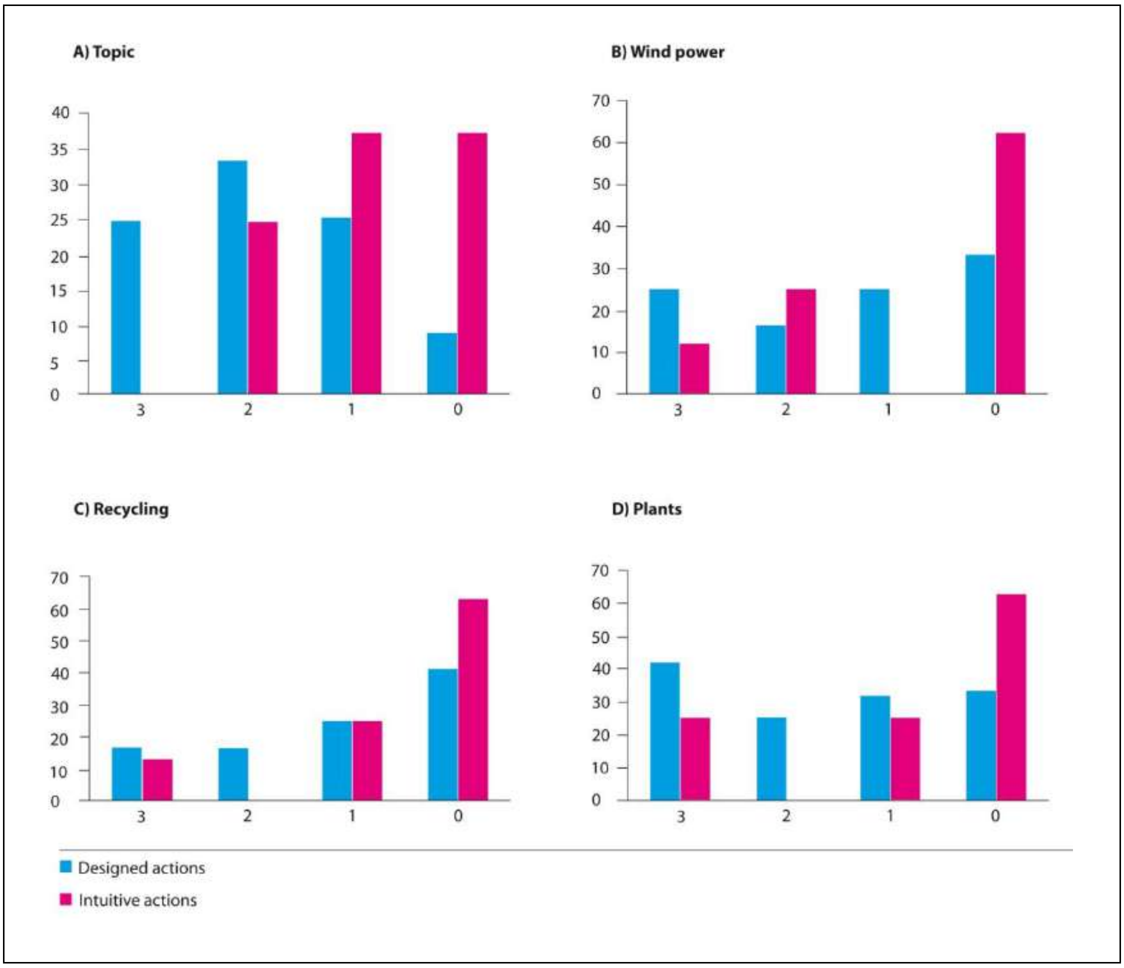

Fig. 10: Overview results of game elements between condition designed actions and condition intuitive action*. Pre-established scale ranging from 0 to 3 points for each question.*
A) Topic B) Wind Power C) Recycling D) Plants (3: correct comprehension of the relationships between elements; 2: partial comprehension of the relationships between elements; 1: correct idea of the element but lack of comprehension of the relationships between elements; 0: misconceptions / no answer)

To sum up, the general comprehension of the topic of the experience was significantly different between condition *designed actions* and condition *intuitive actions* which scores higher in the first condition. No significant difference was found in the other questions related to the game elements (wind power, recycling and plants). However, the groups assigned to condition *designed actions* showed higher scores of achievement in comparison with condition *intuitive actions*. Elements that presented the higher level of conceptual difficulties in understanding their systematic relationships with the whole system dynamics were wind power and recycling.

Due to a tendency of better scores in the overall evaluation of the open-ended questionnaire observed in condition *designed actions* (M = 6.08, SD = 3.576) in comparison with condition *intuitive actions* (M = 3.38, SD = 2.87), t (18) = 2.574, p = .91, we calculated individual achievement scores. This decision was supported by the high levels of standard deviation and the reduced sample size, which made it difficult to generalize the obtained results.

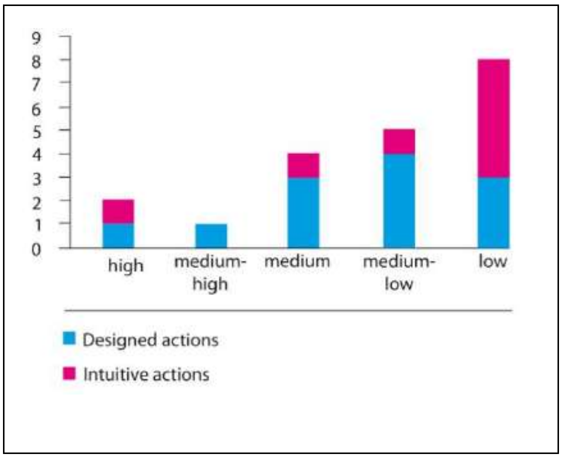

Fig. 11: Five levels of questionnaires answers between the condition designed actions and condition intuitive actions: *high (9 points), medium-high (7 - 8 points), medium (5 - 6 points), medium low (3 - 4 points) and low (0 - 2 points).*

From the high proportion of children included in the lower range, we conclude that is necessary to implement a design strategy aimed at improving the understanding of the systematic relationships between elements.

The last question of the open-ended questionnaire was aimed to give insights about children's knowledge about which other strategies the children knew to reduce the air-pollution. Children assigned to condition *designed actions* (M = .83, SD = .718) proposed significantly more novel strategies than children assigned to condition 2 *intuitive action* (M = .13, SD = .354), t (18) = 2.574, p = .19.

Results obtained by the conceptual map showed that children had an average of 4.2 over 8 possible correct connections (SD = 1.36). No significant difference was presented between the two conditions.

Qualitative Analysis

According to the misconceptions we found out that 9 children did not answer or reported misconception related to wind power (*designed actions*: 4; *intuitive actions*: 5). Main misconceptions were related to the idea that the movement of the windmill "blows" away pollution. Such misconception can be related to the fact that pollution reduces when they activate the windmill and it could give the impression of being "pushed away" by the windmill force.

In relation with recycling we also identified several misconceptions. First, 10 children did not answer or reported misconceptions related this topic (*designed actions*: 5; *intuitive actions*: 5). Main misconceptions were related to picking up waste in order to create more space and with an erroneous connection with carbon dioxide. These misconceptions can be related to the fact that waste was scattered in the floor and occupy a huge amount of space. Secondly, we found in the final evaluation that 4 children related the game only to recycling (*designed actions*: 1; *intuitive actions*: 3). This result was confirmed by observations we made while playing. The children were mainly focused on picking up the waste from the floor. These findings are coherent with the results of our first exploratory study where the knowledge of the children about environmental education referred basically to recycling.

Finally, we identified that 10 children did not answer or reported misconceptions related to plants (*designed actions*: 4; *intuitive actions*: 4). Main misconceptions were related to a lack of understanding of the process of photosynthesis and its relationship with reduction of carbon dioxide through absorption by plants. At the same time, no child mentioned the environmental benefits of local production. 2 children reported planting of local vegetables as replacement for cooking.

The main findings about novel strategies to reduce the air-pollution was to include renewable energies in the game (solar energy, hydraulic energy), reducing consumption of unnecessary things, reducing industries, reducing the use of petroleum, reducing the use of nuclear energy and using electric cars.

