ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

EMBODIED INTERACTION:
A CASE FOR A PLAYFUL LEARNING

M.Sc. THESIS

Özde ÖZDAL

Department of Informatics

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MAY 2015

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Thesis Advisor: Assoc. Prof. Dr. Mine ÖZKAR

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Özde Özdal, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID **523121011**, successfully defended the **thesis** entitled "**EMBODIED INTERACTION: A CASE FOR A PLAYFUL LEARNING**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Assoc. Prof. Dr. Mine ÖZKAR** Istanbul Technical University	....
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Date of Submission : 4 May 2015
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To my family,

FOREWORD

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Özde ÖZDAL
Architect

TABLE OF CONTENTS

Page

ABBREVIATIONS

HCI	**:** Human Computer Interface
TI	**:** Tangible Interaction
TEI	**:** Tangible Embedded Interaction
WIMP	**:** Window, Icon, Menu, Pointing Device

LIST OF TABLES

Page

LIST OF FIGURES

Page

EMBODIED INTERACTION: A CASE FOR A PLAYFUL LAERNING

SUMMARY

For a child, play is one of the most suitable ways to try the ideas and advance in knowledge without being controlled by grownups. In the absence of a limitation, every item and present environment become a proper medium in a child's mind and/or imagination.

As children use their senses to interact with the physical world, by creating new interactions, our spaces could become the medium of today's playful learning environment.

With the ability of being unprejudiced, children could use exploration and basic reasoning to amass inputs from the surroundings. Within this context, children naturally gain experiences by exploring and interacting without secondary thoughts in mind. This simple ability could contribute to the design of enhanced spaces, materials and objects embodying interaction for playful learning. From this understanding any environment and any object existing in the environment holds the potential of becoming the material of the play.

The presence of technology can be always argued. With the power of computation, by using embedded systems, it is possible to enrich every material, accordingly every object and space. This enables spaces to increase their interactive affordances, leading a more unified relation between the physical and the digital world.

The design of interactive environments is founded on the idea of building knowledge through manipulation and transformation of interactions. To provide a joyful sense and motivation, physicality and accordingly the interactions hold an important place in a child's learning process.

The purpose of this thesis is to explore the potentials of embodied interaction within the space as a medium, which encourage children in their natural playful learning process with the help of technology enhanced environments with the isuues of use of technology for learning in free-play, interactive settings and space as a technology embedded medium.

This thesis envisions an idea with the objective of generating a prototype of an interactive space, which is the result of literature as well as the author's observations and experiments. The prototype is developed through both physical and digital experiments regarding playful learning. The experiments were carried out in two phases. First, the preliminary setup (the analog phase), secondly, the interactive prototype.

In the first phase, a physical experiment was conducted with two four years old children to observe the free play with/within the affordances and the limits of the environment. This study enabled the observation of the behaviours of participants in a free physical environment.

In the second phase, the translation of physical data into digital is explored via experiments, which were carried out by the author with the results of the first phase. Also, the children from the preliminary setup participated in this experiment to play with the developed prototype. The aim was to collect data by analyzing the inherent actions of children and the process of making sense during play. As the physical experiments were dynamic systems by their nature, this aspect is represented in digital medium as well to visualize and analyze the potential advantages and deficiencies of such interactive environments for learning. For digital manipulations, Arduino is selected, since this medium is capable of transforming and representing analog data into digital and/or physical data.

The focus of the research is to develop knowledge that is acquired from the both digital and physical experiments. The developed prototype basically captures and transforms the analog data into an interactive medium where children could use their reasoning for occurring representations in the process of playful learning. Consequently, the study aims to find one of many answers to the idea of creating spaces that encourage children in experiencing playful learning through interaction.

ÇEVRE İLE BÜTÜNLEŞEN ETKİLEŞİM: OYUNLA ÖĞRENMEYE BİR ÖRNEK

ÖZET

Oyun, bir çocuk için yetişkinlerin kontrolü altında olmadan fikirlerini deneyebileceği ve bilgisini artırabileceği en uygun yollardandır. Kısıtlamalar olmadığında, her şey ve yer çocukların zihni ve hayal gücü için uygun bir zemin haline gelir.

Çocuk fiziksel dünya ile etkileşiminde duyularını kullandığında bulunduğumuz mekanlar da oyunla öğrenme materyaline dönüşür. Böylece çocuk ikincil yöntemler olmadan, etkileşerek keşfedip araştırarak doğal sürecinde deneyip yaşayarak bilgi ve deneyim kazanır. Bu bağlamda çocuğun çevresinde bulunan her mekan ve nesne oyunun bir parçası haline gelme potansiyelini içinde barındırmaktadır. Çocuğun mantıksal çıkarım ve hayal gücüne bağlı olarak çocuk, çevresinde sonsuz sayıda oyun kurabilir. Çevreyle kurulan bu doğrudan ilişki ise oyunla öğrenme sürecinin içinde bulunulan çevredeki nesnelerin, malzemenin ve mekanların tasarımına katkıda bulunabilir.

Teknolojinin artık yaygın bir çevrede görülebilir. Bilgisayım sayesinde, bütünleşik sistemler aracılığıyla, bu oluşumların etkileşim yeterliğini artırmak mümkün olur. Mekanların etkileşim yeterliğinin artması ise dijital ve fiziksel dünyanın daha bütünleşik olmasına olanak verir.

Etkileşimli ortamların tasarımı, etkileşimin dönüştürülmesi yoluyla bilgi oluşturma fikri üzerine kurulmuştur. Fiziksellik ve buna bağlı olarak etkileşim çocuğun öğrenme sürecinde duyulara hitap eden ve motive eden bir zemin oluşturulması anlamında büyük önem taşır.

Bu tezin amacı çocukların doğal ortamlarında oyunla öğrenmesini destekleyen teknolojik yönden zengin mekanlarda, gömülü etkileşimin barındırdığı potansiyelleri keşfetmektir. Tezin araştırma sorusu için temel oluşturan üç başlıca konu tartışılacaktır: Teknolojinin öğrenme için oyunda nasıl kullanılabileceği, etkileşimli kurulumlar ve teknolojik yönden zenginleştirilmiş mekanlar.

Bu çalışma literatür, gözlem ve deneylerden elde edilen veri ile etkileşimli mekanlar için bir prototip oluşturma amacını taşımaktadır. Buna bağlı olarak iki aşamalı bir çalışma yürütülmüştür. İlk kısım ön çalışma olan fiziksel deneyleri, ikinci kısım ise etkileşimli prototipin oluşturulmasını kapsar. Temel olarak oluşturulan prototip, toplanan analog verinin çocukların oyunla öğrenme sırasında, temel çıkarım becerilerini kullanmalarını destekleyen etkileşimli mekanlara dahil edilmesinin denemeleridir.

Fiziksel deney, mekanda oluşan oyun ve oyunun getirdiği potansiyel ve kısıtlamaların gözlemlenmesi için 4 yaşlarında iki katılımcı ile gerçekleştirilmiştir. Deneyde, çocukların belirli bir alanda serbest şekilde hareket ederken iz bırakarak

ilerlemeleri sağlanmıştır. Çocukların kendi izlerini sorgulamaları ve buldukları çıkarımlar gözlenmiştir.

Çocuklar kendi izlerine ek olarak bir diğerinin hareketleri ile de ilgilenip oluşturdukları sosyal etkileşimler ve birlikte kurdukları oyunlar ile de, mekanın oyuna dahil edilmesi mümkün olmuştur. Sonuçta çocuklar, birey veya grup halinde verilen alanı oyunları için başlangıç noktası olarak kabul edip, kendi oyunlarını kurabilmiş, bunlrdan yeni çıkarımlar türetebilmiş, sosyal ve fiziksel aktivitelerinin de devamlılığını kendileri sağlamışlardır. Bu çalışmadan elde edilen bilgi sonraki aşama için zemin oluşturmuştur.

