BOXED _

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Encouraging active play through basic interactive objects.

Master Thesis
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Master of Arts in Design
Field of Excellence Interaktion

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Abstract

The BOXED project investigates the use of basic interactive objects as tools, which can encourage active play in children's natural environments. It is grounded on the insights gained from child development, technology for children and a user centered design approach as well as research on emerging relationships between child and interactive objects.

BOXED are a series of basic interactive objects, which can be used by children as extensions into the world and which can offer them playful interactions.
I developed those artifacts in order to pose questions about basic interaction design, children's active play and their causal reasoning about interactive technologies.

Through observations I demonstrate ways in which children use such objects and which kind of use-cases, stories and scenarios they invent during those interactions. Thereby, I could validate that interactive artifacts can serve as amplifiers for environmental perception. Overall, my research shows that such objects can support the children in reconfiguring and manipulating their environment in a creative and collaborative way.

General Notes

This research driven Master's thesis is located in the fields of Interaction Design, but draws on insights and inspirations of research from other disciplines. They have been used as reference and foundation of the project and to illustrate interdisciplinary overlaps. Therefore, I have tried to interpret the insights and ideas from areas like computer sciences, development psychology and education. The focus of my thesis is nevertheless the design and evaluation of interactive artifacts.

Aknowledgements

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And not to forget I would like to thank all the participants for their time, their inspirations and comments.

Figure 01 CoEvolution Quarterly: http://www.wholeearth.com/issue-electronic-edition.php?iss=2010

Preface

A conversation between Gregory Bateson and Margaret Mead (1976) moderated by Steward Brand in *The CoEvolution Quarterly*, Summer 1976:

Bateson: Computer science is input-output. You've got a box, and you've got this line enclosing the box, and the science is the science of these boxes. Now, the essence of Wiener's cybernetics was that the science is the science of the whole circuit. You see, the diagram . . .
Mead: You'd better verbalize this diagram if it's going to be on the tape.
Bateson: Well, you can carry a piece of yellow paper all the way home with you. The electric boys have a circuit like that, and an event here is reported by a sense organ of some kind, and affects something that puts in here. Then you now cut off there and there, then you say there's an input and an output. Then you work on the box. What Wiener says is that you work on the whole picture and its properties. Now, there may be boxes inside here, like this, of all sorts, but essentially your ecosystem, your organism-plus-environment, is to be considered as a single circuit.
Brand: The bigger circle there . . .
Bateson: And you're not really concerned with an input- output, but with the events within the bigger circuit, and you are part of the bigger circuit. It's these lines around the box (which are just conceptual lines after all) which mark the difference between the engineers and . . .
Mead: . . . and between the systems people and general systems theory, too…
Bateson: Yes.
Brand: A kind of a Martin Buber-ish breakdown, "I-it", where they are trying to keep themselves out of that which they're studying. The engineer is outside the box … and Wiener is inside the box.
Bateson: And Wiener is inside the box; I'm inside the box . . .
Mead: I'm inside the box. You see …

Contents

Figure 02 In the field

1 Introduction

„The older person is confined within the barriers of memories and experience, the younger breathes the free air of creative fancy."
(Newell, 1884)

1.1 Motivation

What advances children over adults? One possible answer is concealed in Newell's statement and is the reason, why I chose to focus on children and their use of interactive technology in my master thesis. Even if in 1884 Newell did not have the chance to write his book *Games and Songs of American Children*[01] with regards to interactive technology, now, over hundred years later, this statement is still true, and will persist throughout the future. The reason being that children have the incredible ability to look at things without prejudice and use exploration and naïve explanations to describe and acquire new inputs from the outside. In this sense they have a 'natural advantage' over adults who already draw on a great repertoire of experiences, which makes it harder for them to be open for new things. We as designers could draw on this childish explanations to test concepts – especially in Interaction Design.

[01] http://www.archive.org/stream/gamessongsofamer00newerich/gamessongsofamer00newerich_djvu.txt

Childish curiosity is the precondition for learning and to build up knowledge. Thus, playing seems to be the perfect moment where the child is allowed to test ideas without being constrained and influenced by adults.
Looking back on my own childhood, I was constantly exploring with and through simple objects. There was nearly no limit in play. In my imagination a simple cardboard box could transform into a car or a hut. It was possible to put something inside or use a few more boxes to pile them or building something out of them.

Today, we are still surrounded by inanimate objects – like the cardboard box – but technology has enhanced the world around us and somehow has become an ever-present *experience* (McCarthy & Wright, 2004). By adding sensing and actuation capabilities, the box could have been enabled to become interactive and start to communicate with us, and the environment.

The advantages of technology are not always recognized at first sight. Especially if *embedded systems* are so small that it is possible to enrich nearly any object – like boxes – with computational power. This makes it harder to perceive the *interactive affordances*[02] of such computerized objects. It seems to be a paradox that the simplicity and unpredictability of these objects attracts the children's interest, but I will show, that the magic behind such things is the major reason, why children are exploring and playing.

[02] Affordance is a term introduced by Donald Norman(1988), do describe the object's ability to signal its potential uses(Ackermann, 2005).

1.2 Context
"Even the most powerful notebook computer, with access to a worldwide information network, still focuses attention on a single box."
(Weiser, 1991)

This project is based in the field of *Tangible Interaction Design*[03], which also includes embedded systems, as well as ubiquitous material (Weiser, 1991). In its beginnings *tangible interaction design* was seen as giving information an embodiment and to place it back into the real world, outside the computer. The development of many tangible artifacts enabled us to manipulate data in a new way and taught us manifold possibilities to interact through gestures, to organize and browse music and other media.

[03] Ishii and Ullmer first introduced Tangible Interaction (TI) (Ishii & Ullmer, 1987)

However, the art of designing *tangible interfaces* and *artifacts* is about to change. The vision of Marc Weiser and others (Weiser, 1991) has become reality and smart computerized objects are now everywhere. In return, if the objects surrounding us are able to communicate, we have to think about new fields of application and their impact on people (Norman, 2010). Fernaeus, Tholander and Jonsson (2008) give some insights what is about to change in Tangible Interaction. Their central demand is to avoid the simplification of human action by viewing it from a dualistic perspective. That is regarding interaction as a simple matter of input and feedback and a separation of body and mind. They call for a situated and embodied perspective; a perspective, where knowledge, sense making and creativity are dependent on the environment and possibilities we offer through material for *social interaction* (Fernaeus et al., 2008).

The emerging field of *Tangible and Embodied Interaction (TEI)*[04] points into a direction, where the spatial setting of an interface gets more important. TEI envisions an embodied perspective of interaction where interacting with and within the real world is the focus of interest (Honecker, 2011).

[04] visit: http://www.ehornecker.de/TangiblesFramework.html

The design of interactive artifacts always includes thinking about transforming interactions into useful experiences. To promote curiosity and playfulness in interactive objects for children, we have to include thinking about astonishing and magical interactions, which are yet based on very logical rules. Thus, magic is provoking curiosity; curiosity leads to engagement and engagement leads to knowledge.

1.3 Areas of Interest
In my Master's thesis I want to explore the use of basic interactive objects as tools which encourage children in their natural and imaginative approach towards their environment.

In the review of background I will discuss three main areas of interest which form the foundation for the research question of my thesis, and the concepts for the basic interactive objects I developed in the course of my Master project. These three areas can be summarized by the following questions:

How important is free play[05] during the child development?
What is the fascination behind interactive artifacts?
How technology could be used for play and learning?

05 According to Creighton, free play is characterized as: Informal in nature, motivates explorative and creative activities, and has no pre-defined goals (Creighton, 2010).

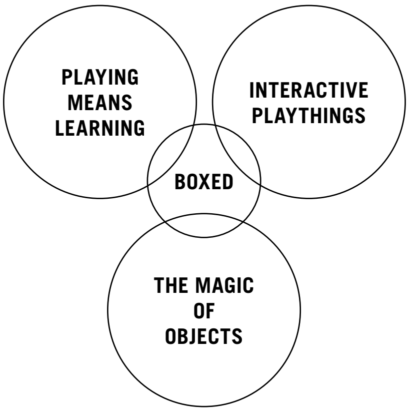


Figure 03 Areas of interest

1.4 Approach

This thesis envisions an approach with the objective to generate interactive prototypes, which are the result of background research as well as my own ideas and observations. In this way they embody the upcoming hypotheses, first in the form of *Analog Prototypes* and then as *Interactive Prototypes*. The developed BOXED prototypes basically enable children to use input and output boxes, which are connected wirelessly. Through doing so, children have the possibility to decide what boxes they would like to connect in order to evoke astonishing and sometimes magical feedback. In observation sessions I was able to see how children used the boxes and what kind of explanations they gave to rate the feedback.

What interested me the most during the observations are the unpredictable *use-cases* in which children include the prototypes and their reasoning for occurring phenomena. They were the main reason for this project, as they demonstrate how generic and unpredictable the impacts of interactive technology sometimes are.

The structure of this paper is as follows. In chapter **2**, background information concerning play, the magic of objects and interactive artifacts is given. As a result of the review of background I will present my research questions and the applied methodology for the project in chapter **3**. In chapter **4**, it will be described how a first contextual inquiry has lead to ideas and concepts how to design basic interactive objects for children. Chapter **5** describes the design process of BOXED and explains the technical details. Chapter **6** shows and analyzes first hand insights about how children actually used and explored BOXED. In chapter **7** I will redirect the original motivation to what I have learned during the process of building and testing BOXED.

1.5 Nomenclature

With the name BOXED I would like to highlight the form and interactive part of the objects I have created. All the possible interactions have been simplified and provided within a boxed housing. In this way the children are able to actively use the boxes to explore certain phenomena, which occur when interactive objects start to communicate and include ambient information as well as directed interaction.

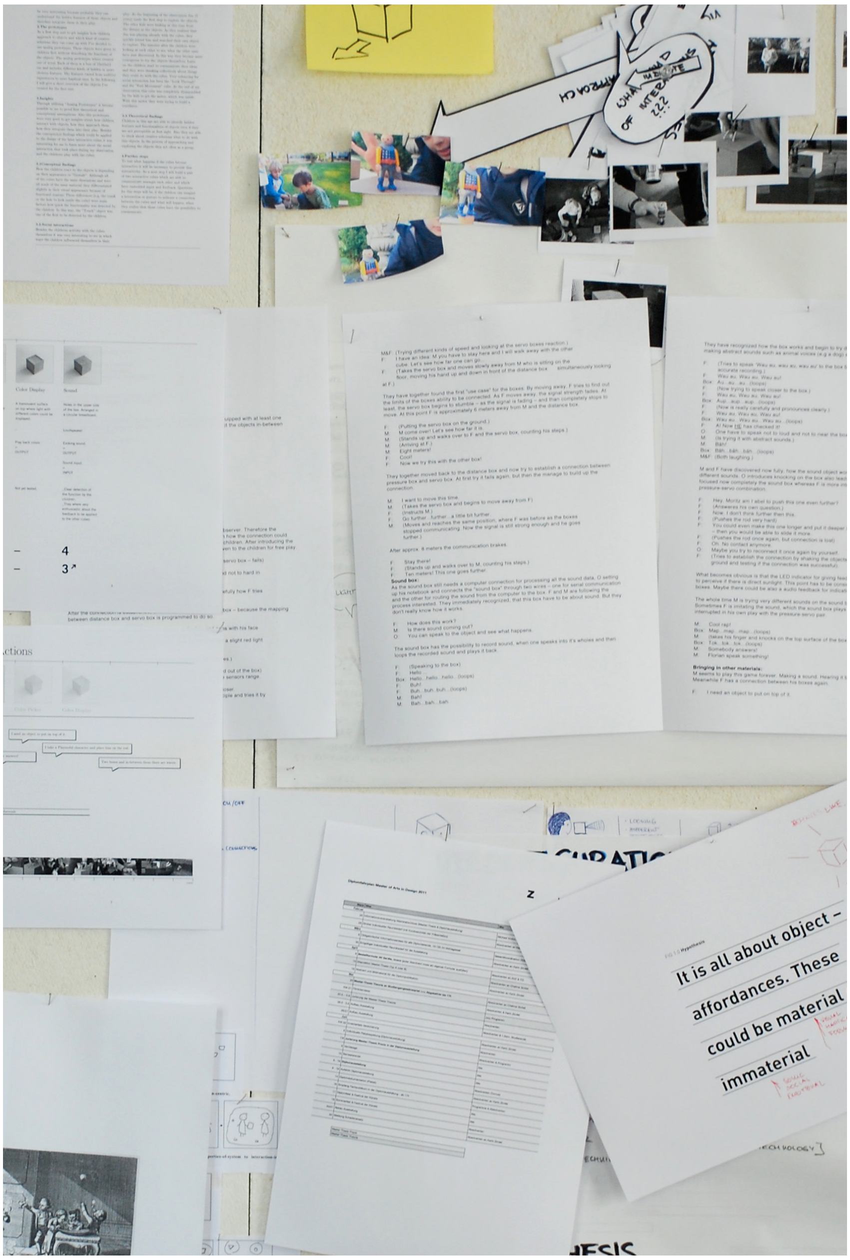


Figure 04 Analyzing the review of background

2 Review of Background

„Children should be able to do their own experimenting and their own research. Teachers, of course, can guide them by providing appropriate materials, but the essential thing is that in order for a child to understand something, he or she must construct it by him or herself, they must re-invent.“
(Piaget, 1972)

How could the theory about child development, about the magic of objects and the opportunities of interactive artifacts lead to the development of basic interactive objects that encourage children in active play? To answer this question, I will outline the three main areas of interest of my thesis and provide background information in order to understand the concept approach of BOXED.

2.1. Premises of play

Before discussing play from the viewpoint of psychology and with regard to interactive technology, I will outline the least important conditions for an explorative and active play atmosphere.
According to Howard P. Chudacoff (2007) play is defined through four major criteria: *material, context, people and limitation*,[06] which I will explain in more detail in the following section.

[06] These are only the most important, for a broader overview see D.W. Winnicott. (2005, S. 69-70).

2.1.1. Material – What do children play with?

We need to draw a line between formal and informal toys. Formal toys are purely functional objects, which are often limited or very special in their use and shall serve for a particular purpose of play. Today, play is strongly connected to such formal objects – especially the desire for new electronic gadgets is high. Already ten years old children are now addicted to their mobile phones or game consoles. This technology offers a lot of opportunities (e.g. communication, e-learning and acquisition of information). But most of this technology is about virtualization, which actually separates the child from its environment and social network, and neither supports, nor encourages interaction within it.

In contrast to formal toys, informal materials are unshaped and unrestricted in their use and provide a high bandwidth of possible interactions. In this way, nearly any object in the environment (e.g. a cardboard box, a wooden stick, a stone etc.) could be described as an informal toy. However, it depends on the child's ability to imagine and invent use cases for such materials – for example if a stone is used as car. Then the stone could serve as plaything and – because of its informal nature – could foster situated social communication as well as face-to-face collaboration. The question arises, *how can we design basic interactive objects that hold these informal qualities?*

2.1.2. Context – Where do children play?

Nearly any place could become a playground for exploration and like the handling of materials, the context of play could either be classified as closed and predefined, or open and definable by the children themselves. In this sense nearly any place could become a playground for exploration and experimentation in the infantile imagination.

Ullrich Gephard, who investigates how children approach their environment and nature, quotes that if children were asked where they prefer to play, they would answer that unstructured and open spaces are special. Such a place could be a backyard or any other place which is not defined as playground. These are places often forgotten by adult planners. Children search such places to be away from the control of adults and able to conduct real free play (Ullrich Gephard in Schreiber, 2010).

In the radio feature titled: *Wenn Kindern echte Naturerlebnisse fehlen – Lila Kühe und gelbe Enten* (Schreiber, 2010)[07] other researchers, teachers and parents emphasize the opportunities the exploration of nature can have for children. In their opinion children need real experiences and not virtual abstractions of the world. They argue that we need to experience physical interaction with our own bodies before we enter virtual worlds, which is mostly the case with today's interactive technology.

I state that basic interactive objects should support mobility of the children. The goal should be, not to create predefined settings where children get stuck in front of a computer screen or the like, but to design systems which foster interaction in real environment.

2.1.3. People – With whom do children play?

Of course, children either play alone or together with others – children or adults. While in solitary play children often investigate a specific phenomenon, playing with others means a lot of fun and fosters social interaction. Whilst playing with others and regarding playmates as models or competitors, children learn social behavior. Hence, it would be excellent to design material which enables children to do both: playing alone and together.

2.1.4. Limitation – How much are children limited in their play?

Adults often limit children in free play – mainly for safety reasons. In contrast, children love boisterous and unrestrained play and to take risks while playing. Without the risk to make a mistake the child would not have the chance to lapse and learn from it.
Besides being limited from the outside, the play could be determined by rules of a toy or game. For a child breaking a rule is fun and success because it means to have the edge over somebody else – *people or objects*.[08]

[07] When kids lack natural experiences – lilac cows and yellow ducks. http://www.br-online.de/imperia/md/audio/podcast/import/2010_05/2010_05_03_21_13_04_podcastiqlilakhegelbeenten0505_a.mp3

[08] For a wonderful illustrated example see Suchmann (2007) Pages 33ff.

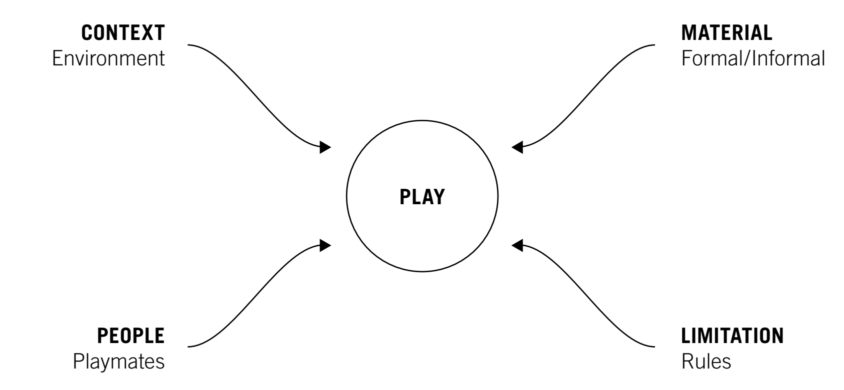


Figure 05 Criteria influencing play. According to Chudacoff

All of these four factors form the basis on which free play could take place. Therefore, they have to be taken into account when designing interactive artifacts for children. According to these factors, play is much more dependent on *open possibilities* which we offer to children and not on *predefined settings*. Therefore, designing material which should encourage free and unrestrained interactions requires an open context setting which gives room for a shared use of objects and setting up basic rules.