Results of the conceptual map confirmed that children had misconceptions related to compost and plants. Other children had problems in understanding indirect relationships such as wind power and air-pollution.

Finally, we analyzed the likeability of the proposed game. 14 out of 20 children reported in the essay that they enjoyed the game saying that it was “cool, funny or enjoyable”. One of the children described it as “a good source of information”. Only 2 of them reported that they did not like it because of the topic.

In relation with possible changes several children commented that they would like more movement and interaction. At the same time 2 children reported that the interaction related to planting plants was “strange” and they would change it.

According to our research question of how the user interprets the system we found an interesting comment evaluating the open-ended questionnaire. One child described that “to make the windmills work, you need to move the arms in circles”. S/he related this gesture with the movements of the mills provoking wind with the velocity of his/her own arms (sense-making of gestures).

The obtained results and new idea proposed by the children were introduced in the development of the second prototype. In the discussion we give detailed information about the required changes.

e) Discussion

Based on our results, we identified useful aspects to be taken into account for the development of the second prototype and adapted assessment methods if necessary.

Concerning certain design solutions, we changed those game elements provoking misconceptions such as the visualization of the air-pollution. For the first prototype, we manipulated cotton wool manually added to the digital model. Due to the misconception related to the wind power where the children believed that the windmills “pushed” the air-pollution away, we decided to integrate the manipulation of the pollution clouds directly into the digital model. Furthermore, we improved the explanation in the role cards to give the children a clear idea of the relationship between wind power and pollution.

Moreover, we realized that we had to change the distribution of the waste to overcome misconceptions related to recycling where the children believe that the recycling had to be done to create more space on the floor projection instead of relating it to pollution reduction. At the same time, we had to tackle the problem that the children concentrated during the game too much only on recycling neglecting other tasks of the game. We hoped through a change of the distribution of the waste within the floor projection to divert their concentration partly from the recycling role.

Another issue was the demand of the children to change the interaction of the plants. In the *intuitive design* condition, we observed that some children started to “rub” the floor with one hand to create plants. We considered this interaction as a natural gesture. It seemed that they tried to imitate “digging in the earth” in a vegetable garden. Through the change of the gesture we also intended to eliminate misconceptions such as planting of local vegetables as replacement for cooking.

Since the children in general asked for more interaction in the game play, we decided to introduce one of the novel strategies proposed by the children, such as a water power station.

Finally, we examined during the evaluation process that conceptual maps as assessment methods were very effective. However, we realized that we had to improve the visualization of the elements. That means the elements had to be equally presented and no element should seem more important than the other. Moreover, it was indispensable to insist on written explanation of the relationships between the answers to be able to evaluate its validity.

With the described constraint in account, we developed a second design iteration. In the next chapter we present how this prototype was improved and tested. Then, we review the effectiveness of our novel design solutions based on the second workshop.

2.3 Workshop Part 3: Children as Testers

For the study *Children as Testers* we improved the first iteration of the design related to the system based on our results from the previous workshop. The research goals of the study were to assess whether the game was effective for the set of learning goals and to evaluate if the use of specific gestures can enhance learning. In the next sections, we present the improvements of the second prototype and the different steps of the design process of the workshop.

a) Improvements of the design

Due to our findings in the study *Children as Informants*, we were able to produce a second prototype. For the experiment we improved the design of the previous study in the following aspects. Firstly, we changed the visualization of the air-pollution. It was digitally integrated in the *Processing* sketch and changed dynamically according to the amount of presented plants or activation of the alternative energies. Additionally, it could be manipulated by keyboard comments. Secondly, we introduced one more role, a water power station, because the children of the previous study asked for more interaction within the game. Thirdly, we changed the location of the waste and placed it only in one specific corner instead of distributing it all over the play ground. Due to observations of the previous study, the aim was to prevent the children focusing more on this task than on other game roles and to avoid misconceptions related this topic. Lastly, we changed the gesture for the plants to touching or "rubbing" the floor. This change was necessary because the designed action in the previous study consisting of remaining still for three seconds led to misconception and was disliked by some children.

The first research goal of the second design iteration was to assess the game effectiveness towards the set of learning goals. Therefore, we explored the children's understanding of the topic and system. We focused on the following research question:

***RQ** Interpretation:* How does the user interpret the system?

Furthermore, we were interested again in the exploration of the role of physical activity. Thus, we assigned the participants randomly to two different conditions: *designed actions vs. designed actions including specific gestures.* The first condition consisted of instructed *designed actions* through the researchers (see Tab. 06), e.g. we asked the children to move their arms in circles to create wind power. In the second condition we used *designed actions including specific gestures* to simulate the connection between the different elements, i.e. make a connection between the power station and the windmill to understand that increased windmill action leads to a reduced need for electricity from the power station.

In this context can be applied the following hypothesis:

***H** designed actions vs. designed actions including specific gestures:*
The design of different kinds of action evokes different interpretations in children and leads to different outcomes in terms of learning.

Then, we had the research goal of testing the effectiveness of the second design iteration. Hence, we conducted two different experiments. The first group of children was exposed to the Full-Body Interaction Learning Environment. Game instructions were mainly introduced by using role cards where each role of the participant and its relation to the common goal and other game elements was defined. In the second group we used a traditional Learning Environment, i.e. only the effectiveness of the role cards in relation with the learning goal were evaluated. Finally, the effectiveness of both groups was compared.

In this context the following hypothesis can be applied:

***H** Effectiveness:* The use of a Full-Body Interaction Learning Environment as learning method facilitates the children to enhance the learning goals better than traditional Learning Environments such as readings.

In the next sections we describe the methodology and experimental procedure of the study. This is followed by a review of the results and a discussion of the main findings in the context of the design process.

b) Methods and Procedure

The experiment consisted of two different testing groups:

1. Testing of the effectiveness of the Full-Body Interaction Learning Environment
2. Testing of the effectiveness of a traditional Learning Environment

In the next section we will present in detail the methods and procedures of the two testing groups.

Testing of the prototype

The first workshop was carried out at one day in our Full-Body Interaction laboratory. Among the participants (*N* = 24), 11 were female and 13 were male (age: *M* = 11.52, *SD* = .12). They were randomly assigned to 6 groups. Each session had a duration of approximately 35 minutes. All groupings knew each other before the workshop because they came from the same school class.

For the experiment we improved the low-tech prototype of the previous study (see previous section about “improvements of the design”). The prototype was again conducted by using the Wizard of Oz method. In general, the setup of the experiment was less complex, i.e. the computer screen was directly connected to the projector. We introduced a start button so that we were able to explain to the children the setup and the roles before the simulation of the air-pollution was activated. The game stopped automatically after 6 minutes with a sign indicating the end of the game. The dimensions of the floor projection were approximately 2 x 3 m.

Fig. 12: Game Setup: *Low-tech prototype (left), floor projection (right)*

We used a between groups design, i.e. the children were divided into groups of 4 and the following two conditions were randomized: *designed actions* and *designed actions including specific gestures.*

C1: designed actions: Children will receive explicit instructions about the physical action that they have to perform.

C2: design actions + specific gestures: Children will receive explicit instructions about the physical action that they have to perform. Additionally, they are asked to make connections between the different game elements when necessary.

Tab. 06: Instructions for conditions designed actions and designed actions including specific connection gestures

C1 (designed actions)	C2 (designed actions + specific gestures)
• to make the wind power run you have to turn your arms in circles in the air • to make the water power station run you have to turn your arms in circles on the ground • to recycle you have to pick up the waste from the ground and put it in the corresponding bin • to plant plants in the vegetable garden you have to touch the ground as if you were digging in the earth	• to make the wind power run you have to turn your arms in circles in the air • to make the water power station run you have to turn your arms in circles on the ground • to recycle you have to pick up the waste from the ground and put it in the corresponding bin • to plant plants in the vegetable garden you have to touch the ground as if you were digging in the earth • to make the electricity of the wind and water power station arrive at the city, you need to connect the mills with the houses. You make the connection by holding hands. The same way, when you have good compost in the organic bin, you need to bring it to the plants.

The idea behind this analysis was to investigate if the gesture of making connections as metaphor (Antle et al., 2013) helps to enhance the learning experience of the Full-Body Interaction Learning Environment and leads to better understanding of the relationships between the elements.