İkinci kısımda, çevreden alınan fiziksel bilginin digital temsilinin çocuklar için oyunla öğrenme materyali olarak sunulması amaçlanmıştır. Bunun için geliştirilen prototip ile ön çalışmadaki çocuklar ile ikincil deneyler gerçekleştirilmiştir. Birinci aşama mekanın çocuklar tarafından oyunun oluşturulduğu zemin olarak irdelenmesi iken, ikinci aşama çocukların oyun içinde fiziksel çevredeki hareketlerinden dönüştürülen dijital bilginin öğrenmeyi destekleyebilme potansiyeli incelenmiştir.

Amaç, çocukların kendinden gelen davranışlarının gözlemlenmesi ile toplanan bilginin tasarım sürecine dahil edilmesidir. Fiziksel sistemlerin doğal olarak dinamik bir yapıya sahip olmaları dijital ortamda da temsil edilip, oyunla öğrenme için olumlu ve eksik yönler bakımından analiz edilmiştir. Ikinci aşama için geliştirilen prototipte analog verinin digital ya da analog veriye dönüşümünü sağlayabilen Arduino kullanılmıştır.

Çocuklara önce basit haliyle prototipin nasıl çalıştığı açıklanmış daha sonra yine kendilerinin keşfetmeleri için ortam sağlanmıştır. Prototip ilk kısımdaki deney alanından farklı olarak küçük ebatlarda sunulmuştur. Iki katılımcı da yine kendileri ve daha sonar birlikte çıkarımlar yaparak prototip ile vakit geçimişlerdir. Sonuçta kendi hareketlerinin sonucu olarak belirli kurallar ile karşılık sunan düzeneğin çocuklar tarafından belirli ölçüde algılandığı görülmüştür.

İleri çalışmalarda çeşitli geçmişlerden çocukların tekil ve çoklu gruplar halinde, mekan algısının daha güçlü olacağı daha geniş kapsamlı prototiplerle araştırma devam ettirilebilir. Zaman kısıtları nedeni ile bu tez dahilinde iki çocuk ile çalışılmıştır. Güvenilir bilginin oluşturulması için farlı yaş grupları ve kültürel kısımlardan gelen çok daha geniş bir katılımcı havuzu için gelişim psikolojisi disiplini ile de çalışmalar gerçekteştirilmelidir.

Araştırmanın odak noktası, hem dijital hem de fiziksel çalışmalardan elde edilen verinin anlamlandırılmasıdır. Sonuç olarak bu tez, çocukların etkileşimler sayesinde oyunla öğrenmesini destekleyen mekanların nasıl olabileceği sorusunun bir çok cevabından yalnızca bir alternatifinin çalışılmasıdır.

1. INTRODUCTION

Human beings are good learners. As children grow up, they explore everything around them to make sense of the world. They build their perception of the world through play and interaction with the surrounding environment. In the era of the digital natives, there is ample technology, grounds, and need to expand ways of how children interact with their surroundings and situate themselves in space.

Unprejudiced, children explore and build basic reasoning to amass input from the surroundings. They naturally acquire experience by exploring and interacting without secondary thoughts in mind. From this understanding any environment and any object existing in the environment holds the potential of becoming the material of the play. Depending on the child's ability to imagine and reason, different realms occur encountering such environments. This provides an opportunity for the design of enhanced spaces, materials and objects embodying interaction for playful learning.

Play is a time for children to try ideas and advance in knowledge without being controlled by grownups. In the absence of a limitation, every item and the present environment become a proper medium in a child's mind and/or imagination.

Technology is ubiquitous in our everyday life and surroundings and has become an unfailing *experience* (McCarthy & Wright, 2004). The benefits of technology can always be argued. With the power of computation, by using embedded systems, it is possible to enhance materials, and accordingly, objects and spaces. This leads to spaces with increased interactive affordances, and a more unified relation between the physical and the digital world. As children use their senses to interact with the physical world, by creating new interactions, our future spaces could become the medium of today's playful learning environment.

1.1 Context

> "Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era,

person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives." (Weiser, 1991)

This study is based on the idea of Weiser's (1991), Ubiquitous Computing, and Tangible Interaction (TI) design first introduced by Ishii and Ullmer (1987). The initial idea of giving data a form and locating it back in the physical environment rather than the computer screen has led the researchers to see the potential of the idea of human interacting through their senses.

Today Tangible Embedded Interaction (TEI) researchers do not only study the objects but, from a wider perspective, they question the expanding limits of tangibility and study spatial affordances for interactivity. Physicality in the real world interaction can be achieved through the embodied interaction where interaction with and within the world is the main focus (Hornecker, 2011). In this embodied perspective, reasoning, knowledge and creativity rely on the spatiality and affordances that are enabled by the behavior and interactions.

The design of interactive environments is founded on the idea of building knowledge through manipulation and transformation of interactions. To provide a joyful sense and motivation, physicality and accordingly the interactions hold an important place in a child's learning process.

1.2 The Aim of the Thesis

The purpose of this thesis is to explore and study the potentials of interactivity embodied within space as a medium, which encourage children in their natural playful learning process with the help of technology enhanced environments.

Three main issues will be discussed which form the basis of the research question of this thesis: Playful learning, embodied interaction and the relation of physical and the digital worlds

This thesis examines and evaluates these issues through the design of a prototype, which is developed to test the potentials and deficiencies. of embodied interactivity for learning through play, by defining the physical and digital outputs regarding the analog input, namely the movements of children in the environment, and to explore the new affordances in this unified medium.

In a near future, computed spaces will not only express the unified integration of the physical and digital technologies, but also evolve in features and adapt to interaction. As children learn about the world by the act of doing (Manches & O'Malley, 2012), learning through play, and ways of interaction for children to experience through their senses stand as important points in this study.

The aim is to design an interactive medium, which engages children in playful learning in a real environment with interactive systems. With respect to this aim, a prototype is designed to represent possible spaces embodying features that challenge a child's curiosity, foster the possibility of manipulations, transformations and reconstruction by using data acquired from the environment.

1.3 Methodological Approach

This thesis envisions a prototype of an interactive space based on the idea of a unified medium of both the digital and the physical worlds. The interactive prototype is preceded with the development of a physical surface for experiments (analog), The final version of the prototype basically captures and transforms the analog data into an interactive medium where children could use their reasoning for occurring representations in the process of playful learning.

Embodied interactivity, as it represents the core idea of this thesis, is explored through both physical and digital experiments regarding playful learning. The experiments were carried out in two phases. First, a physical study was conducted with two four years old children to observe the free play with/within the affordances and the limits of the environment. This study builds a ground via data gathered and regenerated observations.

In the second phase, the translation of the physical into the digital is explored via an experiment, which was carried out by the author based on the results of the first phase. As the preliminary setup was a dynamic system by their nature, this aspect is represented in the digital medium as well to visualize and analyze the potential advantages and deficiencies of such interactive environments for learning. For digital manipulations, Arduino is selected, as this medium is capable of transforming and representing analog data into digital and/or physical data. The aim is to collect data by analyzing the inherent actions of children and the process of making sense during play.

The experiments are documented via video recording, observations and taking notes. Later, these actions are represented in the digital medium to capture the origins of the gathered data.

Both the preliminary setup and the main proposal involve active participation of children in the playful learning process. The main motivation of the research is to develop a proposal by integrating both the digital medium and the physical medium.

1.4 Organization of the Thesis

This thesis consists of two parts that respectively focus on the context and the experiments of the study.