Free play means fun for children, but *how is free and situated play rated in developmental sciences? What is it that children learn during play?* The next section will provide the most important information from a psychological standpoint.

2.2 Playing means Learning?

"Making sense of the world is a basic human activity in which we all engage. It means figuring out how things work, and why things are the way they are […] that's why children play!"
(Ackermann, 2004)

Play is always situated and involves more or less physical objects as well as other people and of course the environment. In the field of developmental research it has been shown that free play – where different objects and materials are used as playthings – is the major driving force for development. It trains multiple skills including *imagination*, *exploration*, *experimentation* and *social behavior* – to name but a few.

2.2.1 Acting in the environment

Jean Piaget, and after him many other researchers in the area of constructivism, sees the child as a *small scientist* who is constantly exploring and experimenting to find simple and sometimes naïve explanations for perceived phenomena. This could be for example the realization, that banging objects together evokes a sound, which is dependent on the object's structural qualities (weight, material, shape etc.). The constructivists view further assumes, that learning is hence strongly related to physical interaction within the real world and about internalizing basic rules as mental representations. In this way, the child is training and strengthening her perceptions, which gives her a deeper understanding of how things work. This is the reason why the constructivists pleaded for *Learning by Doing* – because only through acting the child is able to gain *tacit knowledge*[09] about the environment and things situated in it. Others, as for example Andersen (2008) – see in this the deeper understanding and the foundation of *naïve physics*[10].

Following these arguments, knowledge is generated through referring a perceived stimulus event to an already known event. Through this, a causal reasoning of action and reaction is manifested. In Piaget's theory this is described as the concept of *equilibration*[11]. The perceived stimuli in the world are cut up and adapted into mental classifications. Through categorization, knowledge is structured basically in a linguistic way. For example a perceived image of a tree is saved in the category of plants with certain attributes (has a robust trunk, green leaves and moves in the wind).

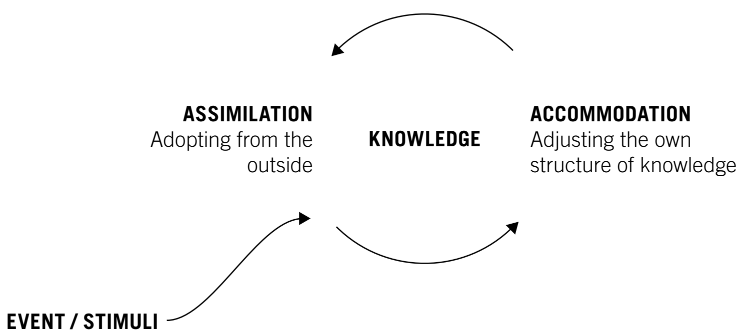


Figure 06 Equilibration. According to Piaget

Eleanor Rosch argues, that – in opposite to clinical test situations – in the real world the attributes of such mental categories are never *independent of one another* (Rosch, 1977). A situation in which an object is perceived is at least as important as the object itself. When we look at the example of the tree, it could also be described as something to climb on, to hear, to dance around etc. In children's eyes – with their intuitive and imaginary approach towards objects, it could also be described as castle or tower. Of course the tree itself stays a tree, but imagination makes nearly everything possible. Or as Bruner would describe it:

09 Tacit Knowledge is opposed to explicit knowledge and could be described as knowing how to do something or knowing why a cause results in a certain effect.

10 Naïve Physics are described as an intuitive understanding about the objects in the physical world

11 Equilibration means the balancing of accommodation and assimilation.

"There is a long tradition of research which indicates that children put things together because of associations, stories, chains, and other non-taxonomic criteria"
(Bruner as cited by Rosch, 1977).

Rosch demands, that children have to learn the taxonomies of basic object categories first. The reason is that these categories are then the foundation for every further exploration. These basic categories have to be ideally learned in various ways – visual, sensory-motor, linguistic and so forth. Once these categories exist, correlations between categories, prototypes and objects could be explored. These correlations could have magic qualities at the beginning, as they impose new questions of how the causal correlation between the already known could be established.

Imagine a child who has just discovered that a cardboard box could be opened and other objects could be placed inside. Eventually this child will start to shake the box in order to hear the sound of the objects being jumbled inside. The majority of children who explore that kind of relation of cause and effect will start to investigate how different objects evoke different sounds. How does the structural quality of the objects inside affect the sound of shaking? Is there a causal explanation for that certain phenomenon?

Learning in the context of play could therefore be described as an interaction between the child and objects in the environment. McCarthy and Wright sum up the view from John Dewey, who is pointing into a similar direction: "Experience is constituted by the relationship between self and object" (McCarthy & Wright, 2004). Thus, acting physically in the environment is inseparable from shaping internal representations of the environment. This view is shared by other researchers in the fields of psychology, technology and design – e.g. (Dourish, 2004), (Noë, 2004), (Verplank, 2003)[Figure 06] (Honecker, 2011). If we assume this point of view the question is, *what kind of objects are at hand and how do children use these objects?* To answer this question I will look at how objects could transform into explorational tools for children in following section.

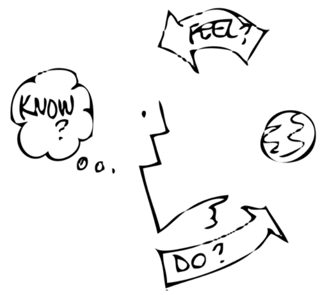


Figure 07 Bill Verplank https://ccrma.stanford.edu/courses/250a/lectures/IDSketchbok.pdf

2.2.2 Tools

One could basically separate tools into two categories: *technical tools* and *psychological tools*[12] (Vygotsky, 1930). The first are used for real manipulation of material, for example a saw, whereas the later are used to form the mind of people, for example an abacus; also known as *objects to think with* (Ackermann, 2007). In this way, tools and basic objects are expanding the children's possibilities for *manipulating* their environments and at the same time *reconfiguring* the internal representations of the world by scrutinizing the results.

[12] Technical Tools control nature (e.g. axes, hammers, computers)
Psychological Tools control thought (e.g. language, counting, art)

From this perspective, it is interesting to observe children who are fully *immersed* in their play. During play everything becomes possible. A stone could become an animal or a car, wooden sticks are used as swords and small, devastated places in the backyard serve as kingdoms where the child could decide what is possible and impossible. Objects are being disassembled and used in various ways in order to get a clue *how* and *why* things are as they seem to be. In this way, objects are used as connections to the world and play serves as *elbowroom* (Ackermann, 2005), where children are the legislation and therefore are able to set their own rules and boundaries.

Thus, offering children open possibilities and materials for the process of exploration is highly important. Therefore, one has to consider not only certain qualities of objects, but also the entire interaction – again context, people and limitations. As designers, we could ask: *How to design objects, which engage children in active exploration of their environments and situated phenomena? How should these objects look like? And what kind of interactive behavior should they offer?*

2.2 The magic of objects

"The thing about playing is always the precariousness of the interplay of personal psychic reality and the experience of control of actual objects"
(Winnicott, 2005)

In the previous sections I have shown that active play is important during child development. I stated that the reason for this is that children have to ensure how things work and the best condition to do this is through free exploration and experimentation. I have also shown that physical and situated objects play an important role in acquiring knowledge about the world. Therefore, objects should first encourage children's curiosity (Buechley, 2010). In this section I will demonstrate, how magic could be used in order to attract the children's interest and for challenging their curiosity.

Figure 08 Esper Domino. Jarashi Suki. http://works.jarashi.tv/

2.3.1 Definition of magic

Magic has no clear definition. However, people have used magical reasoning, whenever something could not be explained through strict causal reasoning. This is particularly true in the history of technology, where the thinking about apparatuses which were beyond peoples imagination, often resulted in wild fantasy about how this machines work. People did not know that the majority of such objects is guided by very primitive and simple rules of mechanics.

Events which are not logically explicable in terms of *cause and effect* could lead to magical explanations. This magical moment could be seen for example in *Jarashi Suki's Esper Domino*[P13]. Five domino-sized blocks are connected wirelessly and if one is pushed and falls, it sends a signal to the next block causing it to fall and then the next and so forth. Whereas the first action and reaction is very obvious – if we push something unstable, it falls – the second is not explicable in *logical* terms. It needs investigation to find out if it only happens once or anytime one pushes the object. In this case one wants to find out the rule behind this behavior.

For children all kinds of objects could inhabit magical qualities, for example they could become *alive* in children's minds (Ackermann, 2005). Therefore, these objects do not have to be *animated* or *interactive*. But Edith Ackermann quotes that especially animated objects are important because they could *capture* the children's imagination. She refers to those objects as being *AniMates* – thus things which catch the children's attention. These could be for example basic gyroscopes, moving objects or simply a ball or sliding slinky.

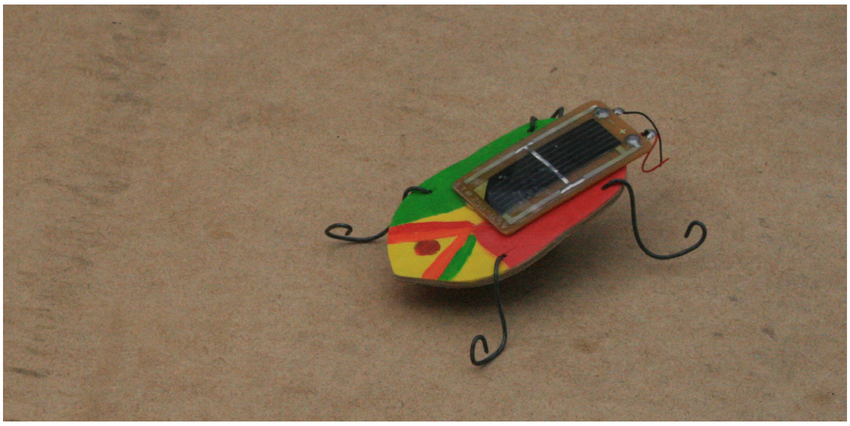


Figure 09 Animated Toy

"Imposing one's order upon things and looking at the unknown in terms of the familiar (assimilation) goes hand in hand with being sensitive to variations in the environment and letting go of previously held believes (accommodation)" (Ackermann, 2010).

In the following section I will outline which criteria could lead to magical reasoning about designed artifacts.

2.3.2 Criteria for magical reasoning

When we perceive events which we cannot explain at first sight, we try to find causal explanations for them. As argued before, this is the reason why children explore the world, and objects situated in it. Interactive objects could communicate magical qualities on different levels.

Structural Qualities – This thing is so fascinating!
Movement – I can't explain why this thing moves!
Behavior – When I do something it reacts!

Whereas inanimate objects communicate through form, material, and sometimes movement, interactive objects communicate on a behavioral level (Suchmann, 2007. p. 33). Suchmann states that the distinction between physical and *psychological* entities could be drawn by comparing the "observable behavior of a thing and its underlying nature" (Suchmann, 2007). Thus, once again one has to investigate the objects in order to find a sufficient explanation.

Designing magical artifacts, which provide affordances for manipulation and play, has been a matter of *Industrial Design* for a long time (Norman, 1988). Industrial Designers shaped the objects through form and material, providing functional yet arresting and sometimes amazing objects. As basic objects are becoming computerized, it needs *Interaction Design*, to develop the behavior of the objects in interdependency of form and people's expectations (Franinovic, 2008).

In the opinion of Ackermann *magical connections* – the interdependency of cause and effect – are the driving forces for exploration. If a child could experience the moment when she feels that something is under her control – thus reacts in the way she expected it – then she has got the clue how it works. Therefore, Ackermann refers to a three year old kid who experiences that pressing the light button causes the light to appear on the ceiling (Ackermann, 2005).

All these insights lead to the following assumptions: children rate especially animate objects magical. The examination of such objects leads to questions like: *How does this thing work? Is there a rule behind it? Does it know me? How does the thing communicate?*

These questions are necessary to encourage the infantile curiosity and impulse to investigate objects and its environment. Especially interactive artifacts trigger these kinds of questions, because using *Interaction Design Methodology* their inhabited *behavior could be formed*.

2.3 The opportunities of interactive technology

„Learning is designing, and designing is a conversation with–and through–artifacts.“
Schön, 1983, as cited in Ackermann (2007)

A lot of research in the past has focused on tangible interactive artifacts for children. Mostly they are based on the epistemology introduced by Piaget and later transformed into programmable environments by Seymour Papert or Alan Kay. The majority of these projects have been elaborated for the sake of the computer, taking the children's requirements into account but adding an educational value.
I would like to give an overview of projects I analyzed and which contributed to the design of BOXED. The projects range from exploring the use of near field[13] communication technology like RFID **P10, P11, P12, P13** to building systems **P07, P08, P09**, sculpting new ways to interact with media and movements **P03, P04, P14, P16** or simply manipulate input and output in unexpected ways **P01, P02, P03, P05, P06, P17**. All of these projects are based on the tangible approach towards the use of interactive technology and include – to a greater or lesser extend – magical behavior.

[13] See: http://www.nearfield.org

2.4.1 Backlink to play: Context, People and Limitations

As argued before, with interactive objects we are able to encourage and sometimes even amplify active play, because interactive material allows us to create specific patterns of interaction (*feedback*). This challenges the child's perception and evaluation of how a thing works, how it behaves and what it is useful for.

As discussed in **2.1**, there are at least three main criteria, which together form the premises to design interactive artifacts for children. To include these criteria into the design of BOXED I will outline them here according to the opportunities which interactive technology offers.

Context – Open to the environment
People – Open for shared use
Limitations – Open for self-initiated ideas

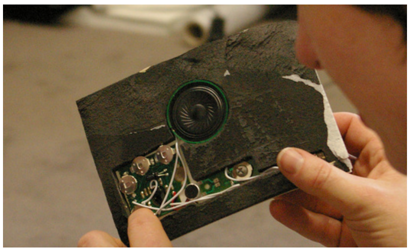
2.4.2 Context

We have seen that the environment is an important factor in the play of children. Everything they do while playing is somehow *situated* in the environment and is at least a very embodied interaction with the materials and objects at hand. Interactive technology enables us to create objects, which are *situated too* and are aware of their context. This means that the object knows certain information about it's surrounding, for *example location, identity, activity* and *time*. According to Dey and Abowd "An entity is a person, place,

P01 Animal Superpowers

Chris Woepken

http://www.woebken.net/animalsuperpowers.html



P02 Black Box

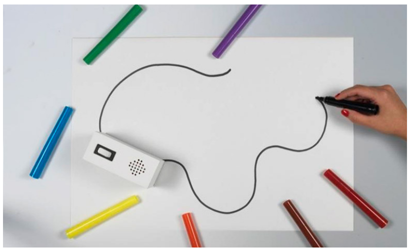
Kristina Andersen

http://www.xs4all.nl/~mwais/thing/

P03 The sound of Touch

David Merrill

http://alumni.media.mit.edu/~dmerrill/soundoftouch.html



P04 Color Chaser

Yuri Suzuki

http://www.yurisuzuki.com/

P05 I/O Brush

Kimiko Ryokai

http://web.media.mit.edu/~kimiko/iobrush/

P06 Curious Sound Objects

Georg Reil

http://www.geschoir.de

P07 Cubelets

Eric Schweighardt

http://www.modrobotics.com/

P08 Topobo

Hayes Raffle

http://www.topobo.com

P09 Olars

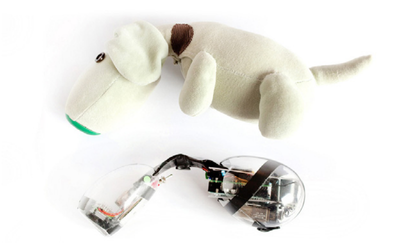
Lars Marcus Vedeler

http://www.vdlr.net/

P10 Skål

Jørn Knutsen

http://www.skaal.no



P11 Sniff

Sara Johannson

http://www.nearfield.org/sniff

P12 Cup Communicator

Duncan Wilson

http://www.duncan-wilson.com

P13 Esper Domino

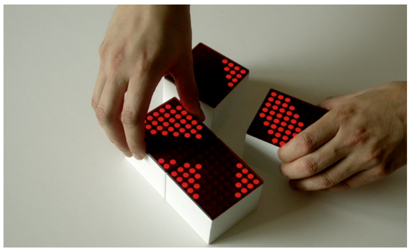
Jarashi Suki

http://works.jarashi.tv/

P14 Fox in an Box

Jonas Loh

http://www.jonas-loh.com/foxinthebox.php



P15 Tile Toy

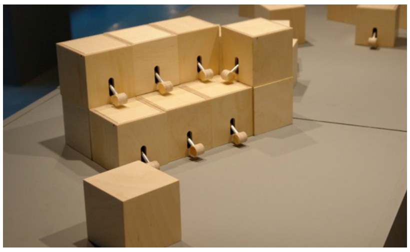
Tuomo Tammenpaä

http://www.tiletoy.org/

P16 Alle Meine Klänge

Daniel Jarosch

http://www.pknts.com/flash-popups/AMK/



P17 Tap Tap

Andy Huntington

http://andyhuntington.co.uk/2004/taptap/

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or object that is considered relevant to the interaction between a user and an application [and] context is any information that can be used to characterize the situation of an entity“ (Dey & Abowd, 1999). A context aware object therefore is for example able to detect where it is and how somebody is acting on it. Only these parameters open a completely new space for thinking about possible playful interactions, which could encourage children in their natural quest for exploration.

Through their embedded sensing and processing capabilities, objects also could offer possibilities for reconfiguring and manipulating *ambient information*. Like a kaleidoscope, children are able to take a certain aspect of nature – for example light – and use it to play around and to manipulate it.

Especially interesting are projects, which envision a phenomenological approach to think about really new ways how children could explore and manipulate their environment. The project *Sound of Touch*[P03] by David Merrill is a good example. It explores ways of how sound could help to identify surface qualities like rigid/soft or smooth/stiff. With an interactive hand-held wand it is possible to stroke over different surfaces. Through a piezo-sensor the surface structure is absorbed and translated into sound, which is played back through a speaker. There exists a video[14], which demonstrates how children, but also adults are fascinated by this simple interaction and are

[14] To see the video, visit the project website: http://alumni.media.mit.edu/~dmerrill/soundoftouch.html

highly motivated in ongoing exploration.
Kristina Andersen's *Black Box*P02 project pursues a similar approach. She was interested in how children perceive and causally describe connections between input and output. Therefore she developed nine boxes, embedded with simple electronic circuits, which combine the input of a sensor with a corresponding output. The inputs of sound, light and touch are mapped to outputs of the same kind. Each of the nine boxes than combines a different input-output pair. One box for example provides the possibility to convert sound into light; the louder the surrounding becomes, the brighter the light glows. The boxes were then given to children in order to see if they find explanations for the occurring phenomena. Andersen concludes from the insights she gained by observing children playing with the boxes:
"Often the child will describe the action either pragmatically "it is like the blinking lights on the road, when we are driving" or fantastically "it is like a little fairy very far away, and it is also in the dark"
(Andersen, 2008).