Fig. 13: Additional role card: water power station

Before the work started, the children were explained the session structure and the topic. To ground their expectations, we informed them that we would use a low-tech prototype (Hanna et al., 1997) and asked them to take part in the improvement process. Using role cards (see Fig. 13) adapted to observations during the previous study, we introduced the common goal and the four different interaction roles (wind power, water power station, plants and recycling) to the children during the game. The cards were read aloud by one child at the time. Before playing they were asked if there were any questions related to the game process. Then, the children played once. The air-pollution increased or decreased according to their actions.

The assessment strategy was based on 3 main methods: conceptual map, semi-structured group discussion and open-ended questionnaire. Before the workshop the children filled out individually a conceptional map to evaluate their previous knowledge related to the topic and their comprehension of the relationships between the different elements. On the assessment sheet all game elements were equally represented (see Fig. 14). Besides the water power station we decided to include the city as new element. In the previous study many children related the steam power station directly to the city. Separating these two elements allowed us to obtain more accurate results related to the connection between the elements. The participants were asked to draw connections and to give explicit explanations of the relationships between the connected elements. After the game, this process was repeated with a new sheet of the same conceptual map. Then, in a semi-structured discussion the individual contributions were discussed and if necessary corrected. We decided to use individual questionnaires first and then group discussions to get a diverse perspective on possible use of theoretical knowledge in designing for children and to reduce reciprocal influence. Then, the children filled out individually an open-ended questionnaire about their comprehension of the played roles in the context of the common goal. The last question asked about comprehension of the learning goals of the game.

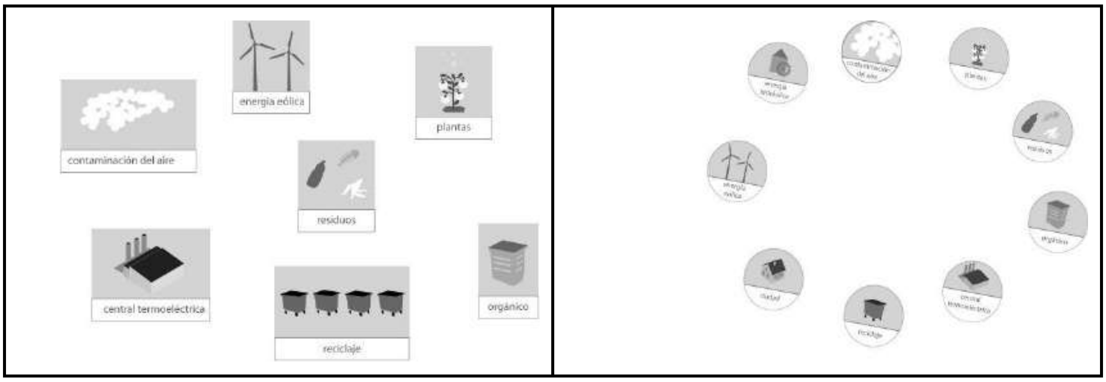

Fig. 14: Presentation elements in conceptual map: *Workshop 2 (left); Workshop 3 elements are equally presented (right)*

Control group: Traditional Learning Environment

The second experiment was carried out at one day in a primary school in Barcelona. Among the participants (N = 24), 14 were female and 9 were male, the information about the gender of one child is missing (age: M = 10.79, SD = .41). They were randomly assigned to 6 groups. Each session in total had a duration of approximately 35 minutes. All groupings knew each other before the workshop because they came from the same school class.

The assessment strategy was only based on the conceptual map method. Before the workshop the children filled out individually a conceptional map to evaluate their previous knowledge related to the topic and their comprehension of the relationships between the different elements. On the assessment sheet all game elements equally were represented. The participants were asked to draw connections and to give explicit explanations of the relationships between the connected elements. Then, the children were divided into groups of 4 and brought to a separate room where each of the children was asked to read out aloud one of the role cards. This procedure was carried out with several groups at the same time, each group supervised by a different researcher. After the readings the children were bought back to the class room and the school teacher distracted the children for around 10 minutes with a different activity. Then, the assessment was repeated with a new sheet of the same conceptual map.

c) Evaluation Methods

The results were obtained by quantitative and qualitative analysis by video recordings of the session, annotations, semi-structured discussions and open-ended questionnaires and conceptual maps. In this section we present our assessment and evaluation methods for the different activities.

Quantitative Analysis

To evaluate the effectiveness of the Full-Body Learning Environment, we analyzed the pre- and post-test of the conceptual map identifying previous and new knowledge. Therefore, we divided the obtained connections into four main categories and several subcategories which were graded according to their relevance to the Learning Environment from 0 to 2 points (compare Tab. 07). In the case of the alternative energy, if only one of both was mentioned, we gave only half of the points. The categories were extracted by a previous analysis of the most common answers of the children. Finally, all answers could be classified into these categories. The results were again Independently evaluated by two different raters. In the next step, the results were compared and discussed until a common agreement could be established.

Tab. 07: Categories of evaluation of connections using conceptual map

	Points
Air-pollution	
The steam power station contaminates	1
The city contaminates	1
The steam power station produces energy for the city	1
The air-pollution affects the plants	2
Energies	
Both are energies	0,5
Both are not contamination / ecological energies	1
Both use natural resourses	1
Both produce energy for the city / replace steam power station.	2
Both improve the environment.	1
Recycling	
Waste has to be recycled	0,5
Recycling helps nature.	1
The city produces waste.	1
Recycling decreases air-pollution.	2
Organic waste is useful to make compost.	2
Plants	
Plants clean the air.	2
Plants need compost to grow.	1

The results obtained pre- and post-test were first analyzed within groups to evaluate whether there was a learning gain through the proposed Learning Environments. Then, we compared the results of the post-test between the groups assessed in the Full-Body Interaction Learning Environment and those children who were only provided with the reading activity of role cards (Traditional Learning Environment). The idea behind this method was to evaluate the effectiveness of the Full-Body Interaction Learning Environment.

Then, we evaluated the open-ended questionnaire by classifying the children's answers into different categories (Tab. 08) and ranking from 0 points (wrong answer or misconception) to 1 point (correct answer).

Tab. 08: Categories of evaluation of playing experience and misconceptions *(open-ended questionnaire).*

wind power	water power	recycling	plants
reduction of pollution	reduction of pollution	reduction of pollution	reduction of pollution
"clean" energy	"clean" energy	contribution creating compost	Absorption of CO2 by photosynthesis
Replaces steam power station	Replaces steam power station		

The obtained results were compared with those of the study *Children as Informants*.

To evaluate the possible differences between the two conditions (designed actions vs. designed actions + connections) during the assessment of the Full-Body Interaction Learning Environment, we compared the number of connections of the post-test (conceptual map), the relevance of the learned topic and the quality of understanding (open-ended questionnaire) between the two conditions.

Qualitative Analysis

In the third study, we limited the qualitative analysis to the identification of new knowledge and misconceptions related to the learned topic. Therefore, we extracted the corresponding information individually from the collected material such as the open-ended questionnaire, conceptual map and group discussions.

In the case of the Full-Body Interaction Learning Environment, we evaluated the pre- and post-test of the conceptual map according to new knowledge, solved and unsolved misconceptions and possible newly created misconceptions. Furthermore, we compared the differences of learned topics between pre- and post-test. To identify this information, based on the grounded theory approach, we classified the children's answers in five relevant game connections:

1. plants – compost
2. wind – water power
3. steam power station – air-pollution
4. air-pollution – plants
5. contamination – waste

Then, we also plotted the answers of the open-ended questionnaire in new knowledge and misconceptions.

In the next section we present our results based on the described assessment and evaluation methods.

d) Results

Quantitative Analysis

The conceptual map gave us insights about the children's comprehension of the game elements and their connections between each other. By conducting a pre- and post-test we were able to evaluate the effectiveness as Learning Environment of the two proposed activities. Thus, we started our evaluation with the comparison of pre- and post-test within the two different Learning Environments. By conducting a Paired Sample t-test we found a significant difference in the number of correct connections within the two Learning Environments. Children (M = -1.979, SD = 2.219) in the pre-test of the Full-Body Interaction Learning Environment reported fewer connections than children in the post-test, t (23) = -4.370 p < .001. Children (M = -0.937, SD = 2.008) in the pre-test of the reading activity reported fewer connections than children in the post-test, t (23) = -2.287, p = .032. Therefore, we conclude that in both cases a learning gain between pre- and post-test was obtained.