The first part highlights the theoretical background of the thesis in the scope of the research. The first chapter introduces the study with the purpose and the objectives. Second chapter presents the concept of playful learning, explaining four basic aspects shaping the playful learning process: material, context, people, limitation, and fields of Tangible Embodied Interaction, Ubiquitous Computing identifying affordances of space within this regard. Third chapter proceeds with providing a preliminary research about nineteen projects, based on learning through play and embodied interaction, and explain the differing factors.

The second part of the thesis is concerned with the physical and digital experimental studies and consists of chapters 4-5. Chapter 4 starts with stating the research questions and methodology, and introduces the preliminary setup. The experiment is the starting point for ensuing digital experimentation with advantages and limitations. Being the first contextual inquiry, the experiment presented in chapter 4 is conducted with the participation of two four years old children. In addition to author's observations and data collection, with the aim of integrating participants in the design process, discussions between the two participants, their reaction to the physical setup and their ideas for the project are included as well.

In the continuing phase of the study, varying digital experiments were conducted by the author in order to investigate the interaction possibilities and affordances of technologically enhanced environments hold for playful learning. Chapter 5 presents the experiments and discusses the outcomes.

In the last chapter, the initial motivation and research questions is redirected to the study of this thesis. Additionally, conclusions are drawn, and projections for the future are given.

2. LEARNING THROUGH PLAY

2.1 Extents of Play

> "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)

Children learn the world through their senses and physical activities (Resnick et al., 1998). For them play is a crucial part of their social and cultural life, their most effective way of making inferences and without surprise, learning. Accordingly, this study starts with identifying the relations between play, learning, space and conditions. To discuss play from the viewpoint of learning with regard to interactive formations, first, the fundamentals of conditions for an explorative and active play environment will be outlined.

Play can be classified in two groups: free play and structured play (figure 2.1). Free play is when the child is in control of the progress and experience, deciding rules, limits and acting out. Structured play is adult guided, pre-planned and structured. The important thing in here is the balance between these two kinds of play.

Figure 2.1 : Approaches to learning through in the early years (DCSF, 2009).

While free play is good for children by being more open and helping in maintaining attention longer, this can easily transform into a repetitive action where few progression is observable. On the other hand, structured play leans to limit the borders and give smaller space to children to act on their own. As a consequence, children need both time and space to play, and balance between the dynamics that matters.

Despite being perceived as exclusive for the children, play is a part of everybody's lives. Adults are highly engaged in games or sports or with every new challenge for the mind. Kerr and Apter (1991) mention that play is generally associated with children, but although there are differences between adults and children, play is a proper way to explain adult learning. With today's technology, play is capable of affording/offering new mediums for both interactive and social learning.

Whether if it is for children or adults, play has its own attributes that do not change: It is mostly voluntary. Active involvement in a play is not for the reward, but for joy, in short, motivating. Play comes with varying levels of engagement. Play differs from other behaviors by involving make-believe (Blanchard & Cheska, 1985).

Howard P. Chudacoff (2007) defines play through four main criteria: *material, context, people and limitation*, which will be explained in detail in the next sections as shown in Figure 2.2.

2.1.1 To play with - Material

With differing needs, space for play and learning, and its defining elements are also progressing with us. Either limited in functionality for a particular purpose of play or a plain space to be given meaning to the act of play, play is connected to the space and so the material – and lately with the desire of technology inclusion. Current generations are being raised up in an environment hosting all kinds of technology. Technology has many opportunities to offer (e.g. communication, data acquisition) including virtual environments, which draws children as well. Yet the meaning of interactivity loosens in the process.

In contrast to predesigned materials in advance, free play does not hold meaning from the beginning and do not restrict their use and idea. As a result they present novel, unexpected and not predesigned interactions and outcomes. From this understanding any environment and any object existing in the environment holds the potential of becoming the material of the play. Depending on the child's ability to imagine and reason, different realms occur encountering such environments. As a result, any material or interface becomes the medium for the child's play, realization of interactivity, collaboration as well as social communication.

2.1.2 To play in - Context

As mentioned before the context can be defined as predesigned and solid or open to child's evaluation of. In addition, with a child's mind any place can transform into a playground for exploration, reasoning, learning and collaboration.

When children play, they begin to have more and better control over themselves and the environment, which also leads to an increased confidence. Wasserman (2000) explains this as the "can-do" attitude as the self-efficacy that children gain through play. Within play, there is no real danger so children are free to try every option, combine every possibility and experience more in their familiar environment, which otherwise would not be possible within the realm of the world. In a way, they gain experience, and shape their behavior for the times other than and play.

To perform a free play, children need places where they are out and able to explore freely, without the presence of control. These places can be any place not particularly defined as a playground. As a result, children are rather in need of spaces and experiences, which are more real than fully virtual representations. Instead of an interaction only possible through a screen -which is mostly the case today- children can engage and participate with physically interactive interfaces.

Interactivity in a child's play can support physical activity and progress of the children. Therefore the goal of this thesis should be creating systems embodying interaction in the physical reality also.

2.1.3 To play with others - People

Children can play either alonen by themselves or together with others –children or adults. While playing alone, they generally inspect distinct aspects, while playing with others enables more fun and the medium for social interactions. They evaluate and evolve through interactions, whether playing as mates or competitors, they learn the characteristics of social behavior.

2.1.4 To play not - Limitation

During free play adults tend to limit their children. On the contrary, children are more into uncontrolled play. They take risks and learn the consequences through making mistakes and learning from them in play. By children, especially when limited, any place with engaging features can be perceived as a playground to explore and inspect – mostly going around the adults and overcoming a difficulty.

Accordingly, opportunities should be provided for interactive playgrounds, for children to be physically active and open to communication and collaboration. This helps in making play more attractive than the computers and televisions (Sturm et al., 2008).

When children accomplish, succeed and move forward in play, they should face new challenges to accomplish. In other words the experience provided must not be limited either (Moore et al., 1992).

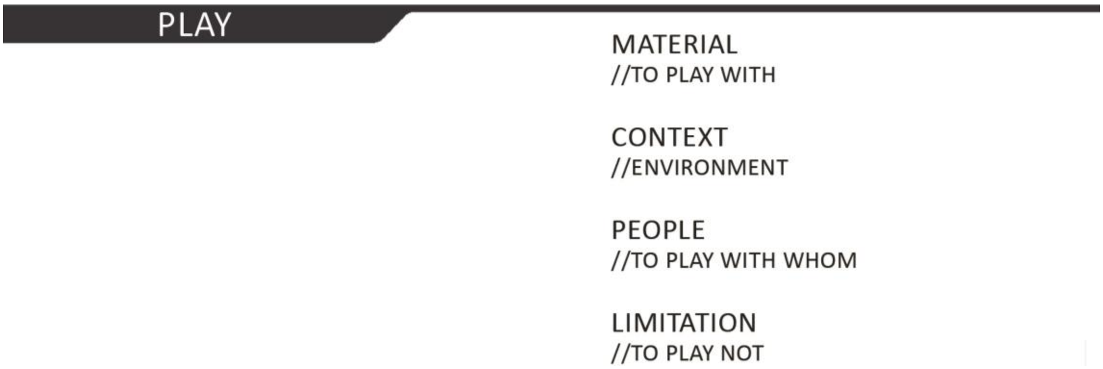

Figure 2.2 : The criteria of play according to Chudacoff (2007).

These explained four aspects attempt to give shape to the basis on which play occurs. For this reason, when designing interactive spaces promoting playful learning for children, these features have to be taken into consideration.

In consonance with these elements, play fluently promotes free exploration rather than step-by-step detailed design arrangements. Consequently, whether a toy or a whole system of space, our designs should stand as a free and open medium for encouraging exploration and interactivity by structuring basic rules and interfaces.

Play sounds fun, yet it is imperative to evaluate how play is evaluated in developmental sciences from the psychological perspective.