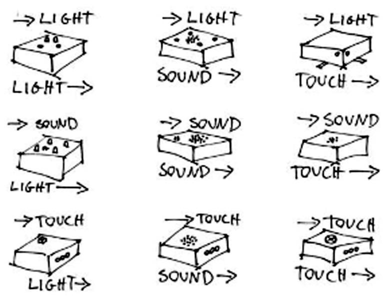


Figure 10 Black Box Schema. Kristina Andersen

2.4.3 People

Playing together with others fosters the children's social behavior. Therefore, interactive objects should provide the possibility for shared use. Either they are equipped for example with a camera which allows multi-user tracking, or they consist not just of one object but are a rather distributed system of many objects, which are able to communicate via radio transmission.

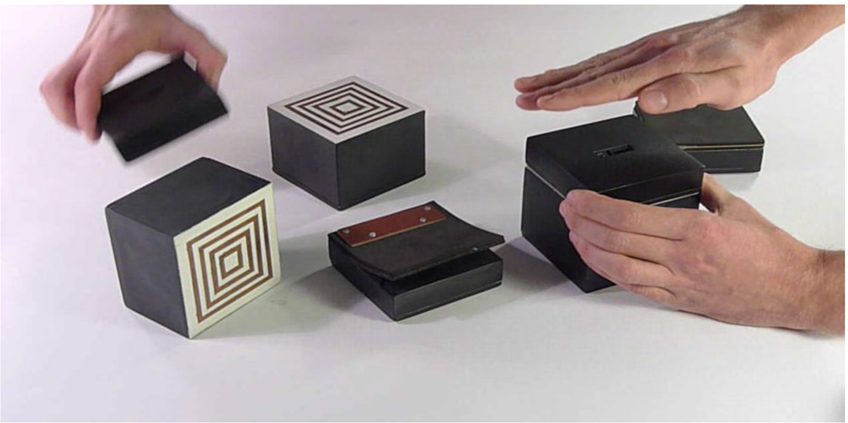


Figure 11 Fox in a box Jonas Loh and Steffen Fiedler

Fox in a BoxP14 presents a way how simple interactive objects could be created to allow a shareable use. By distributing the actual interface among several boxes with different qualities, Jonas Loh opens the interface itself to be explored not only by one person at a time. All boxes are simultaneously controlling the output of sound, which is being processed on a computer and played back by a speaker. Of course, one could play this device alone, but playing it together unveils new sounds which could not have been produced with only one device. Thus, distributing the interface itself encourages social interaction; experiencing interaction together with others promotes the *emotional and sensual quality* of interactive experiences (McCarthy & Wright, 2004).

2.4.4 Limitations

Some basic rules in a system could serve as limitations. These limitations act like interaction boundaries which define the space for exploration and experimentation. Limitations are common elements, but they are defined differently in every interactive system. While some objects and interfaces have very loose boundaries, others only provide a small corridor for interaction.

Loose boundaries have the advantage that nearly everything becomes possible. With a system like Topobo**P08** children have the possibility to build many different *animal-like robots*, which at least could be trained to behave in different ways. The material itself thus offers a wide variety of possible interactions. In comparison, the IO Brush**P05** offers only one function: The recording and playback of graphical patterns. By integrating this functionality into play, the children are forced to explore possible interactions with such objects. *What happens, if we try it with this pattern? What happens if we record moving objects?* Therefore, simple interactive objects focus on the interaction itself and more complex systems focus on the use of the system itself.

Figure 12 Loose vs. straight boundaries

2.4 Conclusion

By exploring the three main areas of interest, I was able to gain insights which actually guided the original question of this project: How can basic interactive objects engage children in active play? Summarizing the review of background I am able to hypothesize, that play in the real world with real objects is important for the overall development of the child – in particular, it trains causal reasoning.

Therefore, objects should have an informal character and challenge the child's curiosity. This could be achieved by presenting somehow magical objects to the children. Basic interactive objects could embody this magical unpredictability. Through *Interaction Design Methodology* it is possible to design and prototype basic interactive objects, which inhabit the possibility for *manipulation* (forming input and output) and *reconfiguration*.

Placing them back in the real world and observing children playing with them would therefore lead to an answer of the following questions:

Do children use causal reasoning for describing the objects behavior ?
Do children detect the qualities of the basic interactive objects ?
What kind of use-cases do children invent by themselves with the objects?

Figure 13 In the field

3 Questions and Methodology

In the following chapter I will demonstrate how I transferred the insights from the background research into research questions for my thesis and an overall methodology of how to design basic interactive objects.

3.1 Research Questions

The focus of my project is to investigate the cause and effect of basic interactive objects on children and to explore the opportunities they offer in order to motivate children in their natural and explorative approach towards their environment. Combining the insights from the review of background, the most evident question for me is:

How to encourage children in active play through basic interactive objects?

My arguments are that: if natural inanimate objects could have certain magical properties and serve as projectors for the children's fantasy, if this objects are used in various and unintended ways, and if inanimate objects are used to invent small games and role plays, then it would be very valuable from an Interaction Design viewpoint to see what happens if we introduce basic interactive objects to children. Do they use and include these kinds of objects as well into their active play?
There are three minor questions, which are necessary for being able to answer the overall question. These questions emerged during the research process and are introduced here, as they influenced the design and research decisions.

3.1.1 Development of the research question

The first question which has been investigated is about the form of the interactive objects. Form in this context means to express possibilities and affordances (Norman, 1988) for interaction, through the shape of the objects. Albeit a classical focus of industrial design, shaping the physical appearance of an interactive artifact is as important as thinking about the interactive responses (Baskinger & Gross, 2010).

How should basic interactive objects for children look like?

This question is also especially important as the inanimate character of the objects is influenced and formed by it. Looking back on the background research there are projects which introduced either basic abstract forms for their objects (cubes, balls, etc) or very cute looking, *children like*, colorful and kitschy playthings (animals, pillows, etc). The latter are doing especially well for building an emotional relationship between child and object (Johannson, 2009), although basic abstract objects are better for real exploration and an active approach towards the environment; only their form fosters exploration.

The second question deals with the responsiveness or interactivity of the objects. Once again Baskinger and Gross point out that "as interaction design matures, designers will focus more on the meaning and impact of form on people [...] computation provides the opportunity to design adaptive, responsive, and highly interactive products and systems" (Baskinger & Gross, 2010).

Like the form, the provided interaction itself could become an indicator for function. The question for basic interactive objects will be what kind of interactivity do we need provide to children to engage them in active play?

What kind of interactive responses can best engage children in active play?

As they should serve as extension and amplifier to the environment they should include parts of it. Kristina Andersen's concept (Andersen, 2008) to enclose input and output in one object and combine them in all possible relations is a promising approach. By designing a system based on similar rules we could provide opportunities to give the control back to children.

The last question leads both other questions back to my initial question of how to encourage children in active play. Form and interactivity are only the conditions for designing an artifact which becomes accepted by the children and is therefore used and integrated into play. The actual use-cases and role-plays are a result of the interaction or relationship between the children and basic interactive objects. Thereby the prototypes should encourage the children to build up a relationship to the objects, the surrounding, and each other. By observing children whilst playing with the objects these kinds of behaviors become obvious. Then the question is:

What kind of relationship emerges between interactive object and child?

3.2 Methodology

To provide open interactions I have chosen a bottom-up design approach, wherefore I conducted a first contextual inquiry in order to get insights about the interactions of children in playing situations in general and how they interact with basic objects in particular. These insights are used later on to transfer them into design requirements for interactive abstract objects.

During an iterative design process the insights have been transformed into the BOXED prototypes. The goal was to develop a principal concept for the BOXED objects in order to support and engage children in natural exploration. To test and evaluate the ideas, I used the prototypes as a tool for giving the concepts form and evaluate them together with children. In this way the prototypes serve as research tools (Ilstedt, 2004) which could be evaluated and tested.

Furthermore, I used ethnographical observation methods to observe the behavior of children. Thereby, the children's suggestions and comments on the prototypes have become part of my design requirements.

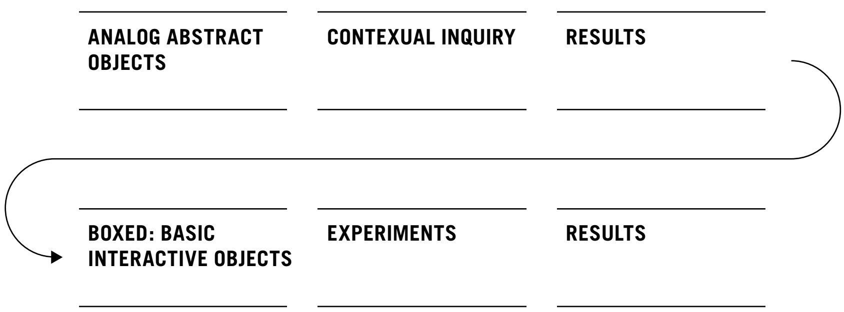


Figure 14 Process Overview

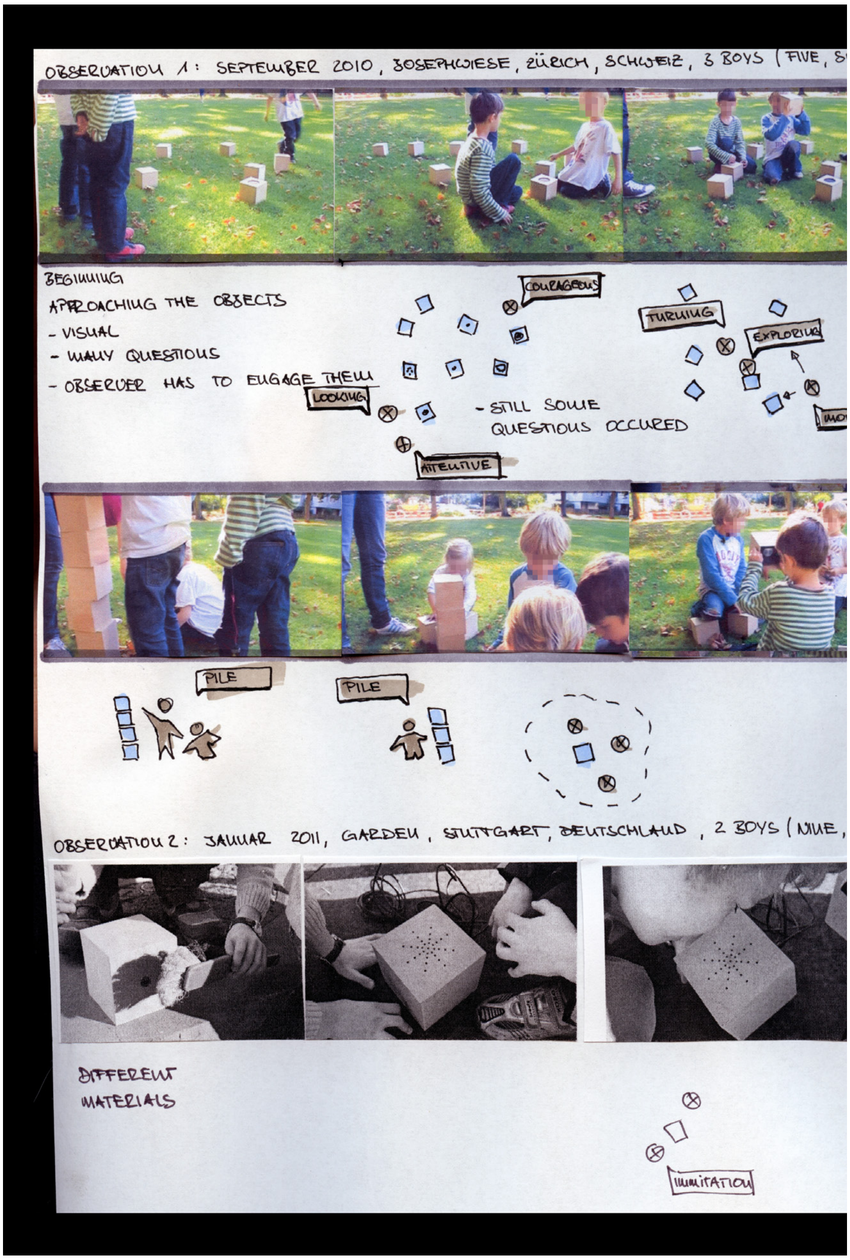


Figure 15 Analyzing the insights from the contextual inquiry

4 Contextual Inquiry

To follow up the bottom-up design approach and to get first hand insights about how children interact and play with objects, I conducted a first contextual inquiry by using *Analog Prototypes* as test objects.

4.1 Analog Prototypes

Analog prototypes are *low-fidelity prototypes*. The term low-fidelity prototype first arrived in the context of application design where it is necessary to present a first prototype with which it is possible to demonstrate some functionality, basic interactions and the order of events (Rudd, Stern, & Isensee, 1996).

4.1.1 Shape, Materiality and Dimension

During a brainstorming session, the prototypes were defined in form and functionality they should offer. To keep them as simple as possible, I chose a cubical shape. Firstly, A cube is interesting, because it is a basic shape, which allows multiple reconfigurations; for example one could pile it, place it, align it in a row etc. All these interactions are already memorized from the play with wooden bricks, stones or similar material. The cube also offers possibilities for different levels of manipulation; these include interactions like opening and closing it, putting something inside, turn it, shake it etc.

To be able to develop the Analog Prototypes quickly, I used wood (Medium Density Fiberboard – MDF) as building material. The advantages of such material are that it is easy machinable and that it could be easy assembled. The cubes were built out of 5mm string sheet material providing a hollow body with a removable top plate. The complete dimensions of the provided prototypes were $120mm^3$. The construction was fixed with glue and was therefore lightweight yet stout.

4.1.2 Functionalities

After defining the basic shape of the prototypes different functionalities were discussed in the brainstorming session. Finally, I selected a set of eight objects and tested them in an observation setting together with children. The functionalities of the selected prototypes included haptic, visual and sonic input, as well as feedback affordances (see next page).

4.2 Data Collection

The observation took place in a public park in Zurich on a sunny September day. The objects were laid on the ground with no further instructions. I used *passive observation* as method of observation. At some points of the observation session, I asked the children certain questions to get deeper insights about why they did this or that with the prototypes. For documentation

A01 Squeeze

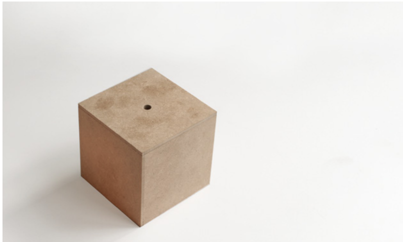
Sponge

This box was clearly detected as Input device and many interactions have been tried.

A02 Hear

Loudspeaker

Clear detection of the function by the children. They where very enthusiastic about the feedback to be applied to the other boxes.



A03 Look

Caleidoscope

The children where very focussed playing with this box.

A04 Look Through

Periscope

Two children looked both in one hole, so they could see the others eye.

A05 Crank

Coffee Grinder

This box was clearly declared as a kind of input device to affect the other boxes (e.g. let them dance).

A06 Rattle

Rattle

At first sight the function of this object wasn‘t obvious to the children. The embodied possibilities where not exciting enough for them.

A07 Feel

Powerball

The functionality wasn‘t obvious to the children. After trying the object they where very fixed to it. Different Use Cases where explored by the children.

A08 Detect

See

The first assumption about this object was that it would be able to light up.

and evaluation I employed a video camera to record the children's reactions. The participants were three boys (age: five, six and seven), one girl (age: three) and her mother (only peripheral).

Immediately after installing the experimental setup there were three boys who were really interested in the *strange looking cubes*. They started using the objects and played with them for more than 40 minutes. During this time it was possible to get good insights about their approach and play with the Analog Prototypes.

4.2.2 Questions

As this inquiry has been done to get first insights about children and objects, the questions which I were aiming to answer were of a more open character.

How do children approach the boxes, what is the process of engagement?
Which kind of interaction occurs during the play with the boxes?
Which kind of social interaction and behavior could be observed?

4.3 Findings

Summing up, all the findings and insights from the contextual inquiry verify the results and hypotheses from the background research. A visualization – containing time and most important events – provides an overview of how the children approached, analyzed and finally played with the Analog Prototypes. To complete the diagram, the following sections will recapitulate the most important factors. This chapter closes with a conclusion of the contextual inquiry and its results.

4.3.1 Approaching the objects

The children found the Analog Prototypes immediately interesting. Firstly they asked me questions about the objects. These questions concerned the purpose of the objects – *"What are the objects for?"* – and what one is able to do with the objects – *"What can we do with the boxes?"* The goal was not to lead them into a certain direction and so I answered in a way not to prevent the children to explore the purpose and functionality of the boxes on their own – *"You can try the objects out"* or *"What do you think the objects are for?"*
In this way the children put away their first shyness and concentrated on the prototypes. To approach the objects the children pursued the following steps: visual exploration from far away, tactile and kinesthetic exploration, full and uninhibited engagement in exploration, and the development of use-cases and social behavior.

The approach was therefore more a matter of breaking the ice and get them into free exploration – free play. The first constraints consisted more of a natural politeness – not only to take the objects and fully let go from the beginning.

After the first approach towards the boxes, the children began to use them according to their own ideas. They tried to build machines by connecting the objects together or they collaborated to come up with new and unusual ideas – for example one object that could be able to make all the others dance.

4.3.2 Analyzing and playing with the objects

When regarding the timeline of detection, it becomes obvious that some objects are explored before others. There exists an order of detection. The time of detection does not mean that this object guarantees a long lasting joy of use, but an obvious communicated functionality.

For example, the possibilities of the object that allows manipulation through squeezing were immediately found interesting. There was a great amount of ideas what could be done with this object (e.g. making music, use it as a sponge, etc). It was mainly seen as a kind of *input device* to evoke reactions. The children accepted the object and they used it extensively *to press on* it and *imitate sounds*, which could have been produced by the object itself.

Other objects were evoking similar reactions. For example the hear object which was detected to be able to either *make sound* or even to *speak inside* – like a microphone. Albeit the object itself wasn't very interesting to the children – the *imaginable functionality* was. They also used the cover plate of this cube to attach it to other objects to transform them into sonic objects – objects that *produce sound*.

Figure 16 Two kids looking through the holes of a box.