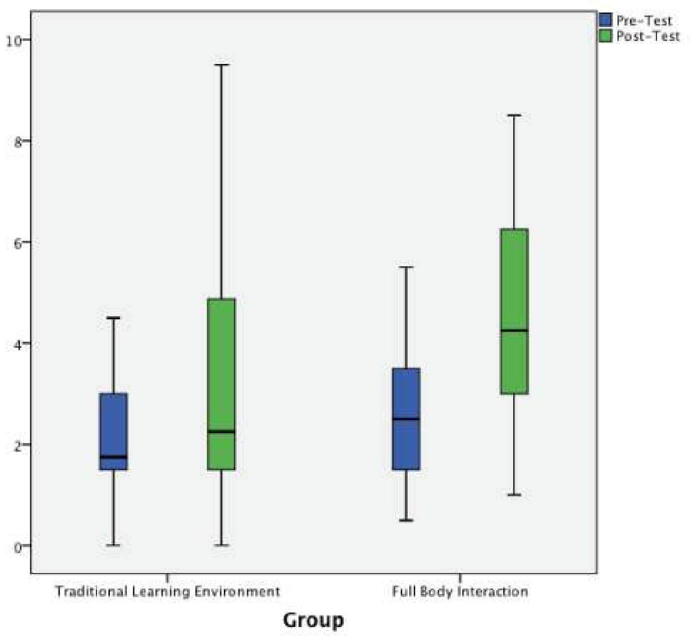

Fig. 15: Box plot comparing pre- and post-test of different groups *(Full-Body Interaction Learning Environment vs. Traditional Learning Environment.*

Then, we compared the post-test of the Full-Body Interaction Learning Environment with the number of correct answers in the experiment where only the reading of role cards was used (Traditional Learning Environment). We did the same with the pre-test between Full-Body Interaction Learning Environment and Traditional Learning Environment in order to avoid biases relating to pre-existing group differences. By conducting an Independent t-test we found a significant difference in the number of correct connections between the two Learning Environments. Children (M = 4.479, SD = 2.285) of the Full-Body Interaction Learning Environment reported a significantly greater amount of connections than children assessed by the role card reading (M = 3.094, SD = 1.980), t (46) = -2.244, p = .03. We conclude that the Full-Body Interaction Learning Environment in combination with the reading activity is more effective than the experiment's Traditional Learning Environment consisting only of the reading activity.

Comparing the results of the open-questionnaire between the studies *Children as Informants* and *Children as Testers* showed no significant differences between the main categories (wind and water power, recycling and plants) and the subcategories of the comprehension level of each game element.

Comparing the two conditions (*designed actions* vs. *designed actions including specific gestures*) we were found no significant differences relating to the correct connections, quality of the answers and learned topic.

Qualitative Analysis

A qualitative analysis of the connections in pre- and post-test related to new knowledge showed improvements in particular in the connections between compost – plants and wind – water power (see Fig. 15). Through this method we were also able to extract solved, unsolved and new misconceptions between pre- and post-test of children assessed in the Full-Body Interaction Learning Environment. The misconceptions were related to the connection of wind and water power to other game elements such as the steam power station (more details, see Tab. 09).

Tab. 09: Results of misconceptions extracted by evaluating connections of conceptual map

Solved misconception	**Unsolved misconception**	**New misconceptions**
better understanding of wind/water energy	lack of understanding of wind/water energy	• the renewable energies contaminate in the same ways as the steam power station • the steam power station works with the energy of wind or water power
3	**2**	**2**

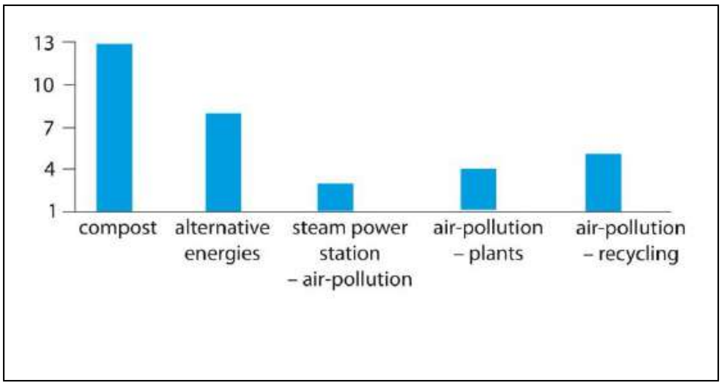

Fig. 16: Overall results of learned topics extracted by quantitative analysis by evaluating connections of conceptual map

Through results obtained by the open-ended questionnaire, misconceptions relating to the different game elements were examined. We detected a noteworthy change of misconceptions between both workshops. The misconception related to the plants and recycling could be eliminated (compare Tab. 10). Furthermore, we observed that the children focused less on the recycling action than in the previous workshop. But the comprehension about the mechanism and role of wind power was still not clear. Moreover, a new misconception relating to the water power station was created. 6 children believed that it cleaned or contaminated water. We assume that they confused the water power station with a water works.

Tab. 10: Evaluation of misconceptions extracted from open-ended questionnaire

	Part 1	**Nº**	**Part 2**	**Nº**
Wind power	The created air pushes the pollution away	3	cleans the air	3
Recycling	Make more space for the plants	1	–	–
Plants	No cooking necessary	2	–	–
Water power	–	–	cleans / contaminates water	6

e) Discussion

To sum up, the results of the second prototype indicated that there has been a significant difference in learning between the Full-Body Interaction Environment and the Traditional Learning Environment. In detail, we conclude that the Full-Body Interaction Learning Environment in combination with the reading activity is more effective than the proposed Traditional Learning Environment consisting only of the reading activity.

Furthermore, the design improvements between the first and the second prototype facilitated to solve misconceptions related to plants and recycling. However, there still remain misconceptions related to the water power station. Additionally, we created new misconceptions by adding the water power station as a new element in the Full-Body Interaction Learning Environment. In this context, we would like to stress that in particular the qualitative analysis has been very useful to detect new knowledge and misconceptions and helped us to improve the guidelines for the game design.

Finally, between the conditions *designed actions* and *designed actions including specific gestures* we did not find any significant differences in terms of learning. Due to the reduced sample size (12 children per condition), we assume that that this topic may require further investigation.

3. FINAL DESIGN PROPOSAL

In this chapter we would like to present a final design proposal taking into account our observations during the previous studies and the detected shortcomings in the second prototype.

a) Improvements of the design

For the final design proposal we suggest the following design improvements:

Fig. 17: Final Design Proposal: *1. Removed water power station; 2. Visual separation between city and steam power station; 3. Markers giving feedback about processes in eco-system; 4. Concrete visualizations such as consumption of the city (e.g. lights)*

Firstly, the water power station as game element should be removed. The reason for this decision is that in the study *Children as Informants*, the subjects had asked for more interaction. Thus, we introduced the water power station as second renewable energy in the game design. But the results of the study *Children as Testers* showed new misconceptions related to this game element.

Secondly, we recommend separating the city visually from the steam power station. During the participatory workshops, many children seemed to have problems to distinguish these two elements from each other.

Thirdly, it is necessary to introduce markers indicating, e.g. production or reduction of the air-pollution, energy replacement of the steam power station by hydraulic energy or the quality of the compost. The introduction of marker gives a concrete overview of the different processes of the eco-system. This experience may be enhanced by concrete visualizations in the game design, i.e. the consumption of the city by showing active lights in houses or streets. Another possible visualization could be the number of circulating vehicles in the streets as indicator of air-pollution caused by the city.

In relation with the connection gesture between the game elements, it would be important to provide concrete indication when such a connection, e.g. between the plants and the compost, is required. This could be done by audio feedback or specific markers.

In general, we propose that the introduction of markers, concrete visualizations and/or connection gestures in the game design will help to solve remaining misconceptions related to the wind power station.