2.2 Playful Learning

> "It is paradoxical that many educators and parents still differentiate between a time for learning and a time for play without seeing the vital connection between them." Leo F. Buscaglia

Many psychologists and theorists relating to the role in playful learning have accepted play as holding huge potential. Theories maintain that play enhances motivational, cognitive and psychological development and more.

Piaget (1962) notes play as the child's struggle to make sense of environmental input, balanced with his/her perception. Vygotsky (1978) sees play as a means of a zone of proximal development, where children explore through problems and improve skills. All these work comment that the play is to open up new vistas for new experiences and developments through imagination, exploration, experimentation and social behavior.

Piaget's (1962) constructivist theory provides a base for understanding children's intellectual development and growing capabilities at different levels with particular stages of development. According to Piaget's theory, children have their own way of thinking different from adults, possibly most suited to their circumstances (Ackermann, 2001). Through acting and physical interaction within the world, they advance in tacit knowledge about themselves and the existing environment.

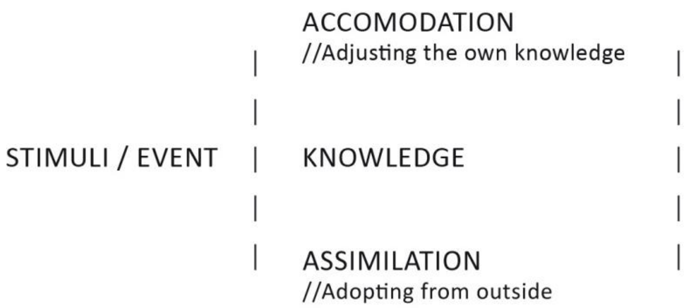

Figure 2.3 : Equilibrium, according to Piaget (1972).

In this theory, learning is defined as structuring new information from previous experiences, and continually, knowledge is an ever-changing matter. He explains the types of the play and stages of progress and development. Piaget asserts the stages as: assimilation, accommodation, disequilibrium, and equilibration (Figure 2.3). He further explains that: "In every act of intelligence is an equilibrium between assimilation and accommodation, while imitation is a continuation of accommodation for its own sake, it may be said conversely that play is essentially assimilation, or the primacy of assimilation over accommodation" (Piaget, 1962, p. 87).

He explains that through action and active involvement children make sense of their world, compose their previous experiences and make inferences from them. Furthermore, play connects children's concrete and abstract thoughts. Yet Rosch (1977) states that these mental states are not freed from one another in our world. As a result what is perceived is in fact as important as the situation itself.

Papert's theory goes further and involves learner in the design process and contraction of actual products. Externalized ideas get tangible and in return enable making inferences and feedbacks as in progress.

In the last decade, theories expanded and varied. Most studies on the individual differences, cultural aspects and differencing variables are still needed rather than general stages and approaches.

As a result, learning through play could be explained as an interaction among children, objects and most certainly the environment. Most researchers in this field agree on the idea of interaction, understanding the whole and restructuring of the previous, moreover, the knowledge strictly dependent on the environment and cannot be interpreted.

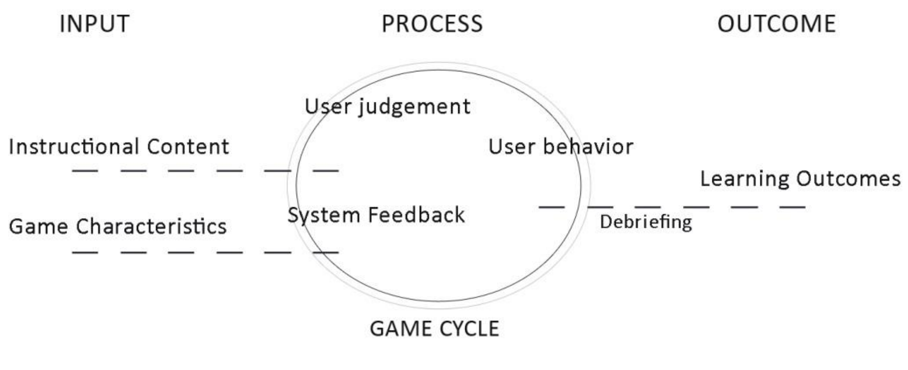

Figure 2.4 : Game-based learning cycle by Garris et al (2002).

Anetta et al. suggest that cognitive engagement with motivation can be an important factor in effective learning and adding that this motivation and engagement lead to a longer training than traditional learning materials (Anetta et al., 2009). Overall, most researchers refer to the Flow Theory of Csikszentmihalyi (1990) regarding the constant attention and engagement, and agree on the effects of motivation and engagement with learning, produced during play.

How these spaces should be designed to encourage children in the active exploration and reasoning process?

2.3 The Context of Interaction– The Role of Physicality

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

Technology is evolving fast not just by means of software abilities, but also physically. Weiser's research on Ubiquitous Computing influenced numerous researchers to enhance pervasive technologies, ambient mediums and tangible computation technologies within the physical world, embedded into our daily life, space and objects. In HCI, Hiroshi Ishii and the tangible media group were one of the pioneers in research on the idea of unified form and computation (Ishii & Ullmer, 1997).

The idea of joining the potential of physical interaction to the digital realms is current and common. Instead of "window, icon, menu, pointing device" (WIMP) interactions, researchers ask the questions regarding post-WIMP to interact with and within the real world. With embedded computing, technology enhanced environments try to find out new ways of interacting in everyday environments.

Nowadays technologies of rapid prototyping like Arduino, designers have now adopted the possibilities of the embedded interactions and consider the physical state of interaction as well.

Seeing new generation tools as Kinect and Wii shows us that this unified approach started to change the way we see our environments and computing. With this transformation, questions have started to merge. Should it be visible? Can they help disabled children to improve their abilities? Do they change the playing habits? Can they help learning? How will our perception change? How will our bodily movements react to these new interfaces? How will these physical affordances help?

Dourish (2001) gives a detailed explanation of how embodied interaction rises on which ground and in fact situated in the everyday environment. In the book Where the Action Is: The Foundations of Embodied Interaction, he states that "Computation is fundamentally a representational medium, but as we attempt to expand the ways in which we interact with computation, we need to pay attention to the duality of representation and participation" (Dourish, 2001). Through engaged interaction, meaning take shape. Consequently, embodied interaction is situated by also socially.

2.3.1 Spatial interaction

Interactivity does not mean being limited to objects and so. When technology is embedded in space, then the users may need to move in space to interact. Interaction with and within interactive spaces could be characterized as tangible interaction (Ciolfi. 2004). Not only that there is also a response from the environment.

Because interaction embedded in space, spatial interaction is an inherent and inseparable aspect. The user's body becomes the origin of perception. We perceive the world and move accordingly with the positioning of our body in a setting. Robertson indicates that another feature of spatial interaction is that spatial interaction can be observed and usually necessitates performative features (Robertson, 1997).

Physical space interactions also enhance engaging full-body interactions. Despite being started in early 1970s Krueger's installations still, support the idea of increased physical interaction and full-body interactive games (Krueger, 2001). Balancing mental and physical skills lead research to movement-based interactions. Full-body interactions trigger the system, human movement and effects, meaning interaction with and/or within the environment becomes visible, even may contribute to communication, collaboration and performative behaviors.

2.3.2 Embodied interaction

In embodied interaction, when people move in physical space, their abstract data is represented in the digital realm and in physical environment. As a result, both of these mediums become partners in the way of interaction and the outcome. Either of them can allow or limit action in overall system or share specified aspects.

Embodied interaction styles could define the movements of users. They can restrain or enhance the physical relations and arrangement directly, for instance to support collaborative work or individual interaction among them.

2.3.3 Tangible interaction

Acting in space inevitably involves interaction, so is the observable performative act. Even with the size of tangible item or interface, actions become more interactive, because users' movements spread and perceived visually easier. In tangible interaction, the main idea has been giving physicality through form to digital information (Ishii & Ullmer, 1997). The user could make better use of reasoning capability through forthright manipulations and transformations of their movement, object and space.