The look through-cube was remarkable, because it enabled the kids strongly in looking through into their environment and at each other. In this manner the object worked as *trigger for social engagement*. In one situation one child

Analog Prototypes

× approaching → □ analyzing and playing →
○ social behavior →

comments

- What is this object about? ×
- Turn the thing on! □
- Is there something coming out? ×
- Open the boxes! □
- We can tinker something ... ○
- This one makes music! □
- One could produce energy ... □
- ... and then all the cubes are dancing. □
- Change the cover plates! ○
- What happens, if we put in some leaves? □
- We could create a rotating pattern! □

actions

Questioning

At the beginning, the kids were very shy and asked about the topic of certain boxes.

Immitation

The imaginable responses were immitated by the children. For example noises, which the objects could produce. Besides the children imitated each other, when somebody did something special.

Approaching

Besides asking about functionlities, they were slowly approaching the boxes from far (visual) to near (sensory-motor).

Exploring

The children used full sensory-motor engagement to figure out the functionalities of the boxes.

Collaborating

Through thinking collaboratively about use-cases, they found new applications.

Different Use Cases

New ideas evolved, about how the boxes could be used (e.g. by attaching other materials on it.

Connecting

Children build machines by placing the boxes near to each other.

Reconfiguring

Children used the boxes to interchange their functionlity by changing the cover plates.

filmstrip

Order of Detection

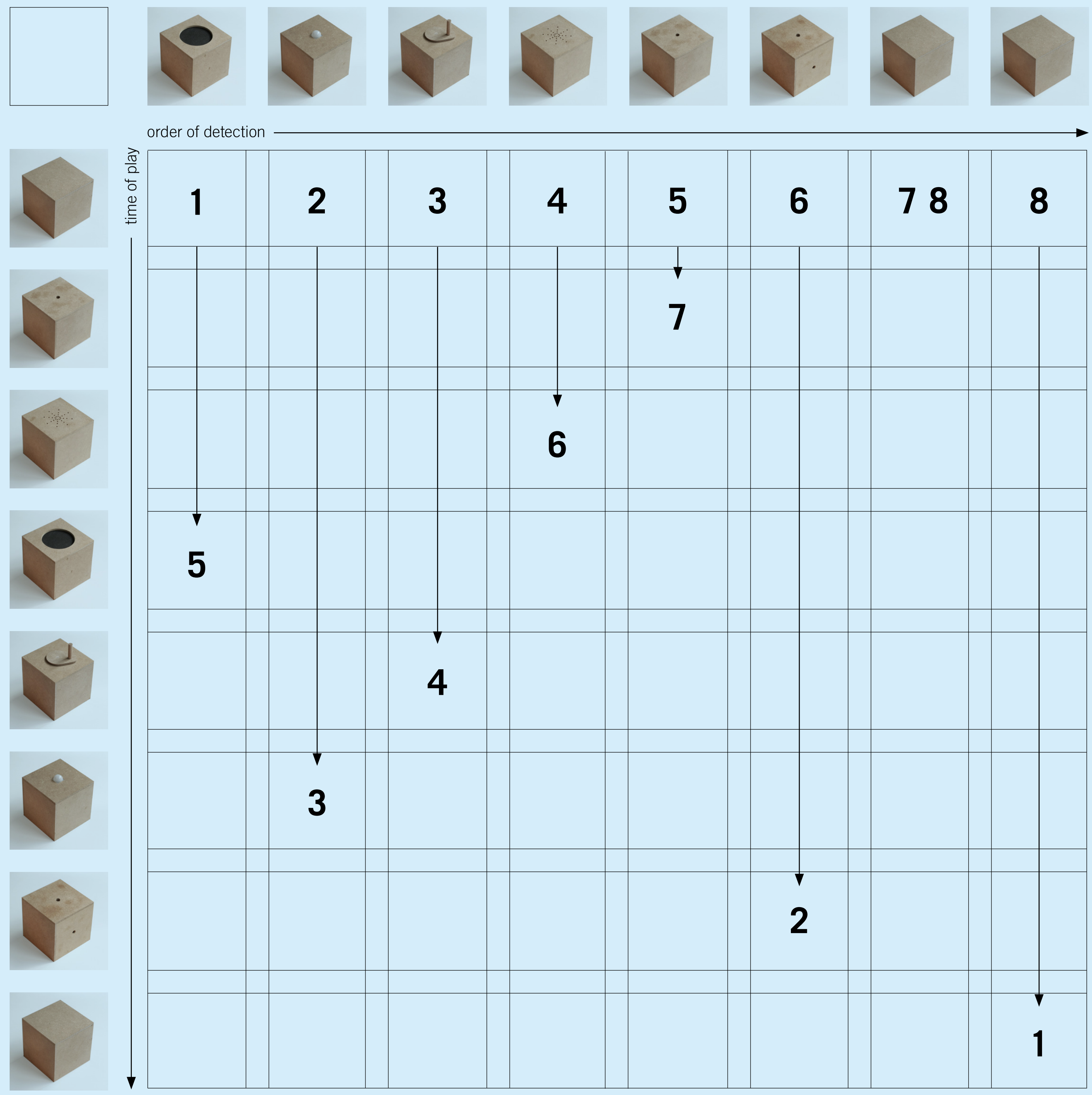


Figure II 01 Comparing the time of detection to the actual time children spend exploring a certain object.

Analog Prototypes with a strong visual affordance engaged the children in exploration and were explored firstly. Therefore, the children approached all the objects in a linear way. One object after the other has been analyzed (looking, touching and complete sensory-motor investigation). After all objects have been explored, the children came back to certain objects and played with them.

The actual playtime children spend with the objects differs from the first approach towards the objects. Surprising and magical affordances kept the children in exploring. The object which was explored lastly has been especially interesting for the children, because it offered the possibility to include various other materials – like leaves and mud.

Objects that have been open to the environment – for example the look through object – evoked social interactions. Closed objects were used to imagine machines consisting out of two or more objects.

Way of Detection

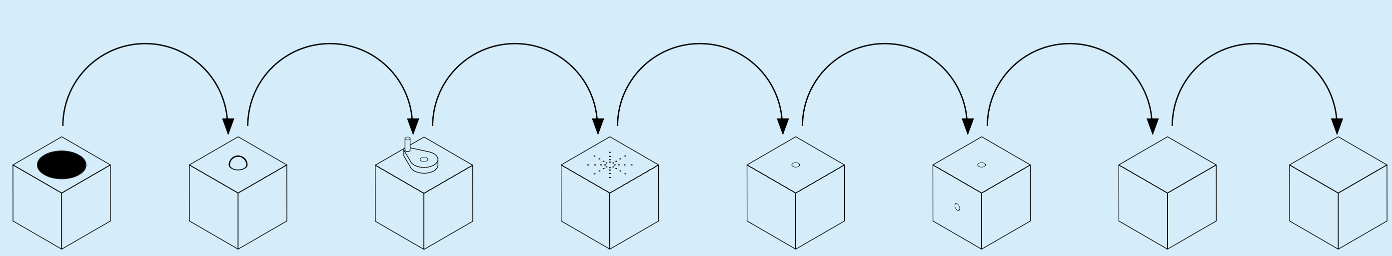


Figure II 02 Way of exploration. Linear, one object after the other has been explored by the children.

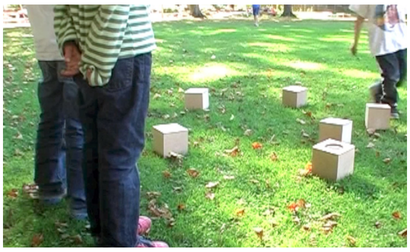


Figure 17 Approach

Far to Near

There has been a clear approach towards the objects. Firstly looking from far away and then coming nearer.

Figure 18 Get in Touch

Sensory Motor Exploration

After visual exploration, the children really got in touch with the objects.

Figure 19 Explore

First ideas

The objects where inspected one after the other and first ideas of usage arrived.

Figure 20 Systems

Building Machines

A strong desire from the kids was to connect the objects in order to build machines or systems out of them.

Figure 21 Social Interaction

Communication

The objects where used as communication medium.

Figure 22 Ventilator

Disassemblement

After disassembling the box, the motor was used to build a ventilator.

looked into the first hole of the object and another in the opposite hole. This interaction enabled them to see each other's eye, which was a lot of fun for them to explore.

The object which had a crank on top was one of the objects the children explored first and there was an immediate and *metaphorical connection* to a coffee grinder. Although the functionality is really banal, the fantasy of the children made it possible that it became another object. This object was also declared to be a trigger for different kinds of reactions – e.g. play back music, let the cubes dance, etc.

All these objects – which provided somehow strong *visual affordances* – were soon accepted as playthings and more and more ideas for reactions and games arrived. On the other hand, the objects which did not provide strong visual manifested attributes were – at the beginning – not as interesting as the others. From the outside they looked simply as wooden cubes, like boxes. The other objects were much more interesting for the kids because they were perceptible from the outside at first sight.

The rattle – for example – was explored by the children lately, but in the course of the observation it was not interesting to them anymore; contrarily to the cube that provided no visible, but perceptible feedback through its imbalance, which gained a lot of attention. They were interested in the kind of feedback of this cube, but even more in the moving part inside. The children began to disassemble the cube, by removing its cover plate and putting things inside (e.g. leaves, stones, earth). For them it was a lot of fun to look how the material began to spin and fly away because of the build in motor. The engagement with this object was very strong. A reason could have been the *multimodal feedback*[15] it provided – unexpected movements, crazy sounds and possibilities seeing things spin around. At the end of the observation, this cube was completely disassembled by the kids to get the motor that was inside. With this motor they were trying to build a ventilator consisting of leaves and mud, to attach the leaves onto the motor.

[15] Multimodal Feedback: http://en.wikipedia.org/wiki/Multimodal_interaction

One more thing which was remarkable happened as the younger girl (3 years) joined the boys at the end of the session. She showed a completely different approach. She was not shy. She immediately engaged with the objects. But it seemed that she was not able to recognize the functionality of the boxes. The only thing she did with the objects was to pile them all on top of each other, and to arrange them in a row on the ground. In this way she used the prototypes passively – without exploring their functionality.

Figure 23 Passive use of the boxes by aligning them in a row.

4.3.3 Emerging social interactions

Besides the children's activity with the cubes, it was very interesting to see in which ways the children *influenced themselves* in their play. This *interference* was invisible for the children because they were concentrated on their play. But it became visible to the observer. The emerging behaviors included *imitation*, *influencing*, and *goading each other* as well as an *exchange of ideas*.

At the beginning of the observation Jan (5) made the first step to explore the objects. The other kids were looking at the objects from a distance at that time. As they realized that Jan was playing already with the cubes, they quickly joined him and searched their own object to explore. The minutes after, the children were looking at each other to see what the other ones just discovered. This way they became more courageous to try the objects themselves.

Once again, this reaction could have been due to their first shyness. It needed at least one child to be the first and most courageous who dared to try the prototypes. When they began to explore the objects they were constantly switching their attention from the cubes to the other children and back to the cubes. In this way they checked what the other children did – in order to not miss out on something they were already exploring. After a while the behavior of looking at each other was discarded and a more relaxed atmosphere for exploration established.

The children started to communicate their ideas and they were thinking collectively about things they could do with the cubes. This phase was characterized through statements like *“Look Jan, what is possible to do with this box!”* or *“We can attach some leaves to make it a ventilator!”*

At most one child expressed an idea to the others, then they tried out collectively the suggested idea. If it worked, or was judged to be good, it was a lot of fun for them. If it failed it was soon forgotten and another idea arrived.

4.4 Conclusion

The children came up with so wonderful, fantastical and creative ideas during the sessions that it would have been difficult to mention all of them. Therefore, I tried to figure out the main points for the kids and included them in the design requirements.

By utilizing Analog Prototypes it was possible to prove first theoretical and hypothetical assumptions gained from the review of background; for example that simple objects could change their meaning and become something else in the children’s minds.

Also, Analog Prototypes were very good to get insights about how children *approach* the objects, how they *interacted* with them, how they *integrate* them into their play. Besides the conceptual findings which could be applied to the design of the later basic interactive objects, it was interesting for me to learn more about the *social interaction* that took place during the observation and the children’s play with the cubes.

Children in this age group (aged five to seven) are able to identify hidden features and functionalities of objects even if they are not perceptible at first sight through exploration. They are also able to think about creative solutions what to do with these objects. In the process of approaching and exploring the objects they act often as a group.

How quick the objects are detected by children is dependent on the physical manifestation of the objects. Although all of the cubes have the same dimensions and were all made of the same material, they differed slightly in their visual appearance because of functional reasons. These differences (e.g. the crank or the hole to look inside the cube) were main influencing factors of how quick the children detected the functionalities. How the children react to the objects is, in contrast, dependent on *hidden qualities* and *imaginative games* the children invented themselves.

Objects

Simple and obvious form guides to immediate detection of the functionality.
Metaphorical connections (e.g. sponge) where naturally for the children.
Common symbols and signs are available for the children (e.g. loudspeaker).
The cover plates could be used to mix the functionalities of the objects.
Distributed objects support single as well as collaborative exploration.
Obvious and banal objects evoke the children's fantasy and creativity.
Building systems consisting of two or more boxes is strongly desired.

Regarding the behavioral insights from the observation it will be interesting, how they will change, if the children are confronted with the interactive prototypes. Will the same behaviors emerge? Will they be stronger? Which kind of other behaviors will emerge?

Behavioral

The first inspection of the objects is visual by looking from far away.
The second step of approaching the objects is through tactile exploration.
The children use metaphorical connections.
Imitation among the kids is a common behavior.
There is also imitation of the behaviors of the objects.
Children are supporting each other by giving and exchanging ideas.
Through collaboration new ideas evolve.
Alternative use-cases were considered.
Small children use the objects without thinking about their functionalities.

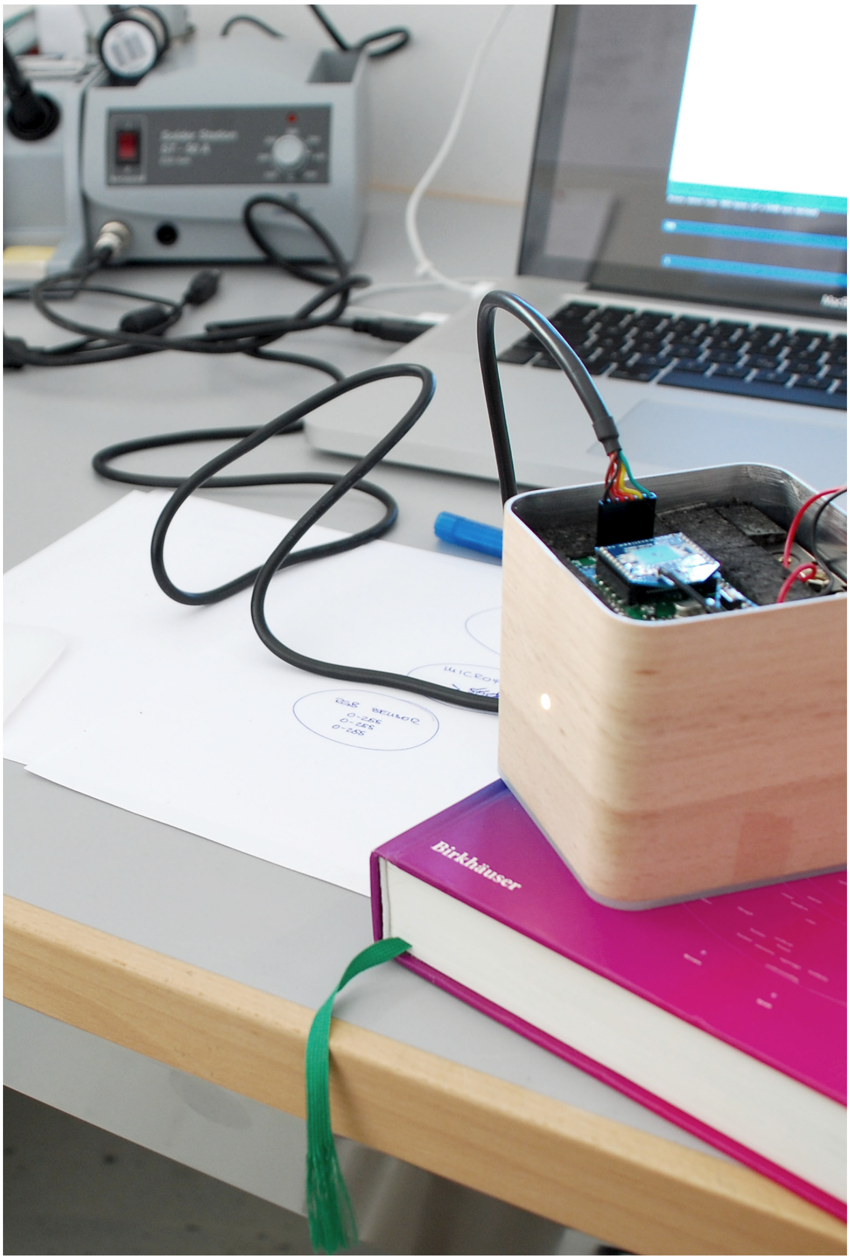


Figure 24 BOXED: Basic Interactive Objects

5 BOXED: Basic Interactive Objects

"Children are empowered when they feel in control of their environment and when they feel they 'own' the environment."
(Druin, Bederson, & Boltman, 1999)

Throughout the review of background and the first contextual inquiry, it was possible to get insights about how children approach basic objects and use them as playthings – as things to *act on*, *act with*, and *act through* (Klemmer, Hartmann, & Takayama, 2006). Alongside it has been demonstrated, that children use the objects *openness* and *undefined spaces* to invent use-cases and games around them.
To approach a concept for basic interactive objects, the findings from the inquiry and the review of background are transferred into design requirements for interactive prototypes.

5.1 Design requirements

The basic form of the cube will be taken over from the Analog Prototypes. This way it will be possible to compare the results of the test with analog abstract objects, to the observations with basic interactive objects. As an outcome of the contextual inquiry the design requirements are categorized as follows.

Openness – Possibilities, channels

The most important fact is openness, which has been already discussed largely in this paper.

Manipulation – Input and Output

Manipulation is possible through the provided input and output. Therefore, a choice of the interactions with the boxes will be discussed.

Reconfiguration – Feedback

One interesting insight from the observation was the exchange of the cover plates of the objects and the combination of different objects to build chain reactions.

The idea behind BOXED is to let the children chose which kind of input and output they would like to connect. That is because it has been discovered that giving the children the freedom of choice about their preferences for interaction would encourage them to explore those objects. Through an iterative design process, consisting of *brainstorming*, *prototyping*, *evaluation* and *discussion*, I have created these objects.

B01 Move in

Pressure

An embedded pressure sensor is able to detect, how strong somebody is pressing onto the stick.

B02 Move out

Movement

Through a servo motor linear up-down movement is produced.

B03 Sound in

Speaking

The build in microphone is able to detect the volume of the surrounding.