For our experiments we used low-tech prototypes through the Wizard of Oz method. Therefore, we present in the following section technical requirements for the development of a high-tech prototype of the Full-Body Interaction Learning Environment.

b) Technical Requirements

To implement the system into a high-tech prototype we suggest the following requirements. Firstly, the interaction of the plants will be implemented in OpenFrame works and Kinect system supporting skeletal tracking (1). This way we can detect specific gestures such as children touching the floor in order to generate plants. Secondly, for the recycling mechanism, the children use a broom covered with a reflecting material. Movement and position of the broom will be detected by an Artificial Visual System based on infrared camera (2). Finally, to implement the interaction of the wind energy we will use physical wheels which have to be turned manually by the user (3). The amount of energy is controlled by a gyroscope sensor connected to an Arduino.

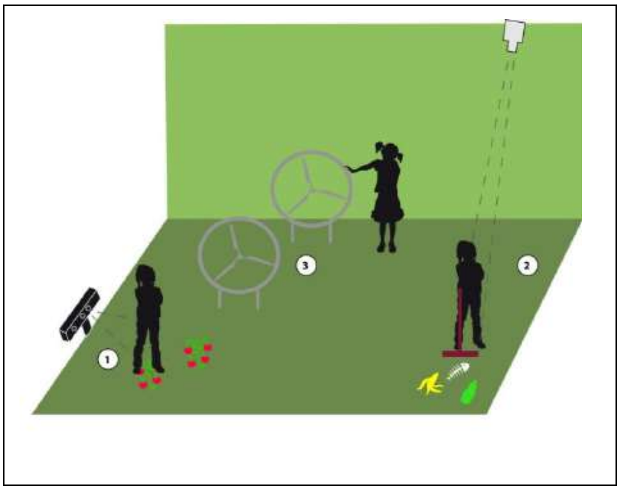

Fig. 18: Setup of technical system. *Skeletal tracking of interaction of the plants is supported by a kinect system (1). For the recycling, movement and position of the broom is detected by an Artificial Visual System based on infrared camera (2). Movement of physical wheels connected to a gyroscope sensor controlled by an Arduino simulates the wind energy (3).*

4. CONCLUSION AND FUTURE WORK

In this master thesis project we have presented a Participatory Design study aimed towards including children in the design of an Interactive Learning Environment based on Full-Body Interaction. We explored how users' contributions can be integrated in the design of Full-Body Interaction Learning Environments (see Fig. 18). Therefore, we proposed a method focusing on the analysis of core meanings and misconceptions by incorporating the user directly in the design process through Participatory Design sessions.

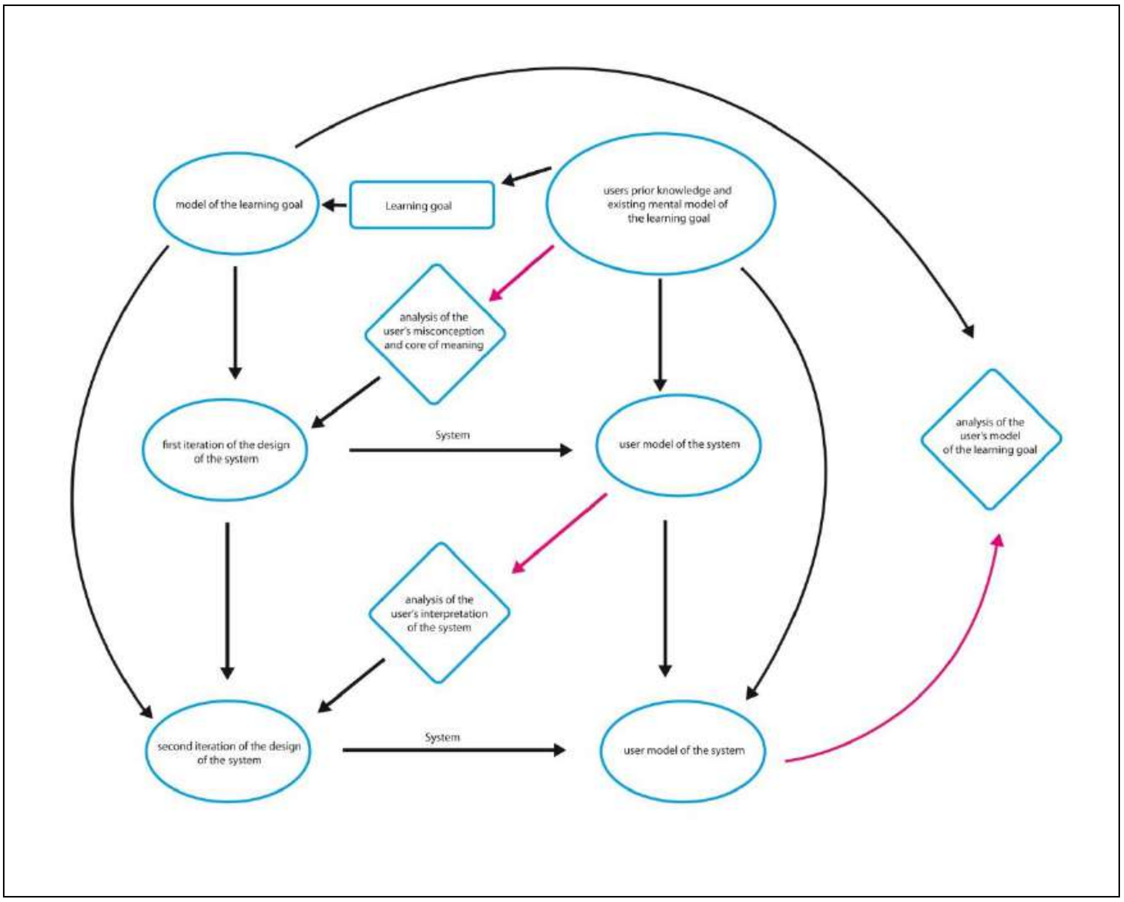

Fig. 19: Schema of integration of users' contributions in the design of Full-Body Interaction Learning Environments

The study was conducted over three Participatory Design workshops: The procedure structure was as follows:

a) *Exploratory Study*
   Definition of the educational needs:
   analyzing previous knowledge and misconceptions

b) *Children as Informants*
   First design iteration: analyzing the interpretation

c) *Children as Testers*
   Second design iteration:
   analyzing the effectiveness in term of learning gain

d) *Final design proposal*
   Third design iteration: design proposal

To sum up, our procedure guaranteed us a fluid design process. Our first prototype was developed according to findings of the *Exploratory Study*. In detail, the process helped us to create bridges between the previous knowledge and mental models of the children as starting point (Rogoff, 1990) for the first iteration of a prototype.

Our results in the first and second design iteration help us to improve the Learning Environment. Finally, since the children still reported misconceptions in the second prototype, we suggest additional improvements for the final design proposal, such as the inclusion of visual aids to provide better feedback and overview of the processes of the proposed eco-system.

This project confirms the necessity of the incorporation of Participatory Design methods in the design process with children (Dindler & Iversen, 2007; Druin, 2002; Nesset & Large, 2004). Moreover, it gives a new approach in terms of combining Participatory Design methods and formative assessment strategies. By identifying previous knowledge and misconceptions related to the learning goals, these strategies facilitate to improve design and evaluation of Full-Body Interaction Learning Environments.

However, the results of the *Exploratory Study* showed that bodily-based training did not facilitate the design of games which are more suitable for the features of Full-Body Interaction. According to these findings, further research is necessary in order to explore how to adapt Participatory Design methods for Full-Body Interaction.

In general, we hypothesized that the use of the presented method would guarantee the effectiveness of the Full-Body Interaction Learning Environment in terms of learning gains. This assumption could be confirmed by obtained results comparing the effectiveness between a Traditional Learning Environment and our proposal based on Full-Body Interaction. We conclude that our methods to improve the design and evaluation of Full-Body Interaction Learning Environments are going in the right direction and helped us to formulate successful design guidelines for a novel design proposal. On the other hand, further research is necessary to deepen in the strategies for properly adaption of Participatory Design methods for Full-Body Interaction.