O'Malley and Stanton-Fraser (2004) indicate that tangible environments support participation and exploration. Additionally, Antle states that embodied interaction develops engagement in children for active learning which could promote cognitive development as well (Antle, 2007).

2.4 New Learners and New Environments

Via play characteristics, the distinction of learning material is blurred. The play is to be engaging and motivating that the learner continues to involve. When talking about participating, the balance in complexity and difficulty matters. Goals must be understandable and easy which to be escalated gradually. Nevertheless, as with time, humans change, improve, evolve. The environment they exist is affected and restructured as well. Combination of engaging power of playful learnig with the learning process in an interactive environment is the key of a balanced union.

Prensky (2005, p. 98) says that "it is interesting to me that so few have observed that our students are no longer the people our educational system was designed to teach". With inevitably ever expanding affordances of technology for interactivity and social learning, Prensky (2001) describes this new generation as native speakers of the digital language of computers as *"digital natives"* while Papert (1993) describes computer as *"the children's machine"*. Prensky (2005, p. 98-99) adds that "the 'mind alterations' or 'cognitive changes' caused by the new digital technologies and media have led to a variety of new needs and preferences on the part of the younger generation, particularly –although by no means exclusively- in the era of learning".

Brown (2002) suggests that learning is the result of a framework or environment that cultivates learning rather than a result of teaching. He maintains that today younger ones see technology not different from their life, but as a tool in learning experiences. Ryan (2001) claims that once one of immersive ideals, our culture is now more concerned with interactivity. Innovations embody interactivity mostly because of joy and potential for learning. Maintaining the learning process depends on sophisticated interactive environments and feedbacks which to be promoted to evaluate the progress. These feedbacks can be realized in many ways to enrich the experience, environment and learning process.

Pivec (2007) implies that considering increasing work and research in the area of games as a way to use technology for learning shows that there is need and will to improve the learning process and the learning environment.

Ishii (2008) indicates that the underlying cause of interactivity is to increase the degree of collaboration, learning and reasoning through technology by making use of our human abilities to shape physicality.

The engaging power of play poses an advantage for interactive learning processes that may take place in embedded environments. In the near future computed spaces are likely to express more than the unified system. They may also evolve as features evolve and adapt to interaction. In return, the new generations will also affect the environments and be effected from the environments they inhabit.

3. AN OVERVIEW OF PRECEDENTS FOR PLAYFUL LEARNING

3.1 Contextualizing the Study with the Related Works

This chapter gives information on studies related to learning through play research published in the last decade. The studied background was based on peer-reviewed studies published in scientific journals, proceedings of international conferences, symposia and book chapters, and is limited to papers written in English. The research was carried out through multiple online databases of academic resources: ACM, ERIC, Elsevier, JSTOR, IEEE, SAGE, Springer Link, Wiley Interscience, MIT Press and Cambridge Journals.

The initial search was based on searching the terms “learning through play” or “playful learning” combined with the keywords: “embodied interaction, interactive learning systems, multimodal interaction, edutainment, embodied learning”. The selection was based on the inclusion of papers that study learning related to play based on interaction.

The initial search yielded over 250 publications published between 2005 and 2015. Since research in this field is recent, yet vast, research papers dealing with issues of role-playing and learning disorders were eliminated alongside those targeting adults and focusing on health. The chronological distribution of publications is mainly focused toward recent years, only two papers being published between 2005 and 2010, and seventeen papers being published between 2010 and 2015.

In this thesis the analysis is oriented toward providing perspective for learning through play and offers a clear schema of design approaches, target users, educational focus and assessment. For this purpose, the study focuses on the following aspects: the design approaches used, the structure of interactions, the assessment applied, and the outcomes of the analysis.

The search results are organized to classify the defined research topics into categories by the author (see Table 3.1 and Figure 3.1).

Table 3.1 : Overview of a selection of relevant projects.

	Author(s)	Projec Name	Design Approach		Educational Focus		Interaction Design			Evaluation	
			composed	adapted	educational context	users	environmental setting	users participating	physical arrangement	learning	user experience
1	(Antle et al., 2011)	Towards Utopia	X		Sustainablity	Children	Public & Classroom	S	Interactive screen	X	X
2	(Bakker et al., 2012)	(Bakker et al., 2012)		X	Music	Children	Classroom	M	Tangible system	X	X
3	(Banerjee & Horn, 2014)	Ghost Hunter	X		Energy	Children & Adult	Home	M	App	X	
4	(Bodén et al., 2013)	Save the wild		X	Sustainablity	Children	Public & Classroom	M	AR Environment	X	X
5	(Chang & Breazeal, 2011)	TinkRBook	X		Literacy	Children & Adult	Various	M	Interactive screen		X
6	(Charoenying, 2013)	Graph Hopping	X		Math	Children	Classroom	M	Interactive screen	X	X
7	(Creighton, 2010)	Jogo	X		Free Play	Children	Public & Classroom	M	Tangible system	X	X
8	(Enyedy et al., 2012)	Learning Physics	X		Physics	Children	Classroom	M	AR Environment	X	
9	(Fisher et al., 2013)	Taking Shape		X	Geometry	Children	Classroom	S	Tangible system	X	
10	(Hansen et al., 2009)	Pendaphonics	X		Physical activity	Children / Adult	Public	S	Interactive environment		X

Table 3.1 (continued) : Overview of a selection of relevant projects.

	Author(s)	Projec Name	Design Approach		Educational Focus		Interaction Design				Evaluation	
			composed	adapted	educational context	users	environmental setting	users participating	physical arrangement		learning	user experience
11	(Hengeveld et al., 2013)	LinguaBytes	X		Speaking	Children	Various	M	Tangible system		X	X
12	(Hettiarachchi et al., 2013)	FingerDraw	X		Drawing	Children	Various	S	Interactive screen		X	X
13	(Horn et al., 2012)	(Horn et al., 2012)		X	Programming	Children	Various	S	Tangible system		X	
14	(Johnson et al., 2013)	KinectMath	X		Math	Teens	Classroom	S	Interactive environment		X	
15	(Jungmann & Fitzpatrick, 2009)	Sim-Suite		X	Cultural understanding	Adult	Public	M	Interactive environment		X	X
16	(Lagerlöf et al., 2013)	(Lagerlöf et al., 2013)	X		Music	Children & Adult	Classroom	M	Tangible system		X	X
17	(Liou et al., 2014)	Step on me		X	Free Play	Children	Playground	M	Interactive environment			X
18	(Olson & Horn, 2011)	NetTango	X		Science	Children	Classroom	S	Interactive screen		X	
19	(Shen et al., 2013)	Beelight	X		Color	Children	Classroom	M	Interactive element		X	X