B04 Sound out

Hearing

A build-in speaker plays back peep tones with different tone pitches.

B05 Color in

Showing

A RGB sensor is capable to detect the color of objects, which are put on the top surface.

B06 Color out

Viewing

Through a bright LED color is generated in this cube and played back on the top surface.

5.2 Affordances for manipulation

„We still lack well-defined practical knowledge of how to design aesthetic interactions […] knowing what is possible to be manipulated [and] mastering how to manipulate the attributes to shape the interactions.“
(Lim, Stolterman, Jung, & Donaldson, 2007)

Following the argumentation of Lim, Stolterman, Jung and Donaldson (2007), the response of an interactive system is basically formed by input and output. Especially in Tangible Interfaces this is a largely discussed field. Mostly the questions are concerning how to transform a certain kind of input into an adequate output of the system to form *aesthetic feedback*. This transformation is called *mapping* and is formed by designers or technologists to fit best people’s expectations. Therefore, semiotic metaphors are often chosen. An example could be to transform the kinesthetic action of turning a knob clockwise into a sonic feedback – in this case it would be the swelling of volume or the increase in the pitch of a tone.

This is the way *system response* (feedback) is formed. For Jod Goodburn[16] there exists a significant difference in responsiveness and interactivity.

[16] See: http://www.creativeapplications.net/theory/what-is-at-stake-in-animate-design-theory/

Responsiveness is described as a simple cause and effect relationship – for example, pressing a button will turn on or off the light – whereas interactivity is "characterized by a relational and circular (or more complex network) causality" (Goodburn, 2011).

This perspective is also shared by others, quoting that feedback is basically formed by input and output, but is at least a matter of *subjective interpretation* and *context* (Bateson & Mead, 1976).

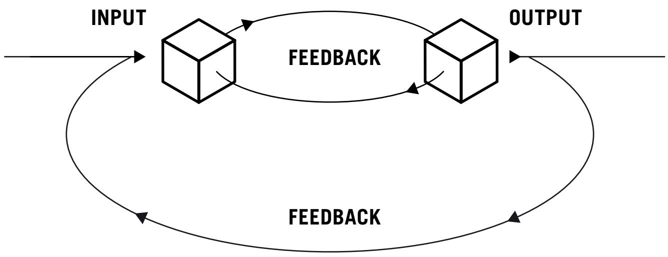


Figure 25 Input Output model as discussed by Brateson and Mead

In return, splitting of input and output onto different objects, means opening *in-between-spaces*. These in-between-spaces of interaction are the basis for the development of BOXED. The mapping delivers the *openness* and space for magical combinations, required by children. It acts like an open space where everything could become possible – light could become sound and kinesthetic movement could become color. Even illogically connections between input and output could become possible. If we enable the kids to choose a specific *input object*, and offer the possibility to connect it to an *output object* it will be observable what will happen. *How will they use the open space between the objects? Do the kids prefer some sorts of input-output combinations? How do they explain the mappings?*

5.2.1 Input–Output pairs

According to Kellman and Arterberry who state that "perception forms the portal between reality and knowledge" (Kellman & Arterberry, 2000), interactions have been explored which stimulate a wide range of the children's senses. In the contextual inquiry with Analog Prototypes I explored and tested a variety of *basic affordances*. To transform the most evident and successful into interactive responses, it has to be taken into account that these inputs and outputs could be *detected* and *produced* by sensors and actuators available on the market. Regarding the insights of the contextual inquiry and through various brainstorming sessions, I explored different types of input and feedback pairs and implemented them in basic interactive objects. The result was a set of three combinations, which allure at least three perceptual levels:

Kinesthetic – Pressure and movement
Visual – Light and color
Sonic – Sound and Structure

5.3 Affordances for reconfiguration

For supporting the children in reconfiguring the objects in various ways – as indicated in the inquiry by replacing the cover plates – it was clear that interactive objects need to have a kind of *connection*, which makes it possible for children to connect the input and output objects in manifold ways. The question arises, how this connection could be established. Basically, there are two ways to connect computational devices in order to enable data exchange. Firstly, this connection could be established physically, possible trough plugs with cables or by attaching the components together. The second technique is a wireless connection.

Wireless communication and transmission of data was found as being sufficient in this use-case as it will enable children to interact with the objects, though they are not physically connected. This will also support the distribution of the objects and the mobility of children. Nevertheless, establishing the connection over distance is much more difficult than having a physical connector – both for the children as well as for being conceptual implemented. Devices that support wireless communication – for example mobile phones, multimedia players or similar – have screens and linking them is done through *onscreen interaction* (choosing a partner to connect, typing in a password etc).

The BOXED objects should not have any display at all. The challenge was to find *a metaphor to connect and disconnect* two objects seamlessly and to avoid interference with the rest of possible actions through a unique gesture.

As described by Kristian Kloeckl (Kloeckl, 2008), there are five qualities which influence the readability of a connection. The most important are to be able to read the status of a connection – connected or disconnected – and a well fitting metaphor how to establish the connection.
An analysis of memorized connecting metaphors shows the wide variety of possibilities. These known connections range from product based (e.g. LEGO or a plug), to more social driven connections (e.g. Handshake). Analyzing the possible connection-metaphors one principle becomes obvious. Physical connections are based merely on a *male-female metaphor*, where two parts fit only in one position. BOXED should offer an open system, where each of the parts could be connected with the other. Therefore, I decided to focus on a *social metaphor*. This seems to be the most natural and playful way to

establish a connection and offers open possibilities for reconfiguration.

5.3.1 Initiate a connection – Handshake

When a connection between two devices is described in technical language, we speak about a handshake as the initial gesture to establish the connection. In this territory the term is borrowed from the social gesture of handshaking – as a guiding act – and is standardized throughout a wide variety of different devices. It could be simply described as follows: first each device has to broadcast its own identification (e.g. *'I am device number four'*). After sending its own information, the device will wait until it receives the identification of another device (e.g. *'Hi device number four, I am device number two'*). Only if the devices know each other they are finally able to communicate together. It is obvious that it is a precondition that each device has to understand the others language in order to start a conversation.

In social communication the gesture of the handshake works in a similar way. By shaking hands, we normally get to know each other better and are able to start a conversation. This analogy was an inspiration for me to transfer it on the cubes for building up a connection and also for breaking the connection when it is not necessary anymore. The developed connection procedure works as follows.

1. Hold two objects close to each other,
2. Shaking both objects together,
3. LED lights up as an indicator if the initialization was a success.

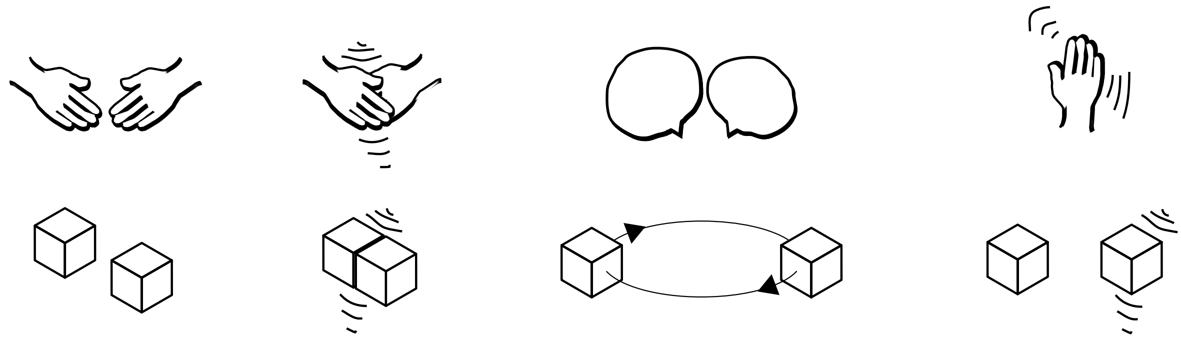


Figure 26 Shake metaphor. The social interaction of shaking hands assinged to the boxes.

During the tests it becomes clear, that the *handshake* works very well, even with children. Shaking is an easy to remember gesture and on a metaphorical level one could say that through shaking the two objects they nearly become one object.

5.3.2 Breaking a connection – Waving goodbye

For breaking an existing connection I stressed the handshake metaphor even further. Thinking once again of *social communication* where we use a handshake in order to start a conversation, we say goodbye by shaking our hands again. I did not want to use the same gesture for initiating and breaking a connection. I wanted to have two particular gestures – one that initiates a connection and a second which breaks the existing connection. At the same time, they should not differ too much – for being remembered easily. I came up with the second important gesture which we use to say goodbye after a conversation: waving hands. Special about this gesture is that it works even over distance.

So, to break a connection one has to shake only one of the two connected objects. In this case the LED indicator turns off and the communication between the objects is stopped.

5.3.3 Topologies

With connected interactive objects the child is in the position to manipulate each object and decide which kind of reaction the manipulation should evoke through connecting a certain type of *input object* with an *output object*. Logical in terms of the concept would be a connection between the pressure-object with the one which represents movement. But as the connections are *not physically manifested* they are open, the children are therefore also able to connect the pressure-detecting object with the one that creates color or sound; in this way BOXED offers many possible topologies.

Even with the very basic possibility for reconfiguration, a lot of interesting combinations could be realized. I also had the idea to create much more possible connections. For example linking two or more input objects to one feedback object, or vice versa: many output objects to one input object. By doing so it could have been possible to manipulate much more points in the environment simultaneously. However, I decided that the possibility to connect only one object with another is sufficient to answer the questions the project is aiming at. Besides this, it offers the kind of simplicity, which I want to achieve – namely to not making the objects complex but to offer possibilities for a rich, simple and playful experience. Linking two objects offers this kind of *simplicity* and enables the children to invent their own use-cases.

Every time two objects are linked, a new form of mapping occurs: mapping pressure to movement, mapping pressure to sound, mapping sound to color, mapping of color to sound, and so forth.

5.3.4 Simple configurations

As described above, with BOXED prototypes it is possible to manipulate and to reconfigure what could be perceived in the environment. To map the inputs to a certain kind of feedback some of the pairs work more intuitively and others are rather complex. For example mapping pressure to a response where a stick moves up and down is simple. The action is directly mapped onto the reaction. The more I press, the more it moves. When pressure is mapped onto sound it is also very obvious. An increase of pressure is used as a trigger for increasing proportional the sound pitch.

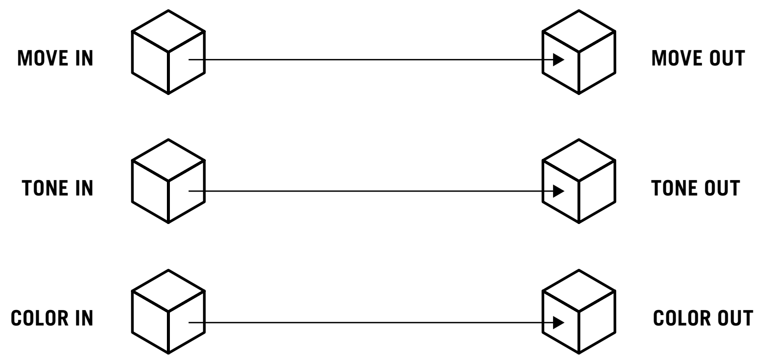


Figure 27 Simple and direct topologies

5.3.5 Complex configurations

A More difficult task is to map not related input and output – for example to map color detection to sound. What kind of sonic feedback should green evoke? Or could you imagine what red sounds like? All these connections are more a question of semantic relationships – and require thinking about these kinds of relationships.

The mapping of color is heavily discussed, even in science. Somehow, there seems to be no common ground for directly mapping a certain color value onto a note or volume. The interpretations are too personal as this will lead to a result which could be accepted by everybody. But it is commonly accepted, that lower tones are darker than higher tones and that loud tones are brighter than soft tones.

The mapping of low equals dark, and high equals bright could be taken as a starting point to realize a somehow logic mapping between color and all of the output objects. But it debars the actual color and takes only brightness into account. For a strict mapping of colors and sound one could reference Alexander Wallace Rimington (Rimington, 1912)[Figure 28] who had developed a color-music code consisting of color values and the resulting tones.
If this topic is so heavily discussed – even in science – will the children find causal or naïve explanations for the mappings?

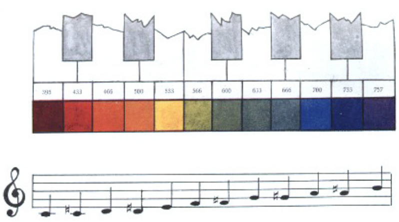


Figure 28 Color to sound mapping by Alexander Wallace Rimington

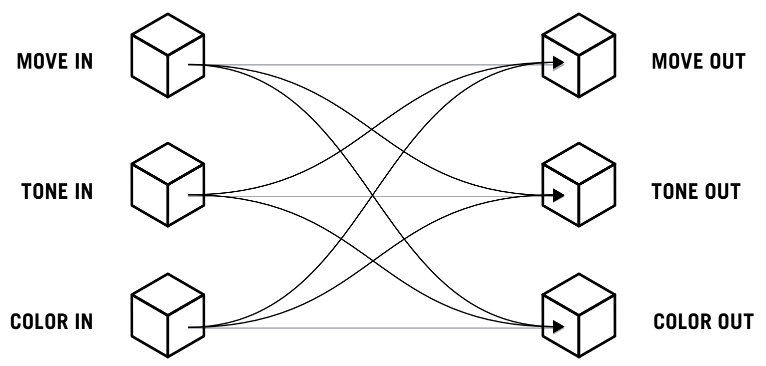


Figure 29 Complex and cross-over topologies

5.4 Interactive prototypes

For actually building the basic interactive objects, I have decided to use the *Arduino*[17] platform. To implement the sensing and actuation capabilities and the connection, I developed a custom circuit board.
During pre-tests, the hardware and software concept had been evaluated together with children and adults. The focus was more on the handling of the objects (*connection, size and appearance*) and the results of this test were implemented in the final prototypes.

[17] http://www.arduino.cc

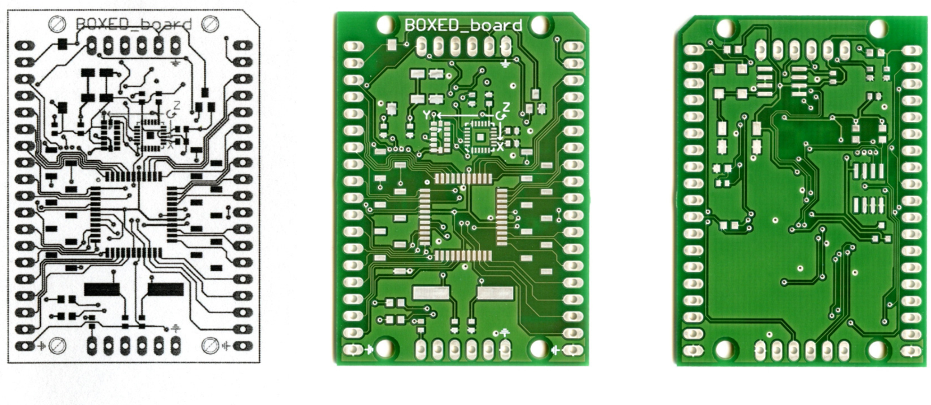


Figure 30 PCB ready for soldering

5.4.1 Hardware Design of BOXED

The basic hardware package consists of an *ATMEL Atmega 644 processor*[18], a *DIGI XBee RF module*[19] and a *Freescale accelerometer*[20]. These three components were at least the minimum for detecting the *handshake gesture*; establish a *wireless connection* and enabling the *integration of analog and digital sensors*.

[18] Atmel ATmega644P: http://www.atmel.com/

[19] Digi XBee Series 1: http://www.digi.com/

[20] Freescale MMA7455L: http://www.freescale.com/

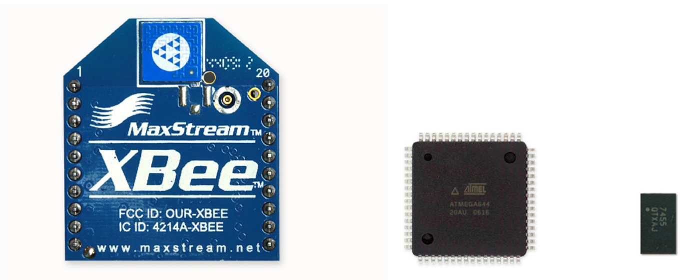


Figure 31 Three main parts of the BOXED prototypes

To be able to build the electronics as small and flexible as possible I decided to develop a special PCB layout. This board was developed around the Atmega644 (details in the appendix) and has *two serial ports*. Using both connections a serial connection to the computer and a connection via XBee have been very useful debugging purposes.

5.4.2 Software Design of BOXED

The software for BOXED is written and developed in Arduino too. The reason is that the Arduino IDE is simple to use, supports a variety of predefined libraries and is at least open source. Arduino was originally created as an educational platform for a class project at the Interaction Design Institute Ivrea and is accepted by many Interaction designers, as state-of-the-art IDE. The focus of the software development was the implementation of the handshake gesture and the general communication protocol.

For detecting the handshake gesture, the readings from the 3-axis accelerometer are used and interpreted to detect, whether an object is shaken. The data, which the sensor delivers, is therefore smoothed and the corresponding force vector including all axis is calculated[21].

[21] For a guide of how to implement IMU readings see: http://www.starlino.com/imu_guide.html

Through measurement of the time interval between shake events above a certain threshold, the handshake is detected. Through tests it has been determined that at least four *shake events* should generate a *shake state*.