One entry path could be to explore more the role of physical interaction of the user with the system. The approach in our study was based on research of Ishii & Ullmer (1997) regarding tangible interface suggesting that the information has to be embedded in the control with the system. We extended this idea to incorporate user meanings such as learning goals directly to the physical actions of Full-Body Interaction Learning Environments. Therefore, we explored the effectiveness of different kind of actions such as *intuitive actions*, *designed actions* and *designed* *actions including specific gestures.* Our study *Children as Informants* showed that *designed actions* helped the children to interpret the system of our Learning Environment more easily. These findings are consistent with the research of Antle (2009) criticizing the intuitive approach. She stresses that users are not aware of how the system works and therefore show a lack of intuitiveness (May & Antle, 2014). As we did not find any significant differences in learning between the two conditions *designed actions* and *designed actions including specific gestures* conducted in the study *Children as Testers*, we suggest for future work further inquiry in relation to this topic.

Additionally, it would be interesting to change the order of the experiment in the last study *Children as Testers*, i.e. first to play the game and then to read the role cards and to see if there are any differences in the learning gain between the two Learning Environments.

Finally, in relation with visual aids of the final prototype, we would like to connect with the idea of the project SMART CITIZEN (http://www.smartcitizen.me/). The project generates participatory processes of different people all over the world. In detail, that means by uploading real-time data about their cities such as temperature, humidity or pollution, the user share information about local environmental process. We would like to use this real-time data by connecting it to the game according to the user's home town. This focus would help to increase the motivation and engagement of the user by providing a personalized context-rich game experience.

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Appendix

Fig. 01: Workshop Part 1: Exploratory Study | Letter narrative inquiry

Hola a tod@s:

Soy Ted. Os escribo desde el año 2114. Vivo en Thneed-Ville, una ciudad que, aparte de sus ciudadanos, es totalmente artificial: Todo está hecho de plástico, metal o materiales sintéticos.

Hace poco, logré plantar un árbol verdadero y el bosque de Truffula está empezando a recuperarse poco a poco. Pero quedan muchas otras cosas que mejorar. El medio ambiente alrededor de la ciudad está bastante dañado. Las causas empezaron hace más de 100 años. Para algunas cosas ya es demasiado tarde, por ejemplo la situación de vuestro mundo actual llevó a la extinción de muchas especies de animales y plantas. Ahí, en vuestro tiempo, yo no puedo hacer nada.

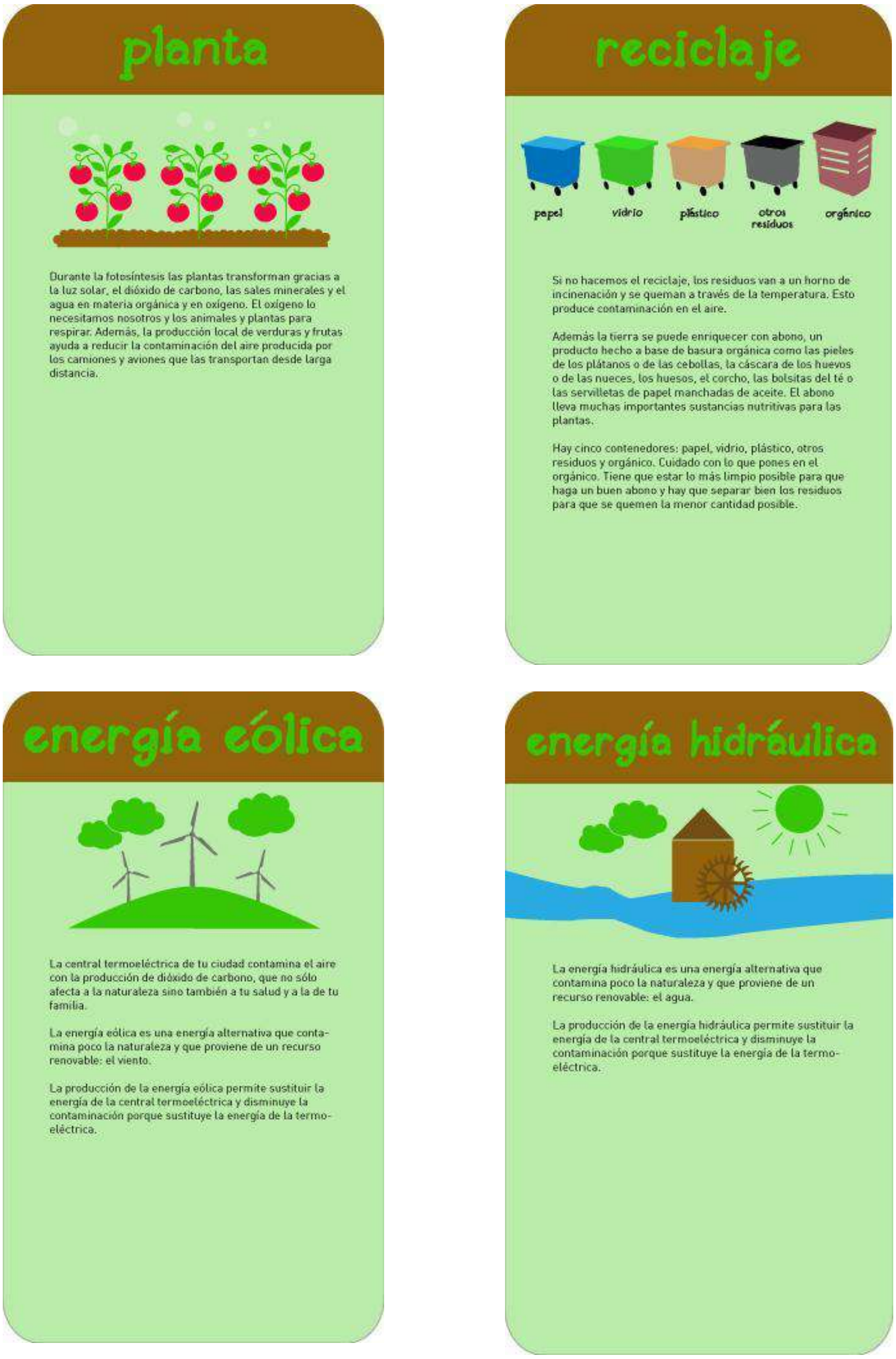
Por eso os pido ayuda. Tenéis que cuidar y salvar al medio ambiente. Tod@s somos responsables.

Para empezar, debéis pensar en más problemas del medio ambiente. Y el siguiente paso sería pensar en como se podría mejorar la situación y que acciones evitar para salvar el medio ambiente. He pensado que una buena idea sería inventar un juego para que todo el mundo entienda como se puede ayudar el medio ambiente: de esta manera la gente se divertirá aprendiendo a ayudar vuestro entorno!

Muchas gracias por vuestro apoyo.

Vuestro Ted

Fig. 02: Role cards for workshops *Children as Informants* and *Children as Testers*



Tab. 01: Workshop Part 1: *Exploratory Study* | Testing internal reliability using Cronbach's Alpha (elements: plants, wind power, recycling)

Alfa of Cronbach	N of Elements
.768	3

Tab. 02: Workshop Part 1: *Exploratory Study* | Correlation questionnaire rating (1 - 10) with questionnaire verbal rating (1 - 5).

		Rating (1 - 10)	Rating (1 - 5)
Rating (1 - 10)	**Correlation Pearson**	1	.572
	Sig. (bilateral)		.000
	N	41	41
Rating (1 - 5)	**Correlation Pearson**	.572	1
	Sig. (bilateral)	.000	
	N	41	41

Tab. 03: Workshop Part 1: *Exploratory Study* | Group statistics before elimination of outliers. We can observe a high standard deviation in the 4th group.

Group	Mean	N	Std. Deviation
1.00	9.5000	8	1.06904
2.00	7.3333	12	3.77391
3.00	7.6667	12	2.60038
4.00	5.7500	8	4.80327
5.00	8.7545	11	1.59710
8.00	8.0938	8	3.54042
9.00	7.0429	14	3.02851
Total	7.6938	73	3.14138

Tab. 04: Workshop Part 1: *Exploratory Study* | Group statistics between conditions (bodily-based vs. verbal-based training) questionnaire rating.