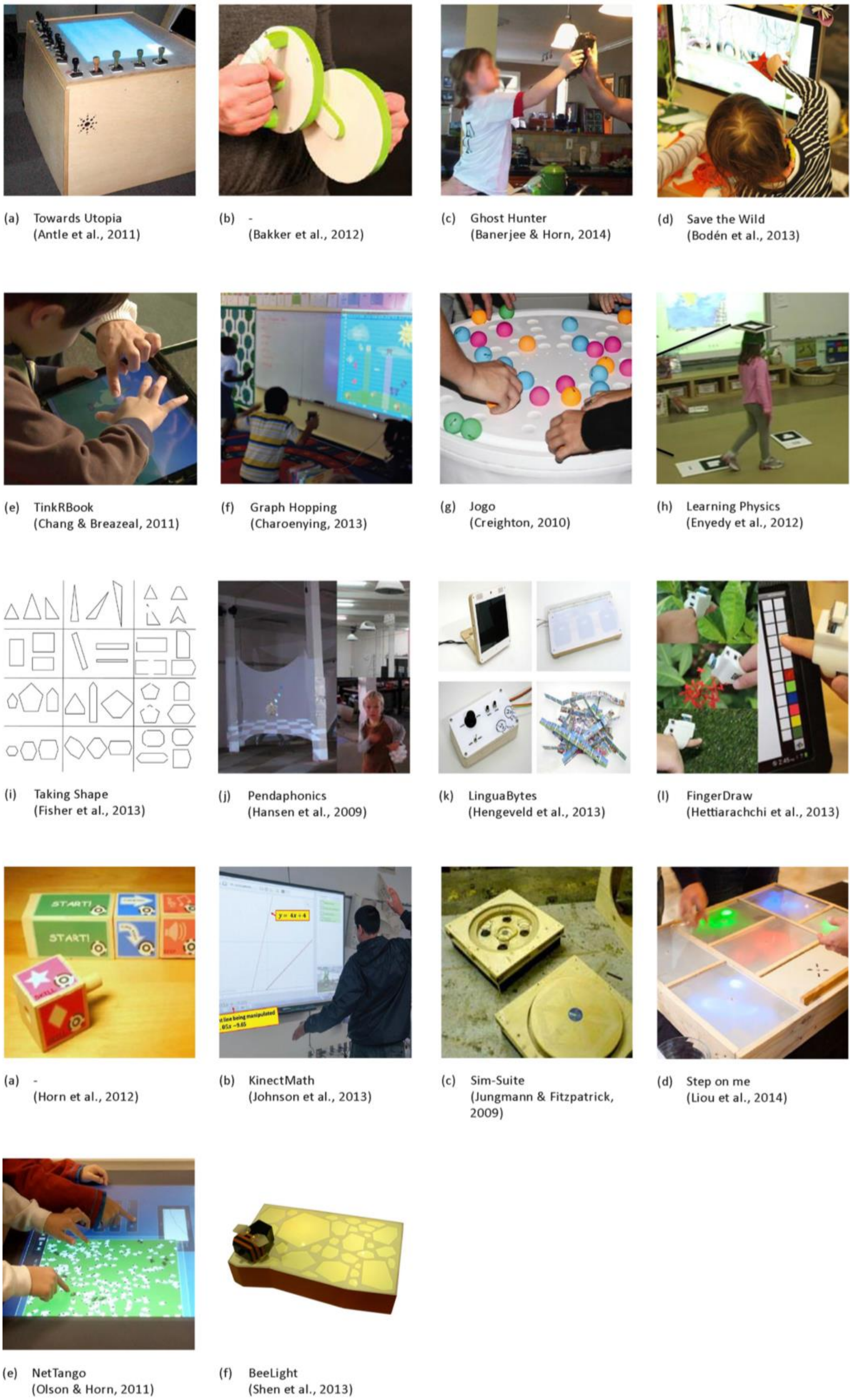

Figure 3.1 : The visuals for the selected relevant projects.

3.2 Design Approach

As learning through play is mostly studied as applied science, we first analyzepapers with respect to their findings towards the future of the research field. Two issues were addressed in this regard: composed and adapted. The first one addresses theories to be composed from data, while the second one addresses theories structured by adapting existing materials/situations

3.2.1 Composed

Of the nineteen projects reviewed, most of them used semantic approach, meaning that a scientific theory can be composed through a set of data regarding the environment and the actions.

Two research groups build their studies on tangible user interfaces, mainly interactive screens in their projects, “Towards Utopia” (Antle et al., 2011) and “NetTango” (Olson & Horn, 2011). The first project is focused on building sustainability awareness in children aged 7 to 10 with a tangible user interface for their learning goals, while the latter project used multi touch tabletop screens to construct knowledge on sustainability and land use in the same age group.

“Ghost Hunter” presents an application to search for sources of electricity consumption firstly in their homes to be used on electronic devices by both children and their parents (Banerjee & Horn, 2014).

In “TinkRBook” Chang & Breazeal (2011) discuss the book and its potential of tangibility to enhance existing shared reading experience with active exploration and engagement for both children and adults.

“LinguaBytes” is presented as a consequence of three years of work with five prototypes designed to improve talking in late speakers with a ten-month evaluation process (Hengeveld et al., 2013).

A considerable percentage of this part focuses on the learning of science related issues with interaction. “KinectMath” encourages students to learn algebra interacting with the game, thus enabling physically active participation (Johnson et al., 2013). Also Charoenying (2013) in the “Graph Hopping” study uses active physicality to improve the learning of mathematics and uses introduces competition to encourage children.

While some projects are designed to be used in the classroom environment, many others support the idea of and work for learning to exist outside of school spaces. “Pendaphonics” Hansen et al. (2009) presents a public installation in favor of experience for participants of all ages. They build an area to experiment with sounds. Furthermore, “FingerDraw” (Hettiarachchi et al., 2013) takes engagement in public one step ahead and also enable the environment to become a source of learning for children.

3.2.2 Adapted

Six of the projects build their research studies by adapting existing materials/situations, and using varying plans to address the issues: developing or adapting from already existing traditional models and building hybrid relations between the physical and the virtual:

Bakker et al. (2012) generates new tangible systems for children to learn abstract sound concepts by conducting several experiments with twelve tangible elements and consummates with three tangible artifacts. In “Taking Shape” levels of learning with tangible elements in a classroom environment with varying scaffolding is examined (Fisher et al., 2013).

“Save The Wild” builds an augmented reality environment with inspiration from a traditional game by combining computers and origami (Bodén et al., 2013). Similarly Horn et al. (2012) in their project use wooden blocks for simplified coding for the learning of children. On the other hand the project Sim-Suite tries to improve human-to-human interaction and cultural understanding by stepping upon sensor-enhanced blocks (Jungmann & Fitzpatrick, 2009).

Finally, the project “Step on Me” promotes free play by maintaining an interactive playground for most outdoor activities and is the adaptation of an existing model (Liou et al., 2014).

3.3 Educational Focus

3.3.1 Educational context

Five projects focus on science related topics: two refer to math (Charoenying, 2013, Johnson et al., 2013), one to physics (Enyedy et al., 2012), one to geometry (Fisher et al., 2013) and one to science (Olson & Horn, 2011).

Three of the projects are focused on environmental issues: Two with sustainability (Antle et al., 2011, Bodén et al., 2013) and on by energy consumption (Banerjee & Horn, 2014). While the project "Towards Utopia" focuses on consequences of geographical issues (Antle et al., 2011), "Save the Wild" tries to build awareness for sustainability (Bodén et al., 2013). In addition, the energy related issue "Ghost Hunter" is an application to detect and show hidden energy consumption in the household.

Two projects focus on music as an abstract concept. In their research with tangible elements Bakker et al. (2012) investigates the role of physical activity and use of objects for learning. On the other hand, study of Lagerlöf et al. (2013) is concerned with the children's participation and engagement in a musical dialogue, and they indicate that through communication musical production during the play was accomplished.

Literacy related project "TinkRBook" investigates the possibilities upon the perception of a *tinkerable book* (Chang & Breazeal, 2011), whereas "LinguaByte" aims to stimulate language development of late speaking children (Hengeveld et al., 2013).

Two of the projects focus on enhancing free play (Creighton, 2010, Liou et al., 2014). Both of the works focus on enhancement of social interaction during play.

The remaining five of the projects varies in an educational context. Horn et al. (2012) examine three of their studies regarding tangible programming. Hettiarachchi et al. (2013) introduces novel drawing interface, "FingerDraw" to keep children engaged with the surrounding environment. "Sim-Suite" focuses on the cultural understanding through play, as a social practice (Jungmann & Fitzpatrick, 2009). Finally, "BeeLight" aims to engage children to promote their color cognitive development (Shen et al., 2013).