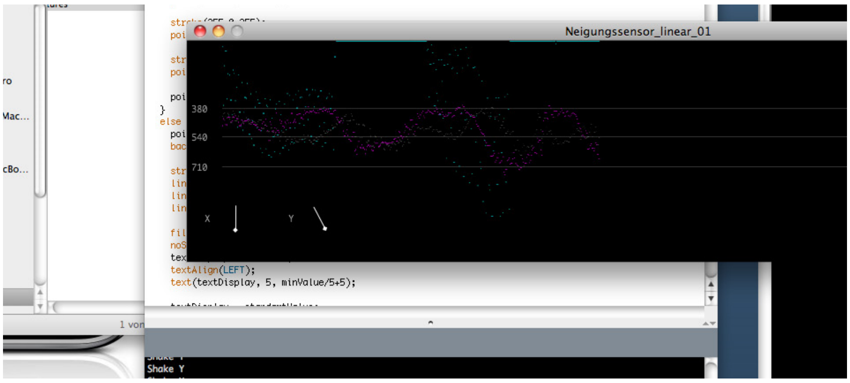


Figure 32 Unfiltered sensor readings

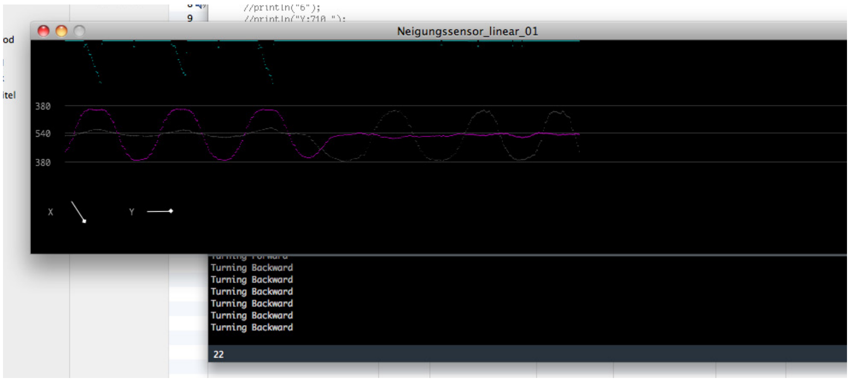


Figure 33 Four sensor readings causing a shakeEvent

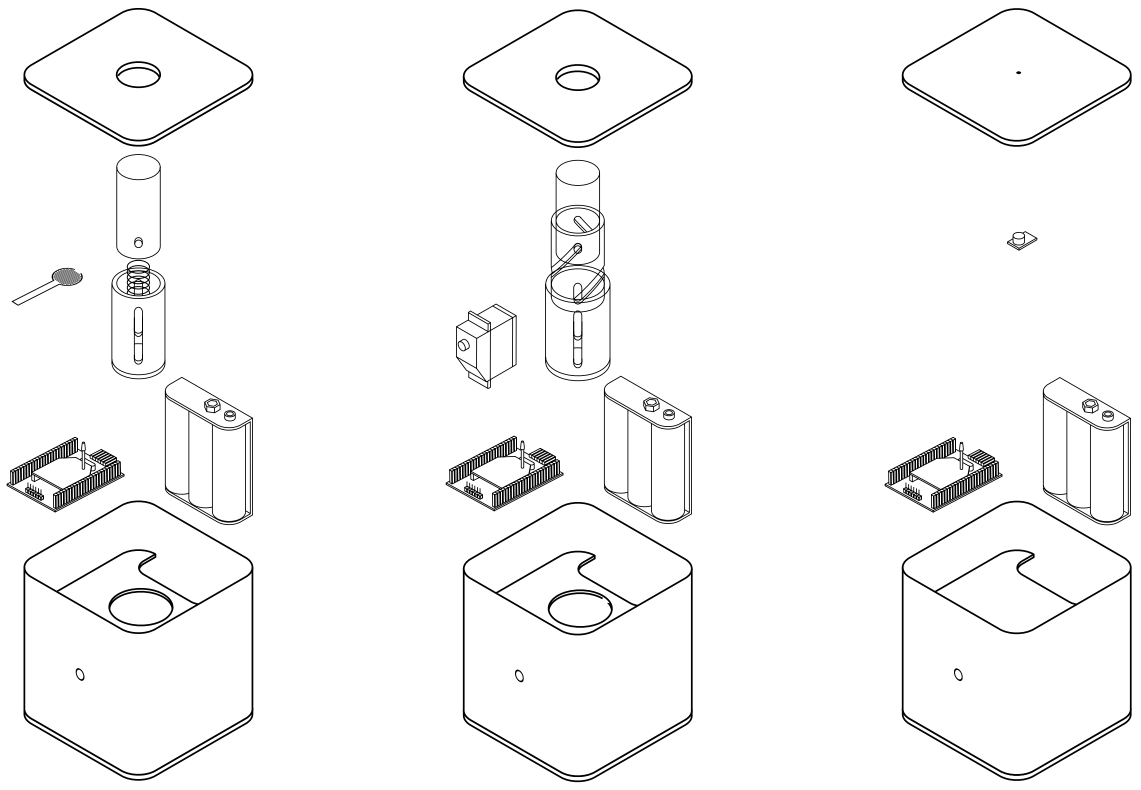
Trough visualizing and analyzing the data, it was possible to set the thresholds for a shake detection and it had become possible to make first tests with people. In this way the handshake gesture was evaluated and finalized.
If the shake state is true, a *connect-request* is sent through the XBee to communicate the *clear to receive status*. If there is a response from another object – using the same method to detect the handshake and sending the request – a permanent connection between those two objects is established.
If an established connection exists, and the shake state occurs again, a *disconnect-request* is sent to the address of the other object.

The data exchange protocol is fairly simple, as the used *XBee library for Arduino*[22] supports a variety of commands. Basically a wrapper containing the address, the data and the data-length is sent between the objects. Through doing so, it does not matter, which data we send, because the receiver knows the address and could interpret the data.

22 XBee Library:
http://code.google.com/p/xbee-api/

```
Tx16Request disconnectRemote = Tx16Request(remoteAddress, disconnect, sizeof(disconnect));
Tx16Request data = Tx16Request(remoteAddress, payload, sizeof(payload));
```

Overall, the combination of an accelerometer and the developed board allows a very reliable way of connecting and disconnecting, as well a quick way to exchange data.



Box No. 1

Box No. 2

Box No. 3

MOVE IN
Force sensitive resistor which is coupled with a wooden staff.

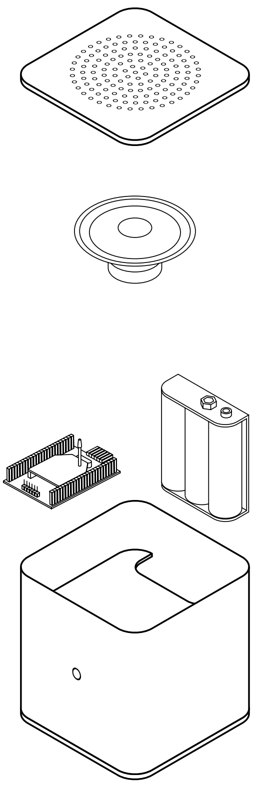
Pressing on top of the staff delivers different value readings at the sensor.

MOVE OUT
Servo motor drives a thread with an attached wooden staff.

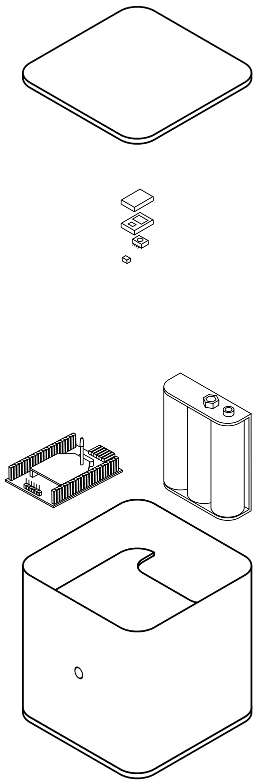
Received data is translated into an angle by the servo and causes the staff to move up and down.

TONE IN
Microphone with a build in preamplifier.

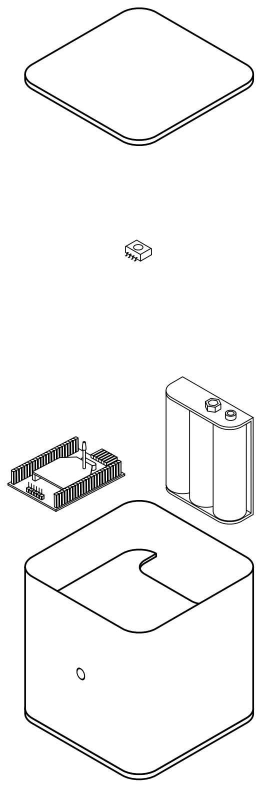
The louder the surrounding becomes or the more one speaks inside the hole, the higher the values are.



Box No. 4



Box No. 5



Box No. 6

TONE OUT
Speaker with the ability to playback simgle tones.

Data is traslated into tones in a range of 100-10000kHz with a lenght of 100ms.

COLOR IN
Color sensor which is measuring the light waves of all RGB colors.

The color is detected by measuring the light waves.

COLOR OUT
Light emitting diode able to display RGB colors.

Incoming data is translated into values for each seperate chanel of the RGB LED.

Figure 34 Playing with BOXED

6 Experiments and Results

I this chapter, the questions that occurred during the project will be linked back to reality. This has been done through mainly two observation setups in different sessions.

6.1 Data Collection

The questions, I were aiming to answer with those experiments included questions about the causal reasoning and explanations from the children, as well as use-cases children invent by using BOXED as a tool to explore within their environment.

6.1.1 Setup and Methodology

Insights gained from the fields of *occupational therapy* lead me to the decision, that it would be useful to scrutinize an occurring behavior or comment by asking the children situational. In this way the child has to *recapitulate* her own behavior. Therapists use this method *to make children aware* of something which just had happened. Thus, this method could be compared to a *Cognitive Walkthrough* or *Talk Aloud Protocol*, which are more common in HCI research; in contrast, it provides *live* and *unfiltered* feedback. The observations took place in the natural environment of the children (e.g. their gardens, children's rooms and school). Environment therefore plays a major role in all of the observations.

6.1.2 Setup 1: How do children describe and rate the objects?

The reason for this setup was to study the reasoning and naïve explanations the children gave to explain the connection and mapping between the objects. Interesting from an point of view of Interaction Design is the question, *if children are able to find causal explanations, and to describe the connections in a logical way? Or whether they will find naïve and rather infantile explanations? Whether they really could or could not imagine, how the connection and mapping works*. Alongside, it will be observable which steps the children take during the involvement with BOXED.

6.1.2. Setup 2: Do children have preferred objects?

To figure out which combinations of BOXED the children prefer, and for what kind of reasons they use them, I chose a passive observation for this setup. Besides asking the children about their preferences, it was important to observe how long they played with a certain combination of boxes. The longer they played with one combination, the more interesting this combination was. This setup is very free and should also demonstrate which use-cases and games the children invent by themselves with and around the objects. To give an overview of the most important points, which occurred during the test situation, and to visualize the spreading over time, I prepared an overview of the tests.

6.2 Findings

Generally speaking, the BOXED prototypes were found interesting from a design perspective. Especially the parents were excited about the basic concept. *"I have never seen a toy, where radio transmission was used in such a way"*. And they emphasized the versatility of the boxes, quoting that this could be very valuable for their children. They even come up with ideas how to promote the concept or develop it into further directions (e.g. as creative tool, something like a Rubik's cube, or as toy for adults).
Besides the parents, the children invented their own ideas and made a lot of comments how the prototypes should be developed further. In contrast to their parents, their ideas were much more concrete, yet imaginative (e.g. make the boxes more stable, the objects should name the colors, providing an on-off switch, providing the boxes within a set, with instruction manual and everything etc.).

SETUP 1	SETUP 2
Cognitive Walktrhough Talk aloud protocol	Participant Observation
Present the method to connect two objects (Pressure and Light)	Present the method to connect two objects.
How do children rate the connections? Do they find causal or naive explanations?	What kind of connections do children prefer and which kind of use-cases do they invent?

Figure 35 Observation Setups.

The generally prevailing shyness has been observable in these tests as well as in the contextual inquiry (**4**). But through engagement with the prototypes this behavior disappeared very quickly.

Although the majority of the children are used to play with electronic toys like the iPod or Playstation, they were very curious to play with the BOXED prototypes.

Six first graders (5-6) playing with BOXED 09.May 2011

This evaluation was conducted in order to answer the questions of the first setup I found that a school might be the most adequate place to test the objects and to observe the children playing with BOXED. The evaluation took place with six first graders in a school in Germany.

The children were picked by their teacher in order to represent a homogeneous group consisting of girls and boys. They were also chosen in order to represent a wide range of developmental stages. The evaluation took place in a small room inside the school. A table with chairs was provided and the session was audio recorded for later analysis. Before introducing the BOXED objects to the children, I did a short warm-up to overcome the first shyness of the children and to get their attention.

The objects were introduced as a whole by placing them on top of the table and telling the children that all of these objects are able *to do something*. To attract their interest they were told that they were the scientists who should investigate what the objects are capable to do. *"I will need you as scientists to try, if the objects work they way they should."*

To explain how to connect and disconnect the boxes, the pressure box was used together with the color box; verbal explanations completed the instruction. Realizing that pressure evokes the color to change was an *aha-experience* for them. Then the children were asked if they would like to try it by themselves – whereupon they all agreed. They tried to connect and disconnect the boxes and commented their actions. *"It is not that complicated." "You only have to shake little."*

Other possibilities for connecting the boxes were suggested by the children themselves: *"And you could place this one on top of the other?"* The boy who introduced the question was asked if he would like to try the new connection. After connecting the pressure with the movement box the reaction once again lead to common amusement. *"There is something coming out!"* The same boy tried to explain what is happening: *"That thing does have a spring ... and a motor. Because there is a noise, there must be a motor!"*

After having realized that it is possible to connect the boxes in various ways, new combinations were suggested: *"Would it be possible to try this?"* Suddenly, all children grabbed one pair and tried to connect them, which resulted in total chaos. This behavior occurred a few times during the session. It happened very often that, after one child detected a new combination which seemed interesting for the others, the other children also wanted to give it a try. Then statements like: *"I would like to try it too!"* or *"Now, it is my turn!"* arrived. For drawing attention to only one connection at a time, I decided that each child could propose a certain connection she would like to explore. The objects were then passed to the children one after the other.

The visual appearance of the objects sometimes caused confusion. For example the sound box was rated as: *"Probably, there are lights coming out"*. But somehow, after heaving explored it the first time, it was remembered which purpose a certain object had: *"What was that again?"* and by turning the box in her hands, looking at it she reminds herself *"...Ah, for shining!"* Especially the color detection box seemed strange to them. The purpose and functionality of this box did not become obvious to the children. *"This one is able to perform magic!"* Although I gave them this box after the others had already been introduced, this was the only object which was disregarded by the children.

Figure 36 Collaboration

By playing together the children had a lot of fun and invented games, which would not have been possible alone.

Figure 37 Concentration

One connection was investigated completely until new boxes were included in play.

Figure 38 Testing

Through examining one functionality, it was figured out how it works.

Figure 39 Trial and Error

Including other combinations into play broadens the horizont and facilitates the emergence of new use-cases and ideas.

Figure 40 Combination

Ever new combinations were explored by the kids, if they failed the next pair were in the focus of their interest.

Figure 41 Integration

Other playthings have been used to extend the abilities of BOXED or simply for having fun.

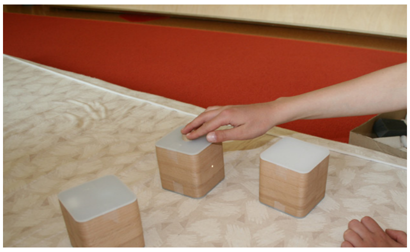


Figure 42 Chain Reactions

Chain reactions have been invented. Some of them were even not designated by the concept.

Figure 43 New Appliances

Abductive explanations for certain reactions were common amongst the children.

Figure 44 Focus

Through focussing a certain connection the children memorized their functionality.

Figure 45 Role models

People like relatives act like role models for the children, but also they had a lot of fun during the exploration of BOXED.

Figure 46 Advising

Through collaboratively thinking about new applications the child orientated himself by other people around.

Figure 47 Integration of the environment

The whole environment could become a part in the play with BOXED.

Sometimes, the reactions of the boxes were compared to already known behavior: *"It sounds like our telephone at home."*

The exploration of BOXED was a matter of trial and error for the kids: *"Hey cool. I have blown in here and then, this one has moved upwards."* Therefore, also combinations occurred, which did not work. For example, if the children connected two input boxes. The explanations for this phenomenon were vague. *"It does not work with these two!" "Why do you think, it does not work?" "Because it does not go through it."* But the children did not get tired to try the connections again and again, until they succeeded. When that happened it was immediately shared with the others, which encouraged them for further exploration.

The ratings of the connection itself were also a matter of fantastical and sometimes very pragmatic and explicit explanations: *"It works with the lights!"* or another child *"It works via radio transmission."*

Social interaction took place during the whole session. But one special situation occurred. After asking the children how they think the objects communicate and the realization that it could only work through radio transmission, one boy was very nervous and presented his idea: *"I have a really good idea. I blow in here and someone else is taking the other box."* He was the first to introduce, that the control and reaction of the boxes could be shareable. In this way, the understanding of the transmission lead to new ideas among the children. By trying this possibility it was interesting to see, that the strict focus on the boxes was relaxed and the children started playing in a more dispersed atmosphere. This test observation in the school had been especially interesting, because it gave a taste of the comments and explanations of children about BOXED and how they explore different ways to handle the objects.

Marc (6) and Florian (9) playing with BOXED 16.January 2011

The prototypes which have been tested together with Marc and Florian were a previous version of the final BOXED prototypes. Nevertheless, they provided the same functionalities. Besides the insights about their integration into play, this test has been conducted in order to find design relevant insights.

After demonstrating how to handle BOXED Marc and Florian were soon immersed in exploration of only the introduced pair of boxes. They firstly tried to find the rule behind the boxes and then invented small games using the boxes. For example they tried to measure the distance the boxes could bridge over. Therefore, Florian took one box and went slowly away from the other box, which was controlled by Marc. As the communication between the boxes began to fade, Florian stopped moving and measured the distance by walking the way back.

The sound box, which had been included in this test, was a previous version and combined both input and output in one box. The children were able to record sound onto the box by simply speaking into it. The recorded sound kept playing back, until a new sound is recorded. It captured the attention on this certain object, although it offered the possibility of being connected to other boxes. By connecting it to the other objects, it would have been possible to manipulate the recorded *sound speed*. But this function did not seem to be as interesting for the children as the simple ability to record and playback sound.

In general, the presented version of prototypes was too big and too heavy for the children in order to handle them. Therefore, some general improvements of the boxes were considered.

Figure 48 Marc and Florian playing with BOXED

I decided to make the prototypes smaller and to separate the sound box into input box and output box in the final version as well. One disadvantage of this decision is that sound processing has to be done on the embedded IO board. The board only provides simple tones and does not support high quality sound.

This first test was very interesting to get first insights and a feedback about the concept of BOXED. It could validate that the handshake gesture works very well and was soon memorized by the children. The improvements of the design have been included in the next version of BOXED.

Florian (9) playing with BOXED 24.April 2011

The introduction of how to connect the objects led to exploration of that certain connection. The action was very focused on one object. Interactivity captured Florian's attention i.e. he did not explore all of the connections first, but kept focusing on one pair.
The introduction of the reconfiguration led to a broader investigation of all objects. Thereby, the focus of attention got broader. Nevertheless, the objects

BOXED Prototypes

× approaching → □ analyzing and playing →

○ social behavior →

comments

- What is this object about? ×
- How does it work? ×
- There is a light inside! □
- It can detect my hand! □
- I have an idea ... □
- This object could be used to do ... ○
- Come on! We try how far it goes! ○
- Now we try this with the other box! ○
- This box could tell what it sees! □
- Oh no, this really does not work ○
- Somebody answers! ○
- I need an object to put on top of it. □
- I take a Playmobil character and place him on the rod. □
- Two boxes and in-between them there are waves. □

actions

Questioning

The questions, which occured were mainly the same as with Analog Prototypes.