Condition	N	Mean	Std. Deviation
Bodily-based training	40	8.75	1.554
Verbal-based training	28	7.10	3.986

Tab. 05: Workshop Part 1: *Exploratory Study* | Independent t-test between conditions (bodily-based vs. verbal-based) questionnaire rating.

	t-test for Equality of Means						
	t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
						Lower	**Upper**
Equal variances assumed	2.377	66	.020	1.649	.694	.264	3.034
Equal variances not assumed	2.081	32.794	.045	1.649	.792	.037	3.262

Tab. 06: Workshop Part 1: *Exploratory Study* | Paired Sample t-test on questionnaire rating between groups, divided in condition bodily-based and verbal-based training.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Condition 1								
Group 1+3	.88750	2.01809	.71350	-.79966	2.57466	1.244	7	.254
Group 1+5	1.21250	2.39669	.84736	-.79118	3.21618	1.431	7	.196
Group 1+9	1.55000	2.31887	.81984	-.38862	3.48862	1.891	7	.101
Group 3+5	-.03000	2.25773	.71396	-1.64508	1.58508	-.042	9	.967
Group 3+9	.44000	2.90706	.91929	-1.63959	2.51959	.479	9	.644
Group 5+9	.42727	1.99554	.60168	-.91335	1.76790	.710	10	.494
Condition 2								
Group 2+4	2.37500	5.52753	1.95428	-2.24613	6.99613	1.215	7	.264
Group 2+8	.03125	5.72968	2.02575	-4.75888	4.82138	.015	7	.988
Group 4+8	-2.34375	4.12080	1.45692	-5.78883	1.10133	-1.609	7	.152

Tab. 07: Workshop Part 1: *Exploratory Study* | Results Research Question of which of the two methods (verbal-based vs. bodily-based training) facilitate children thinking about bodily-based games?

	Average
Mann-Whitney U	79.500
Wilcoxon W	145.500
Z	-.157
Asymp. Sig. (2-tailed)	.875

Tab. 08: Workshop Part 1: *Exploratory Study* | Results regarding if previous experience or contact with Full-Body Learning Environments facilitates children thinking about bodily-based games

	Average
Mann-Whitney U	27.000
Wilcoxon W	42.000
Z	-.929
Asymp. Sig. (2-tailed)	.353

Tab. 09: Workshop Part 2: *Children as Informants* | Group statistics Independent t-test on the open-ended questionnaire between conditions *designed actions* and *intuitive actions*

Type of answer	N	Mean	Std. Deviation	Std. Error Mean
Condition 1				
Topic	12	1.92	.996	.288
Wind Power	12	1.33	1.231	.355
Recycling	12	1.08	1.165	.336
Plants	12	1.75	1.357	.392
In total	12	6.08	3.579	1.033
Number of new strategies	12	.83	.718	.207
Condition 2				
Topic	8	.88	.835	.295
Wind Power	8	.88	1.246	.441
Recycling	8	.63	1.061	.375
Plants	8	1.00	1.309	.463
In total	8	3.38	2.875	1.017
Number of new strategies	8	.13	.354	.125

Tab. 10: Workshop Part 2*: Children as Informants* | Independent t-test on individual scores of the open-ended questionnaire between conditions *designed actions* and *intuitive actions* (equal variances assumed)

	t-test for Equality of Means						
	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Topic	2.437	18	.025	1.042	.428	.143	1.940
Wind Power	.812	18	.428	.458	.565	-.728	1.645
Recycling	.892	18	.384	.458	.514	-.621	1.537
Plants	1.228	18	.235	.750	.611	-.534	2.034
In total	1.786	18	.091	2.708	1.517	-.478	5.895
Number of new strategies	2.574	18	.019	.708	.275	.130	1.286

Tab. 11: Workshop Part 2: *Children as Informants* | Distribution of results of answers between conditions *designed actions* and *intuitive actions* total score.

	correct comprehension of the relationships between elements	partial comprehension of the relationships between elements	correct idea of the element but lack of comprehension of the relationships between elements	misconceptions / no answer
C1 (12 children)	4 (33,3%)	4 (33,3%)	3 (25%)	1 (8,3%)
C2 (8 children)	0 (0%)	2 (25%)	3 (37,5%)	3 (37,5%)

Tab. 12: Workshop Part 2: *Children as Informants* | Distribution of results of answers between conditions *designed actions* and *intuitive actions* wind power.

	correct comprehension of the relationships between elements	**partial comprehension of the relationships between elements**	**correct idea of the element but lack of comprehension of the relationships between elements**	**misconceptions / no answer**
C1 (12 children)	3 25%	2 16,6%	3 25%	4 33,3%
C2 (8 children)	1 12,5%	2 25%	0 0%	5 62,5%

Tab. 13: Workshop Part 2: *Children as Informants* | Distribution of results of answers between conditions *designed actions* and *intuitive actions* recycling.

	correct comprehension of the relationships between elements	**partial comprehension of the relationships between elements**	**correct idea of the element but lack of comprehension of the relationships between elements**	**misconceptions / no answer**
C1 (12 children)	2 16,6%	2 16,6%	3 25%	5 41,6%
C2 (8 children)	1 12,5%	0 0%	2 25%	5 62,5%

Tab. 14: Workshop Part 2: *Children as Informants* | Distribution of results of answers between conditions *designed actions* and *intuitive actions* plants.

	correct comprehension of the relationships between elements	**partial comprehension of the relationships between elements**	**correct idea of the element but lack of comprehension of the relationships between elements**	**misconceptions / no answer**
C1 **(12 children)**	5 (41, 6%)	3 (25%)	0 (0%)	4 (33,3%)
C2 **(8 children)**	2 (25%)	0 (0%)	2 (25%)	4 (50%)

Tab. 15: Workshop Part 2: *Children as Informants* | Overview statistical data of the three game elements wind power, recycling and plants

	wind power	**recycling**	**plants**
Condition 1			
M	1.33	1.08	1.75
SD	.88	1.16	1.357
Condition 2			
M	.88	.63	1
SD	.835	1.06	1.307
p	.428	.384	.235
t(18)	.812	.892	1.228

Tab. 16: Workshop Part 2: *Children as Informants* | Overall achievement of scores divided in 5 levels.

Scores	condition 1	condition 2
high (9 points)	1	1
medium-high (7 - 8 points)	1	0
medium (5 - 6 points)	3	1
medium low (3- 4 points)	4	1
low (0-2)	3	5

Tab. 17: Workshop Part 2: *Children as Informants* | Report right connections conceptual map

Mean	N	Std. Deviation
4.2000	20	1.36111

Tab. 18: Workshop Part 2: *Children as Informants* | Independent t-test right connections conceptual map between conditions (*designed actions* vs. *intuitive actions*) (Equal variances assumed)

	t-test for Equality of Means						
	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Connections	-.797	18	.436	-.50000	.62731	-1.81793	.81793

Tab. 19: Workshop Part 3: *Children as Testers* | Comparison learning gain pre- and post-test within Traditional Learning Environments and Full-Body Interaction Learning Environments

Pre- vs. post-test				Paired Differences				
	t	df	Sig (2-tailed)	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	
							Lower	Upper
Full-Body Learning Environment	-4.370	23	.000	-1.97917	2.21889	.45293	-2.91612	-1.04221
Traditional Learning Environment	-2.287	23	.032	-.93750	2.00847	.40998	-1.78560	-.08940

Tab. 20: Workshop Part 3: *Children as Testers* | Group statistics learned topics post-test between Traditional Learning Environments and Full-Body Interaction Learning Environments

Group post-test	N	Mean	Std. Deviation	Std. Error Mean
Traditional Learning Environment	24	3.0938	2.28513	.46645
Full-Body Interaction Learning Environment	24	4.4792	1.98077	.40432

Tab. 21: Workshop Part 3: *Children as Testers* | Independent t-test about learned topics post-test between Traditional Learning Environments and Full-Body Interaction Learning Environments (Equal variances assumed)

	t-test for Equality of Means						
	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Learned topics (post-test)	-2.244	46	.030	-1.38542	.61729	-2.62797	-.14287

Tab. 22: Workshop Part 3: *Children as Testers* | Comparison answers of open-ended questionnaire between workshops *Children as Informants* and *Children as Testers*