Table 3.2 : Educational focus.

	Aspects	Number of Projects
Educational context	Sustainability & Energy	3
	Math & Physics	3
	Music	2
	Free play	2
	Other	9
Users	Children	11
	Children & Adult	5
	Children / Adult	2
	Teens	1

3.3.2 Target users

Out of nineteen projects, sixteen of them related directly with children. Yet five of them have been studied with the existence of an adult on purpose. Projects include a parent (Banerjee & Horn, 2014, Chang & Breazeal, 2011, Horn et al., 2012) or a teacher (Fisher et al., 2013, Lagerlöf et al., 2013) to participate as a user and engage with children or scaffold the process. Remaining eleven projects focus on just children.

Project “KinectMath” is the only study in this group to research on helping teenagers improve their math skills (Johnson et al., 2013).

Lastly remaining two projects “Pendaphonics” (Hansen et al., 2009) and “Sim-Suite” (Jungmann & Fitzpatrick, 2009) are structured for both children and adult play.

3.4 Interaction Design

3.4.1 Environmental setting

Eight projects have been developed to be embedded in the classroom environment. While three projects are for both the classroom and public, two projects are for public only, one project is for home and one is for the playground. The last four projects have the vision and potential of being suitable for various formations. With these different formations, decisions taken are in direct relation with the expectations of design and inevitable outcomes. As a result, designs evaluated with environmental setting data: public, public and classroom, classroom, varying or a free environment, may lead to certain limitations for the target users.

3.4.2 User participation

Twelve projects have been designed for multiple users, whereas seven have been designed for a single user. The main purpose of including this aspect is the levels of participation and collaboration related to design decisions and conveying potential for social interactions, which seem helpful for learning through play.

Single user based projects such as “FingerDraw” (Hettiarachchi et al., 2013), and adult-participating projects like “Ghost Hunter” (Banerjee & Horn, 2014) promote interaction with the outer world. On the other hand, most of the cases built with multiple users, show that interactivity between the players escalates. As a result, it can be said that group activity promotes both interactivity and participation. For example, “Ghost Hunter” generates discussion and shared learning experience (Banerjee & Horn, 2014).

Except for one project, other multiplayer projects build collaborative environments. “Graph Hopping” (Charoenying, 2013) project defines challenge, if balanced well, as a beneficial aspect in play, and uses competition between two users to this end.

3.4.3 Physical arrangement

Sixteen of the examined projects used either interactive or tangible systems. Tangible interaction and elements were used as an interface in six of the projects (Bakker et al., 2012, Creighton, 2010, Fisher et al., 2013, Hengeveld et al., 2013, Horn et al., 2012, Lagerlöf et al., 2013). Three of the projects were planar based, enabling participants to experience and observe from close (Hansen et al., 2009, Jungmann & Fitzpatrick, 2009, Liou et al., 2014). Seven of the projects used interactive screens as their interfaces, by doing so, they ensured either audiovisual or visual outputs (Antle et al., 2011, Chang & Breazeal, 2011, Charoenying, 2013, Hettiarachchi et al., 2013, Johnson et al., 2013, Olson & Horn, 2011, Shen et al., 2013).

Table 3.3 : Interaction design.

	Aspects	Number of Projects
Environmental setting	Classroom	8
	Public & Classroom	3
	Public	2
	Home	1
	Playground	1
	Various	4
Users participating	Single	7
	Multiple	12
Physical arrangement	Interactive environment	3
	Interactive screen	7
	Tangible system	6
	AR Environment	2
	App	1

Finally, two projects, "Save the Wild" (Bodén et al., 2013) and "Learning Physics" (Enyedy et al., 2012), defined their study as augmented reality (AR) system. The last project "Ghost Hunter" (Banerjee & Horn, 2014) was developed as an application for electronic devices.

As a result, mainly two general approaches were used: Tangible systems and interactive surfaces. Although there are more alternative approaches than those reviewed in this thesis, it would not be wrong to say that these ways hold affordance for the future of learning discipline.

3.5 Evaluation of Learning and User Experience

Of the nineteen projects, six of them indicate learning related results, three of them user experience related results and ten of them give evaluations about both grounds: user experience and learning.

In "KinectMath" project, it is indicated that learners are mostly excited about participating in an interactive learning process (Johnson et al., 2013).

In addition to learning benefits, most of the projects come with secondary benefits. The three studies Horn et al. (2012) indicate in their paper show that collaboration is also observed and found helpful among children. Furthermore,“LinguaBytes” precisely indicates that children’s participation is enhanced and learning time is escalated (Hengeveld et al., 2013).

User experience expands in various aspects. Besides active exploration, free will is also used as an efficient trigger. Chang & Breazeal (2011) explains that the “TinkRBook” project encourages active exploration of the environment, while project “Pendaphonics” (Hansen et al., 2009) gives an explorative tangible system, and “Step on me” (Liou et al., 2014) presents a ground for free play.

Similarly, the “FingerDraw” project (Hettiarachchi et al., 2013) promotes engagement with the surrounding environment with color and drawing activities, while the “Ghost Hunter” (Banerjee & Horn, 2014) accomplishes this by building curiosity towards electric consumption.

The studies of Bakker et al. (2012) and Lagerlöf et al. (2013) are based on the relation between learning and physical activity. Bakker et al. (2012) experiment on the learning of abstract sound concepts with tangible elements and in the end indicates learning outcomes in all 39 participants.

Among all other mentioned studies, one project steps up with the duration of the project. Not in a limited amount of time, “Learning Physics” (Enyedy et al. (2012) is embedded in a fifteen-week curriculum.

Assessment of learning is carried out in multiple methods such as pre and posttests, clinical interview assessments, data recording and also naturalistic observations, and different data are analyzed such as levels of engagement and motivation and enjoyment regarding learning. To conclude, numerous techniques that are experimented can lead to the introduction of new technology, which enhances learning through play, and is considerably affective and beneficial.

3.6 Discussion: Establishing a Context with Precedentss

Within this research, examining several theories and design choices enabled identifying the preliminary structure of needed information for learning through play research. The exploration of educational contexts, user focus, physical interfaces and in short interaction design presented that these attributes are thought for a certain purpose.

When conducting a research on learning through play, questions emerge about the design of the projects, mainly in two categories. The first one is the educational context with sub questions and requirements: The definition of the learning process, how children are supposed to learn, definition of targeted users and the outcomes of the proposed project, and how are they supposed to learn. The second category covers the issues of physical interface of the study and its potential to support collaborative work for how many people, the duration of process and lastly the success of the mapping must be taken into consideration.

Within the light of these aspects, the study of this thesis presents cases where a single child or more children can freely explore and interact with(in) their environment as their process of playful learning. With further research, new relations between the designed environments, user behavior and cognitive processes can emerge and/or be discovered.

4. DESIGN OF AN INTERACTIVE PLAYFUL LEARNING ENVIRONMENT

4.1 Research Questions

The focus of the project is to study the causes and effects of a basic interactive playground for children and to explore the affordances they offer in order to increase the level of reasoning, motivation and collaboration in children during their playfull learning process within the environment. With the review of background, the first question of this thesis is: How to encourage children in experiencing playful learning through an interactive platform?

In this thesis, children are to join in the transformation of the physical environment through playful interaction. If they participate in and include these kinds of interfaces into their active play, new perspectives can be identified for extending computation and interactivity into playful learning spaces. Furthermore, data observed could lead to future work as interactive architectural elements.

The first criterion is about the form of the interface developed to establish learning through experience. Form in this sense means to state possibilities and affordances through the shape (Norman, 1988) since the physical appearance as the interface is as important as the interaction also.

When defining an element of interaction as an interface, form is specifically important since the system is under the direct influence of physical character. As mentioned in the previous chapter, there are projects introducing mostly colorful varying objects as interfaces.