Approaching – Explanation

There was an explanatory go-through the objects. Connecting, disconnecting and functionalities have been explained.

Exploring

Through exploration the children firstly explored the single functionalities of one pair of BOXED.

Manipulating

Manipulation of the input has been used at various levels. The children tested and proofed the objects behavior through small games.

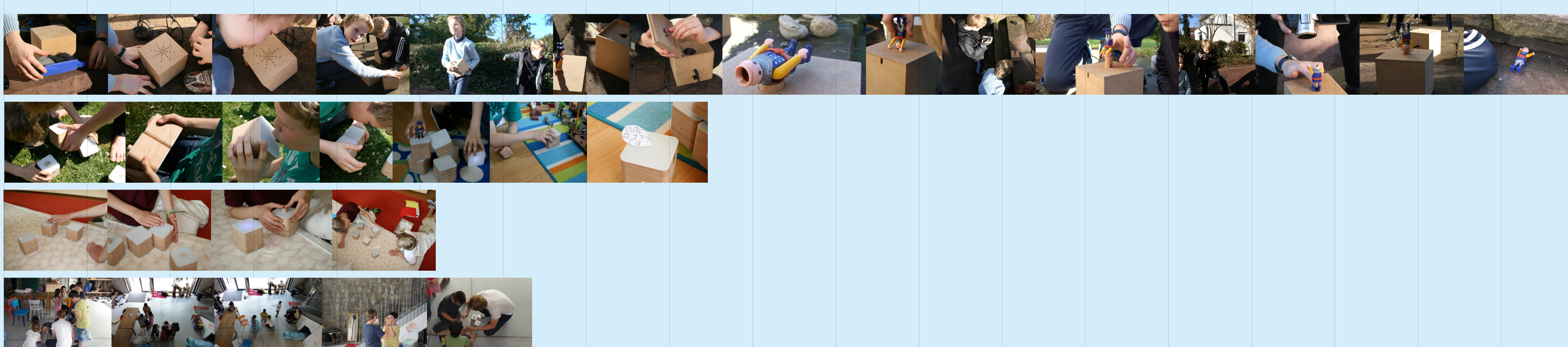
Collaborating

Through thinking collaboratively about use-cases, they found new applications.

Reconfigurating

After a while they start to figure out how reconfiguration and the mix of different input output objects works and what kind of feedback occurs.

filmstrip



Used Combinations

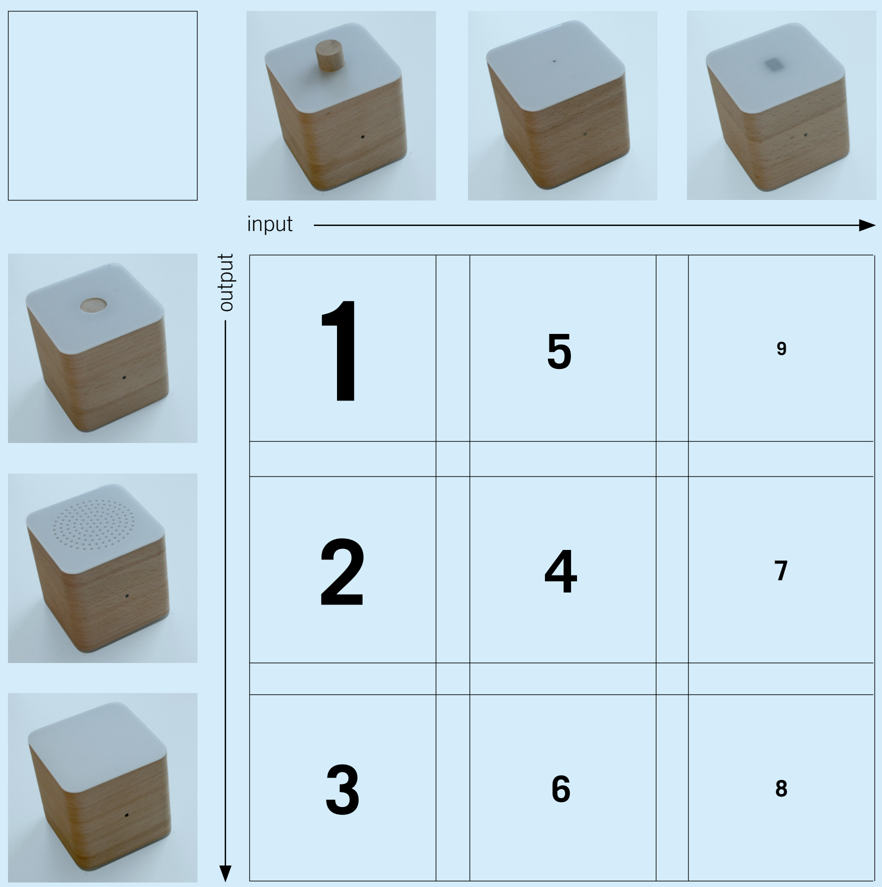


Figure IV 01 Comparing the different input and output boxes to how often children used a certain kind of connection.

Way of Detection

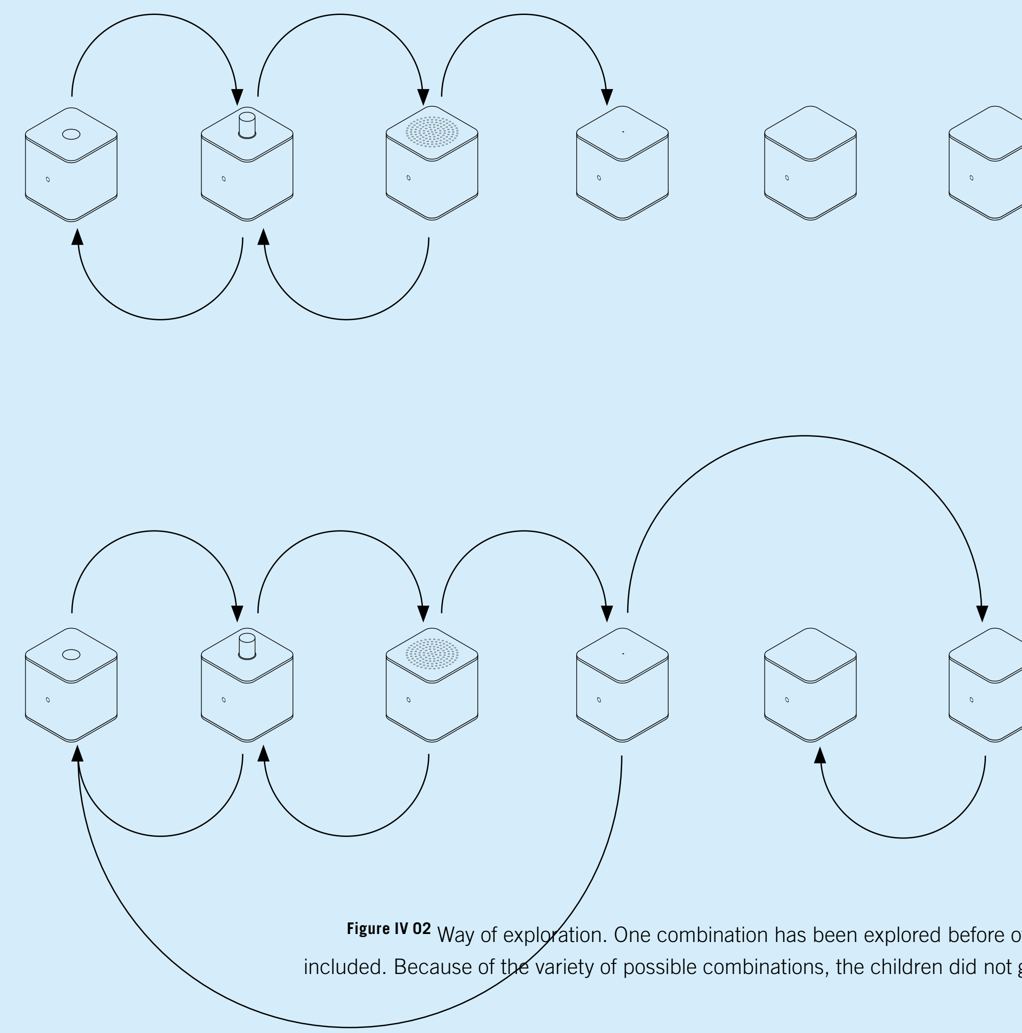


Figure IV 02 Way of exploration. One combination has been explored before other objects were included. Because of the variety of possible combinations, the children did not get tired of trying.

had still been most interesting at this stage.

Figure 49 Florian playing with BOXED

Florian suggested including a manual with the boxes. With this is would be easier to see how to establish all the connections. Besides he quoted that it would be nice to have some examples of how to use the objects. Even though, through further exploration he included more objects into play.

Often questions occurred i.e. *"How does this one work?"* Through providing only directing answers, he kept on playing and tried it by his own. It needs all the steps of approaching and trying the objects to, at least, include other materials and think about different use cases. At this point metaphors as descriptions were given *"The colors are like a bouquet"* or *"It is like it is living. It breathes!"* It needed acceptance of the objects and confidence, before other ideas arose.

Through trial and error with the objects, Florian generated some very interesting ideas what could be done with the boxes. For example he tried to put one box onto the moving box to lift it up, when he pressed at the pressure box. That did not work, as the force was not strong enough. Thus he tried it with a plastic cup, which worked. This trial and error behavior occurred, because the objects were not limited to a specific use case. In this way, the openness of the system evoked Florian's creativity about what kind different other materials could be included.

The functionality of the color box was hard to detect. Only through introduction Florian was able to use this object. Once he realized the functionality, it was fun to him to attach it to the color out box or the sound box to see what happens. Therefore, he slid the color box over the carpet in his room, which consists of colored stripes.

Overall Florian understood the concept of BOXED and showed a variety of different interactions. In this setting it needed a longer time to leave the prototypes at his home and see what happens if he had the possibility to play with them during a longer period of time.

Figure 50 Cuboro: http://www.cuboro.ch/de/Info/Produkte

Cedric (9) playing with BOXED 25.April 2011

Cedric was able to realize very quickly how the connection between the boxes works. He was comparing the BOXED system to his Cuboro**Figure 50** toy at home, quoting that: *"You have to think, to invent new systems. It is not that easy!"* He was very focused in trying different combinations, sometimes stumbling upon things that did not work. For example, he was trying to connect the pressure box with the sound in box, which did not work because they are both input boxes. Asking him why he thinks that this certain combination is not possible, he argued: *"Because you can act on both of them"*.

During the test with Cedric one very special thing happened. As he was trying to put a box on top of the movement box, to see if it is possible to lift it – like Florian did it – he realized that it is impossible, because the movement box is not strong enough. By trying to engage him in further experimentation he decided to connect the pressure box to the color box, which of course worked. Then he took the color-in box and connected it to the sound box, which also worked. By placing the color-in box on top of the color-out box he had created a small chain reaction. Pressing on the first box caused the second box to change in color, which was detected by the third box and send to the fourth box, which finally translated all that into sound. This was a great moment of *delight* for him.

Figure 51 Cedric playing with BOXED

Cedric demonstrated a very different behavior and interaction with BOXED, than the others. He was really focused and engaged into figuring out how he could invent something *out of the boxes*. In this way he somehow reached the limits of the current BOXED system. For him, it would have been nice if there has been another level of complexity. Maybe this would have challenged him to explore further and invent more use cases.

A group of children (5-10) playing with BOXED 11. April 2011

This observation took place at "Kindertreff Viadukt" and was strongly influenced by the environment and the diversity of the children's backgrounds. Kindertreff Viadukt is a place where children are allowed to come for playing in the afternoons. It is designed for those children who would otherwise roam around in their neighborhood. Thus, Kindertreff is a ´melting pot` where different age groups, nationalities and stages of development come together. It was not easy to establish a regular observation setting in this environment. But it was this very atmosphere which made the results especially interesting.

Figure 52 Session in Kindertreff

At the beginning of the observation I introduced the objects and their basic functionality only to a few children. They were highly motivated to start playing with the objects. Therefore, they took the objects in their hands and tried to realize different combinations. Some children, who first watched the others playing, joined them, and, after a short time, a whole bunch of children surrounded the objects – which resulted in total chaos. Each child wanted to have a try and shaked the boxes, because this method was adopted without really realizing the functionality behind it. Through the variety of different interactions it was nearly impossible to establish a proper connection between the objects. If it happened by chance, the children were bound to this hazardous combination.

After a while, most of the children lost their interest in the objects and focused on other games and toys. Only a few children who were really interested stayed and investigated further in how the objects work: "How did you do this?" "How do the cubes work?" Through the investigating the boxes the kids explored manifold connections. If they found a pair which worked, they were very focused and concentrated. For example, they pressed carefully to change the color or they took the sound object near their ears, whereas another child spoke into the microphone.

Large and unstructured groups seem to be inappropriate for playing with BOXED. There are too many factors of interference which disturb the exploration of the objects and their possible functions. In unstructured setups, children who expect a quick effect, soon turn away from BOXED and focus on other playrooms. Then, it needs their concentration and caution to establish a connection and then investigate what the boxes can do.

6.2.4 Emerging social behavior

The emerging social behavior whilst engaging in the play with BOXED varied in every session and could not be directly compared. It was dependent on various factors of influence such as the people around and the location. Still, some common behavior occurred and should be documented.

The children encouraged each other to invent new possible combinations and use cases: *"Look Flori, i've got and idea… .I've got an idea, Flori…!"*. In this way they motivated themselves for further exploration.

Other people encourage the child for further exploration and thus a deeper understanding of the objects. For example in the test with Florian through the engagement of his father and sister Florian took the role of an expert and explains the functionality. *"You know daddy, you can shake these boxes and then they are connected"*. This also encouraged him in deeper understanding of how the boxes work.

6.3 Conclusion

At the beginning it is important to demonstrate how the connection between the boxes could be established. Most of the time the children kept exploring that certain combination and did not try other possibilities. But then, after a while, they use the new insights to think about new applications.

The difference to the observation with Analog Prototypes becomes clear. Whereas Analog Prototypes where all basically explored after approximately five minutes, the interactive objects captured the children's attention right away. Hence, they need longer time to investigate into one combination. This insight could be compared to what Ackermann points out. Interactive, animate objects are challenging the understanding of how things work (Ackermann, 2005). They inhabit the ability of surprise – when something magical could be described logically and causal. Therefore, they capture the attention of the child until she has found a logical explanation for that certain phenomenon. By realizing that input and input did not work together and the invention of the chain reaction, Cedric demonstrated ways to think laterally. When this works with that, then, this has also to work with this. But input and input could not work together, because they are both an input. So, input could only work with output. But when combining two pairs of input and output then the system could be extended.

The steps which children followed in exploring BOXED are as described below. These steps were observable in all of the conducted observations and have been preserved to emphasize the most important points.

1. *Cool!* (Astonishment)
2. *Can I try it?* (Urge for investigation)
3. *That is because there is a hole.* (Explanation naïve and explicit)
4. *I blow in here, and then this one moves.* (Affirmation/Reassurance)
5. *I have an idea!* (Other use-cases emerging)

The observation of children whilst playing with BOXED demonstrated ways, in which they use the objects. It has become clear, that BOXED could be used as an explorative and creative tool to encourage investigation about certain phenomena.

However, it would have been interesting to see what happens if children are able to keep the objects at home and play with them over a longer period of time. Therefore, some improvements of the design would have been necessary (e.g. reloading the batteries, easy on-off function and improvements of the code). This was not possible to realize until the end of this project, but I see the chance to develop BOXED further into this direction. The BOXED prototypes seem to be a stable platform for future research and the first results are very promising.

Figure 53 Observable order of events with BOXED prototypes.

Figure 54 Playing with BOXED

7 Discussion and Outlook

7.1 Overview

In this thesis I have introduced BOXED – basic interactive objects – which encourage active play. Therefore, I have drawn upon the insights of *playing as learning*, the *magical qualities of objects* and a *tangible approach* to actually create objects, which offer a way of manipulating and reconfiguring certain aspects of the environment.

It was demonstrated that, especially by forming the *feedback*, children were encouraged to include various parts of the environment (movement, color and sound) and to explore how their inclusion affects the feedback. Secondly it shows the *social interaction* when children are playing with the BOXED prototypes. This social behavior has been observed and categorized in order to provide an overview of the most common *use-cases* and *interactions*.

During the observations with Analog Prototypes it has become clear, that even inanimate objects could inhabit magical qualities, which engages children in exploration and imagination. With BOXED prototypes I am able to reassert the proposition that especially animated and interactive objects could serve as amplifiers for active play and questioning causal dependencies of objects. The reason for this is the own behavior computerized objects have.

7.2 Design discussion

Trying to summarize and conceptualize all the insights I have gained during this project, I hypothesize that the magic in every interactive system is the driving force for exploring and investigating. Therefore, embodied interaction within the real world is strongly desired. When causal reasoning could be used and applied to an interactive artifact it leads to understanding of how the thing works. The integration into everyday experiences or disregarding the possibilities of a basic interactive object is then a matter of openness (system) and personal preferences (subjective interpretation).

Curiosity enables the child to explore without pre-assumptions about reactions or with general expectation about what an object should or should not do. Children simply try the objects out.

The children’s natural advantage over adults could therefore be described as the urge for exploration and not so much the dependency onto strong visual affordances of an object.

7.3 Outlook

During the observations many other ideas arrived of hat could be done with the basis BOXED creates. These ideas were suggested from the children as well as from their parents and siblings. Not all of these ideas and comments from the final observations are included in the design of BOXED, due to time reasons.

I do see the chance to include those in a future version of BOXED – which could be also larger discussed with experts in the fields of *developmental psychology* and *occupational therapy.*

Whereas we have seen BOXED prototypes been used by children, one possible future direction could be the use of BOXED prototypes as a creative tool for *Interaction Designers*. It allows ways to think about new kinds of input and output criteria of interactive systems, without having to concern about the actual hardware implementation. By providing BOXED prototypes to designers, it would be possible to use them like the kids did: *As open tools for exploration of input and output, respectively the resulting feedback*.

Another possibility could be seen in therapeutic applications. In this emerging field the BOXED prototypes could serve as platform to build tools for children, who suffer from *attention deficit hyperactivity disorder (ADHS)* to encourage a focused and concentrated way *to situate them in their environments*. This has been discussed with occupational therapists who see a chance of developing BOXED further into this direction.