	Wind Power	Recycling	Plants	Wind Power (in total)	Recycling (in total)	Plants (in total)
Mann-Whitney U	182.500	190.500	187.000	185.000	172.500	187.000
Wilcoxon W	392.500	400.500	397.000	395.000	382.500	397.000
Z	-.507	-.275	-.373	-.450	-1.025	-.373
Asymp. Sig. (2-tailed)	.612	.783	.709	.652	.305	.709

Tab. 23: Workshop Part 3: *Children as Testers* | Comparison of amount of connections pre- and post- test workshops *Children as Informants* and *Children as Testers*

Pre- vs. post-test				Paired Differences				
	t	df	Sig (2-tailed)	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	
							Lower	Upper
Right answers	-5.575	23	.000	-1.667	1.465	.299	-2.285	-1.048
Wrong answers	-4.920	23	.000	-1.667	1.659	.339	-2.367	-.966

Tab. 24: Workshop Part 3: *Children as Testers* | Comparison of two conditions (*designed actions* vs. *designed actions including specific gestures*) correct and wrong connections conceptual map (post-test) (equal variances assumed)

	t-test for Equality of Means						
	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Correct connections	.594	22	.558	.417	.701	-1.038	1.871
Wrong connections	.796	22	.435	.583	.733	-.937	2.103

Tab. 25: Workshop Part 3: *Children as Testers* | Ranks of two conditions (*designed actions* vs. *designed actions including specific gestures*) learned topic conceptual map

Groups	N	Mean Ranks	Sum of Ranks
Designed actions	12	10.17	122.00
Designed actions + specific gestures	12	14.83	178.00

Tab. 26: Workshop Part 3: *Children as Testers* | Comparison of two conditions (*designed actions* vs. *designed actions including specific gestures*) learned topic conceptual map

	Learning
Mann-Whitney U	44.000
Wilcoxon W	122.000
Z	-1.706
Asymp. Sig. (2-tailed)	.088

Workshop Part 3: ***Children as Testers*** **| Comparison of number of connections about subcategories between weeks (Study** ***Children as Informants*** **and** ***Children as Testers*****) (Binomial Test)**

Tab. 27: Relationship of wind energy with reduction of air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	14	.70	.50	.115
Number of children reporting no or wrong connection	6	.30		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	16	.80	.50	.012
Number of children reporting no or wrong connection	4	.20		
Total	20	1.00		

Tab. 28: Wind power is a "clean energy" in comparison with steam power

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	7	.35	.50	.263
Number of children reporting no or wrong connection	13	.65		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	6	.30	.50	.015
Number of children reporting no or wrong connection	14	.70	.50	
Total	20	1.00		

Tab. 29: Wind power replaces energy of steam power station

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	5	.25	.50	.041
Number of children reporting no or wrong connection	15	.75		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	2	.10	.50	.000
Number of children reporting no or wrong connection	18	.90		
Total	20			

Tab. 30: Relationship of recycling with reduction of air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	11	.55	.50	.824
Number of children reporting no or wrong connection	9	.45		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	9	.45	.50	.824
Number of children reporting no or wrong connection	11	.55		
Total	20	1.00		

Tab. 31: Production compost through organic waste

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	4	.20	.50	.012
Number of children reporting no or wrong connection	16	.80		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	9	.45	.50	.824
Number of children reporting no or wrong connection	11	.55		
Total	20	1.00		

Tab. 32: Relationship of plants to reduction air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	11	.55	.50	.824
Number of children reporting no or wrong connection	9	.45		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	13	.65	.50	.263
Number of children reporting no or wrong connection	7	.35		
Total	20	1.00		

Tab. 33: Relationship of plants to clean the air

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Workshop Children as Informants				
Number of children reporting right connection	11	.55	.50	.824
Number of children reporting no or wrong connection	9	.45		
Total	20	1.00		
Workshop Children as Testers				
Number of children reporting right connection	10	.50	.50	1.000
Number of children reporting no or wrong connection	10	.50		
Total	20	1.00		

Workshop Part 3: *Children as Testers* | Comparison of number of connections about subcategories between conditions (*designed actions* vs. *designed actions including specific gestures*) (Binomial Test)

Tab. 34: Workshop Part 2: *Children as Informants* | Relationship of wind energy with reduction of air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	6	.50	.50	1.000
Number of children reporting no or wrong connection	6	.50		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	8	1.00	.50	.008
Number of children reporting no or wrong connection	0	.00		
Total	8	1.00		

Tab. 35: Workshop Part 3: *Children as Testers* | Relationship of wind energy with reduction of air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	10	.83	.50	.039
Number of children reporting no or wrong connection	2	.17		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	6	.75	.50	.289
Number of children reporting no or wrong connection	2	.25		
Total	8	1.00		

Tab. 36: Workshop Part 2: *Children as Informants* | Wind power is a "clean energy" in comparison with steam power

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	4	.33	.50	.388
Number of children reporting no or wrong connection	8	.67		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	5	.63	.50	.727
Number of children reporting no or wrong connection	3	.38		
Total	8	1.00		

Tab. 37: Workshop Part 3: *Children as Testers* | Wind power is a "clean energy" in comparison with steam power

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	1	.08	.50	.006
Number of children reporting no or wrong connection	11	.92		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	5	.63	.50	.727
Number of children reporting no or wrong connection	3	.38		
Total	8	1.00		

Tab. 38: Workshop Part 3: *Children as Testers* | Wind power replaces energy of steam power station

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	4	.33	.50	.388
Number of children reporting no or wrong connection	8	.67		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	1	.13	.50	.070
Number of children reporting no or wrong connection	7	.88		
Total	8	1.00		

Tab. 39: Workshop Part 3: *Children as Testers* | Wind power replaces energy of steam power station

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	2	.17	.50	.039
Number of children reporting no or wrong connection	10	.83		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	8	1.00	.50	.008
Number of children reporting no or wrong connection	0	.00		
Total	8	1.00		

Tab. 40: Workshop Part 2: *Children as Informants* | Relationship of recycling with reduction of air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	7	.58	.50	.774
Number of children reporting no or wrong connection	5	.42		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	4	.50	.50	1.000
Number of children reporting no or wrong connection	4	.50		
Total	8	1.00		

Tab. 41: Workshop Part 3: *Children as Testers* | Wind power replaces energy of steam power station

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	7	.58	.50	.774
Number of children reporting no or wrong connection	5	.42		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	2	.25	.50	.289
Number of children reporting no or wrong connection	6	.75		
Total	8	1.00		

Tab. 42: Workshop Part 2: *Children as Informants* | Production compost through organic waste

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	2	.17	.50	.039
Number of children reporting no or wrong connection	10	.83		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	2	.25	.50	.289
Number of children reporting no or wrong connection	6	.75		
Total	8	1.00		

Tab. 43: Workshop Part 3: *Children as Testers* | Production compost through organic waste

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	4	.33	.50	.388
Number of children reporting no or wrong connection	8	.67		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	5	.63	.50	.727
Number of children reporting no or wrong connection	3	.38		
Total	8	1.00		

Tab. 44: Workshop Part 2: *Children as Informants* | Relationship of plants to reduction air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	8	.67	.50	.388
Number of children reporting no or wrong connection	4	.33		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	3	.38	.50	.727
Number of children reporting no or wrong connection	5	.63		
Total	8	1.00		

Tab. 45: Workshop Part 3: *Children as Testers* | Relationship of plants to reduction air-pollution

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	9	.75	.50	.146
Number of children reporting no or wrong connection	3	.25		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	4	.50	.50	1.000
Number of children reporting no or wrong connection	4	.50		
Total	8	1.00		

Tab. 46: Workshop Part 2: *Children as Informants* | Relationship of plants to clean the air

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	7	.58	.50	.774
Number of children reporting no or wrong connection	5	.42		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	4	.50	.50	1.000
Number of children reporting no or wrong connection	4	.50		
Total	8	1.00		

Tab. 47: Workshop Part 3: *Children as Testers* | Relationship of plants to clean the air

Condition	N	Observed Prop.	Test Prop.	Exact Sig. (2-tailed)
Condition: designed actions				
Number of children reporting right connection	8	.67	.50	.388
Number of children reporting no or wrong connection	4	.33		
Total	12	1.00		
Condition: designed actions including specific gestures				
Number of children reporting right connection	2	.25	.50	.289
Number of children reporting no or wrong connection	6	.75		
Total	8	1.00		