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List of Figures

Preface

Introduction

Review of Background

Questions and Methodology

Contextual Inquiry

BOXED: Basic Interactive Objects

Experiments and Results

Discussion and Outlook

Appendices

A. Further readings

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Edith Ackermann *giving a talk at Walkercenter*: http://www.youtube.com/watch?v=l3jI19vR5bI&feature=player_embedded

Alan Kay *Doing with Images makes Smybols* http://www.archive.org/details/AlanKeyD1987

B. Code snippets

```
SETUP;
READ ACCELEROMETER;
SEND SHAKE STATUS;
READ XBEE;
CONNECT/DISCONNECT;
LED DRIVER;
SEND/RECEIVE DATA;
```

Figure 01 Overview

This figure demonstrates the principal software-logic. The structure is applied to all boxes, whether they are input or output objects.

The SEND/RECEIVE DATA is dependend on the used sensor or actuator.

```
void setup()
{
  Serial.begin(9600);
  xbee.setSerial(Serial1);
  xbee.begin(9600);
  pinMode(sleepPin, OUTPUT);
  digitalWrite(sleepPin, HIGH);
  pinMode(greenLED, OUTPUT);
  setupMMA7455();
  initMMA7455(SENSITIVITY);
  Serial.println(„Ready!“);
}
```

Figure 02 Setup

In the setup() routine the two serial ports and the basic pinModes are defined.

Serial is used for programming and communicating with the computer, whereas Serial1 is used for communicating via XBee.

During setup() the MMA7455 is powered up and measurement range is selected (2g, 4g, 8g).

```
void setupMMA7455()
{
  pinMode(POWER_PIN, OUTPUT);
  digitalWrite(POWER_PIN, LOW);
  Wire.begin();
}
```

Figure 03 Setup for MMA7455

Pin 23 is used to power the I2C devices. By pulling it to LOW VCC /I2C is turned on.

```
void initMMA7455(int gSensitivity)
{
  delay(1000);
  Wire.beginTransmission(MMA7455_I2C_ADDRESS);
  Wire.send(0x16);
  if(gSensitivity == 2)
  {
    Wire.send(0x25);
  }
  if(gSensitivity == 4)
  {
    Wire.send(0x29);
  }
  if(gSensitivity == 8)
  {
    Wire.send(0x21);
  }
  Wire.endTransmission();
  delay(1000);
}
```

Figure 04 Initialize the sensitivity of the MMA7455

Through the Mode Control (0x16) the measurement range is selected. Delay(1000) waits until the MMA7455 has fully powered up.

2g = 0x25

4g = 0x29

8g = 0x21

```
unsigned char readRegister(unsigned char axis)
{
  unsigned char buffer;
  Wire.beginTransmission(MMA7455_I2C_ADDRESS);
  Wire.send(axis);
  Wire.endTransmission();
  Wire.requestFrom(MMA7455_I2C_ADDRESS, 1);
  buffer = Wire.receive();
  return buffer;
}
```

Figure 05 Reading the MMA7455

The readRegister() function is called everytime the sensor should be read. readRegister() has to be called seperately for every axis.

X Axis = 0x06
Y Axis = 0x07
Z Axis = 0x08

```
void shakeDetection()
{
  char xVal = readRegister(X_OUT);
  char yVal = readRegister(Y_OUT);
  char zVal = readRegister(Z_OUT);
  shakeVector = sqrt(sq(PREVxVal-xVal)+sq(PREVyVal-yVal)+sq(PREVzVal-zVal));
  if(!shakeCase)
  {
    if(shakeVector>shakeThreshold)
    {
      if(!firstShake)
      {
        shakeTimer = 0;
        shakeCounter++;
        firstShake = true;
      }
      else
      {
        if(shakeTimer<shakeOverallTime)
        {
          shakeCounter++;
        }
      }
    }
    if(firstShake)
    {
      if(shakeTimer>shakeOverallTime)
      {
        firstShake = false;
        shakeCounter = 0;
      }
    }
    if(shakeCounter>shakeMinCounter)
    {
      shakeCase = true;
      shakeTrue = millis();
      shakeCounter = 0;
    }
  }
  if(shakeCase && millis()-shakeTrue>shakeTimeOut)
  {
    shakeCase = false;
  }
  PREVxVal = xVal;
  PREVyVal = yVal;
  PREVzVal = zVal;
  shakeTimer++;
  shakeDelay = millis();
}
```

Figure 06 Shake detection calculation

The shakeDetection() routine returns the shakeCase which indicates, if a box is shaken. Therefore, the shakeVector is calculated and compared to a defined threshold. When the shakeVector value extends the threshold four times during the time of shakeTimeOut shakeCase is set true.

```
if(millis() - shakeDelay > shakePeriod)
{
  shakeDetection();
}
if(shakeCase)
{
  if(millis()-lastShakeEvent>shakeEventOut)
  {
    if(!thisNode)
    {
      connectXBEE();
    }
    else if(thisNode)
    {
      disconnectXBEE();
    }
  }
}
```

Figure 07 Shake detection trigger

A true shakeCase effects thisNode to change its state and sends a connectXBEE() or disconnectXBEE() wireless to the other nodes.

```
xbee.readPacket();
if(xbee.getResponse().isAvailable())
{
  switch(xbee.getResponse().getApiId())
  {
  case RX_16_RESPONSE:
    {
      Rx16Response retrieveData;
      xbee.getResponse().getRx16Response(retrieveData);
      if(retrieveData.getData(0) == 'A')
      {
        if(!remoteNode)
        {
          remoteNode = true;
          disconnectTimer = millis();
          remoteAddress = retrieveData.getRemoteAddress16();
        }
      }
      if(remoteNode && thisNode)
      {
        if(retrieveData.getData(0) == 'B' &&
        retrieveData.getRemoteAddress16() == remoteAddress)
        {
          disconnectXBEE();
        }
      }
      else if(remoteNode && retrieveData.getRemoteAddress16()==remoteAddress)
      {
        if(retrieveData.getData(0) == 'B')
        {
          disconnectXBEE();
        }
      }
    }
    break;
  }
}
if(thisNode && !remoteNode)
{
  if(millis() - disconnectTimer > disconnectMax)
  {
    thisNode = false;
    remoteNode = false;
    remoteAddress = 0xFFFF;
    disconnectTimer = millis();
    lastShakeEvent = millis();
  }
}
```

Figure 08 Connection logic

The XBee is readout looking for a remoteNode sending a connect or disconnect announcement. Therefore, 'A' stands for a connect announcement and 'B' stands for a disconnect announcement.

If a connect announcement is received, the address of the sender is stored in remoteAddress.

A disconnect announcement is only accepted, if the address of the sender is already known and stored in remoteAddress.

If thisNode is true (trough shakeDetection routine) and no remoteNode sends neither a connect, nor a disconnect announcement, thisNode is reset.

```
void connectXBEE()
{
  thisNode = true;
  disconnectTimer = millis();
  lastShakeEvent = millis();
  Tx16Request connectsRemote = Tx16Request(remoteAddress, connects,
  sizeof(connects));
  xbee.send(connectsRemote);
}
```

Figure 09 Connecting the boxes

This part represents how a connect announcement is send via XBee.

The Tx16Request connectsRemote contains the actual data (Address if known/broadcast if unknown, 'A', the size of the sended data). xbee.send sends the data via XBee.

```
void disconnectXBEE()
{
  thisNode = false;
  remoteNode = false;
  disconnectTimer = millis();
  lastShakeEvent = millis();
  Tx16Request disconnectRemote = Tx16Request(remoteAddress, disconnect,
  sizeof(disconnect));
  xbee.send(disconnectRemote);
  remoteAddress = 0xFFFF;
}
```

Figure 10 Disconnecting the boxes

The disconnect announcement is send the same way as the connect announcement.

After sending the disconnect announcement is send out, the remoteAddress is reset to broadcast (0xFFFF);

```
void ledConnection()
{
  if(thisNode && remoteNode)
  {
    digitalWrite(greenLED, HIGH);
  }
  else
  {
    digitalWrite(greenLED, LOW);
  }
}
```

Figure 11 LED Connection

If a connection exists – indicated through thisNode and RemoteNode – the indicator LED is set to HIGH.

If a connection does not exist the indicator LED is set to LOW.

C. Schematics

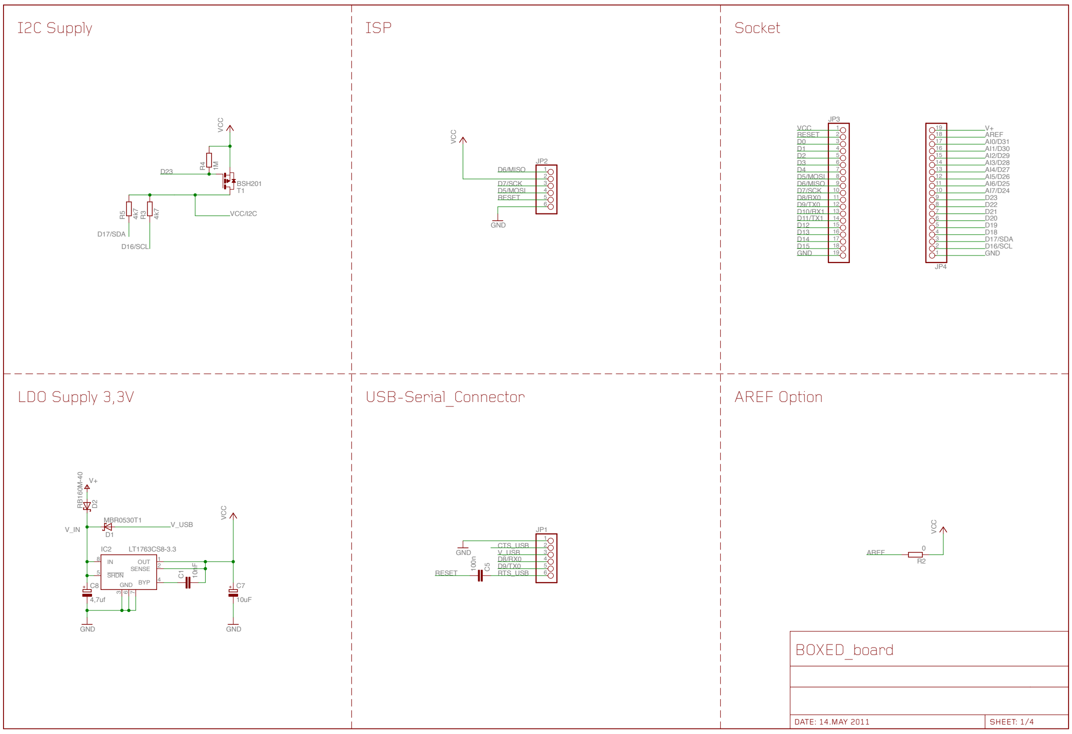

Figure 12 BOXED_board schematics 1/4

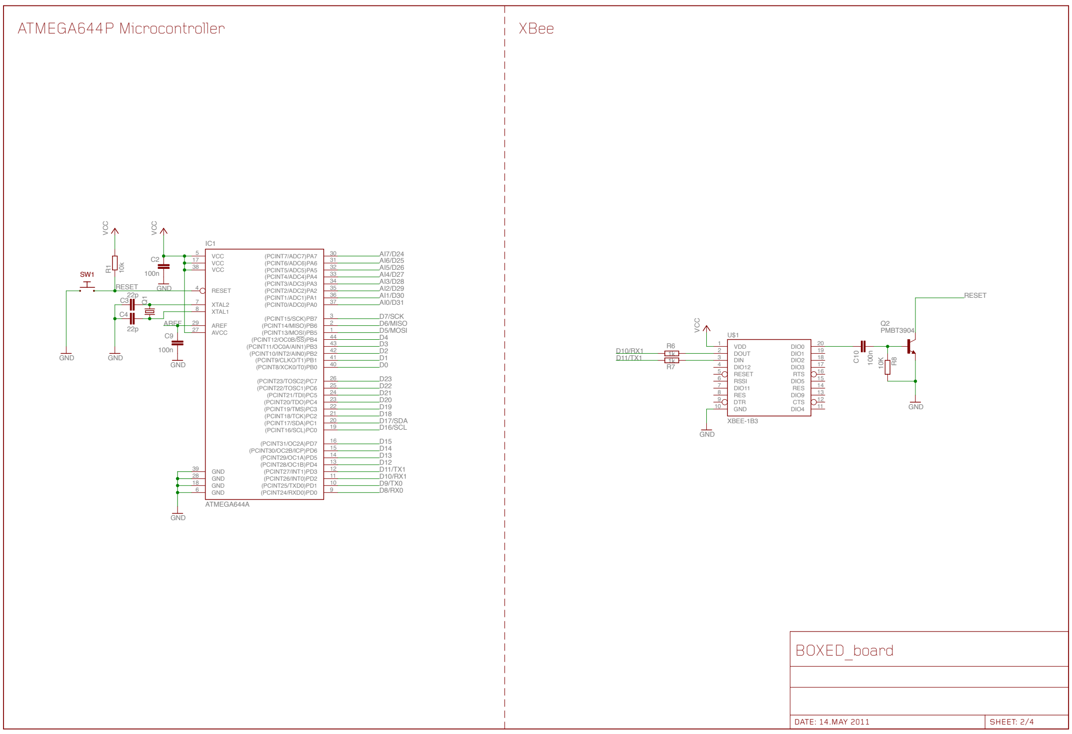

Figure 13 BOXED_board schematics 2/4

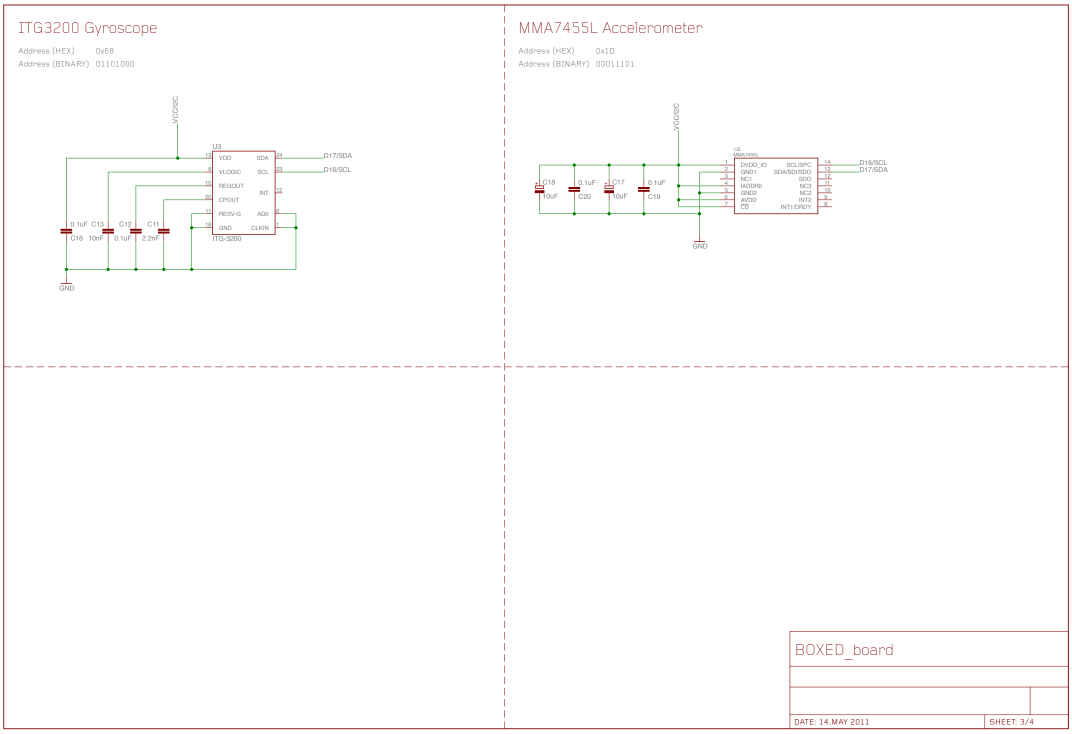

Figure 14 BOXED_board schematics 3/4

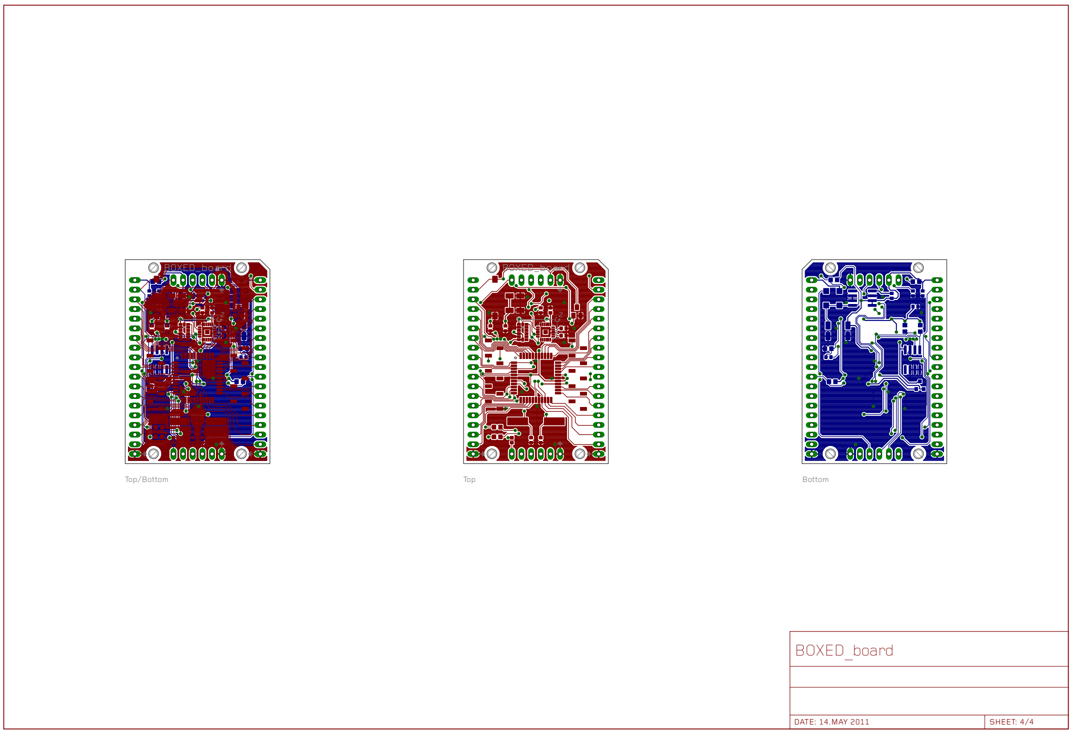

Figure 15 BOXED_board schematics 4/4