The second criterion relates to the interactivity of the proposed study. Baskinger and Gross state that “as interaction design matures, designers will focus more on the meaning and impact of form on people” and adding that “computation provides the opportunity to design adaptive, responsive, and highly interactive products and systems” (Baskinger & Gross, 2010). As a consequence, the interaction proposed matters when aiming at an engaging, playful learning experience in children.

The last criterion covers the previous criteria also. During play, children struggle, explore, reason and develop through the play, appropriately, the state of *"flow"* should continue for children. In other words, play should evolve and expand to keep children engaged in play either by design or with children's imagination. The real use of prototypes and continuity of the play depends on the interaction between children and the proposed project. As a result, the prototype should motivate children to participate and perceive the environment and other children.

4.2 Methodology

The study presented in this thesis is a prototype for interactive learning environments. An interactive element, detecting movement of children and in response, transforms this data into learning patterns to promote learning via playing. This unlimited interaction in play, enables both -scaffolded- learning and free play experience to enhance the chance of children building their own play.

Through programmed control interface LED lights embedded in the environment, simultaneously visualize the movement of children as color, number, or any intended information to be passed onto children. The lights are visualized through a screen in the limits of this study.

To visualize real-time response from the movement indicated module contains piezoelectric sensors within itself. Piezoelectric sensors are capable of harvesting energy from its users through movements and convert into electrical energy so that when programmed the learning environment can operate in its own systematic arrangement.

Two phased experiments test the setup regarding learning, notably reasoning (see Figure 4.1).

In the first phase, an area covered with paper is defined as initial playground. Two 4-year-old children are invited to participate in free play with color markers to observe their trace and play patterns. Inferences from these trials are defined as routes with attributes including the information of velocity, weight and positions relatively to each other on microcontroller and visualized through a screen. In addition to preliminary setup, simulations of future configuration are also presented as the continuing form of the study.

In the second phase, the movement taken from the environment is used as data transformed into an interface featuring color, zoning and scale. The children from the preliminary setup participated in this experiment to play with the developed prototype.

Ongoing trials aim at more sophisticated ways of computing the data collected. The code continuously reads the value from the potentiometer and writes the interrelated value to change the variables on the screen read from the data of movement. Children simultaneously perceive the current state of players, their locations and system and proceed accordingly. With interrelated value, changing features are to be realized as learning material via making inferences and reasoning. The setup requires the conversion of data and in this case achieved again by the help of Arduino boards converting analog input to output and visualized on screen.

Furthermore, data provided from the constant movement, players can build their own play. They can figure out what visualizations express and what to do other than the outcomes planned in advance. This opens up further possibilities to parameters such as brightness, zoning, and color differentiation on a planar surface rather than one point indicators to enrich expression and meaning of the movement during play. It is also important to have children test the initial prototype as this interaction with children could contribute in developing better interactive environments for the original users as well (Landry et al., 2012).

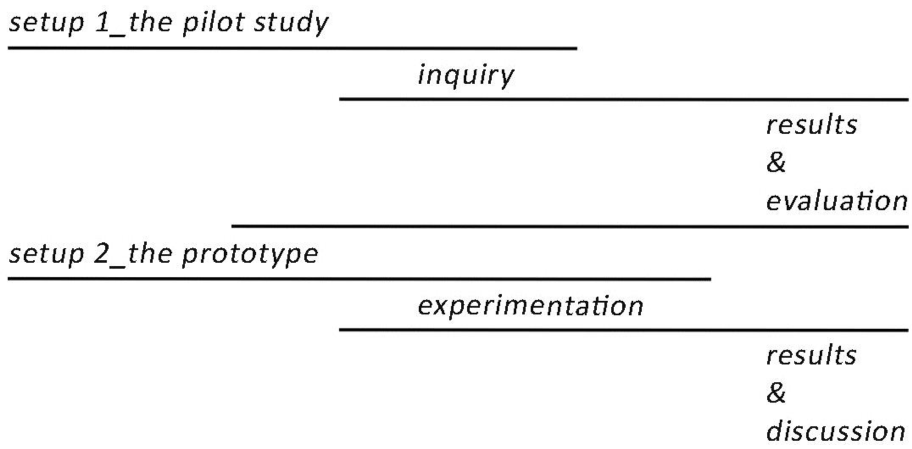

Figure 4.1 : The process overview.

4.3 The Playground – A Preliminary Setup

To get a better understanding about how children interact and play, a contextual inquiry had been conducted by using an analog setup as playground, offering limited simulated functionality and enabling basic interactions. The preliminary setup enabled the identification of the categories defining play: Approach and engage, explore and play, interact and socialize. After visualizing the general framework, relations between the children and the environment, behaviors and interactions and level of engagement and motivation is observed and structured. The section finalizes with a conclusion of the preliminary setup and its results.

4.3.1 Material, dimension and formation

After examining varying functionalities, general framework of this study is defined as testing and observing the traces of movements of children during free play, by color marks on observation setting. The functionalities included in this setup are visual and haptic feedbacks.

The prototypes were defined in functionality to successfully hold the potential they should. As this experimentation was planned as a prototype for further experiments, the step up is kept as basic as possible. Consequently, a planar surface is chosen to be presented, as planar surface is a basic formation, which could afford numerous manipulations in possible reconfigurations. Furthermore, it could offer possibilities for varying interactions for not just one child or numerous participants, but for space as well.

Kraft paper was used for assembling the planar experiment area. This material was chosen of the advantages such as being light and easily assembled. The experiment area was defined by assembling twenty craft papers (0.5mm). Total work covered an area of 8.4m² (2.8mx3m). The construction was fixed with tapes and strengthened for the air streams (see Figure 4.2).

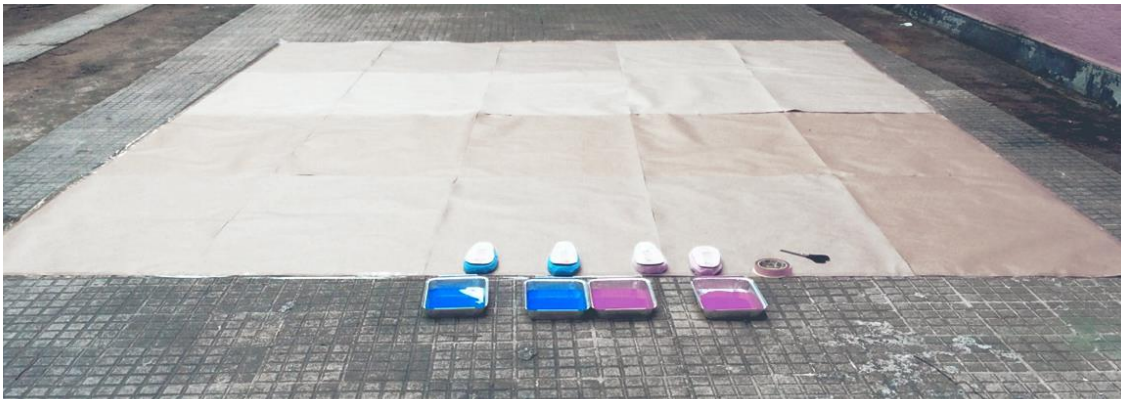

Figure 4.2 : The initial setup.

To observe the movements of the children, a plain formed sponge attached to participants' shoes. Each child was matched with one color, as a result, movements of the children were recorded and identified with distinctive colors (see Figure 4.3).

Figure 4.3 : Tactile exploration.

4.3.2 Data collection

The data collection and the observation took place in an outdoor environment at Yildiz Technical University Architecture Faculty in April. The cover was laid on the ground. The process was explained to the children and after questions, the experimenter helped them to get some paint in their shoes and step on the specified area. At specific points, more paint was provided.

For data collection and evaluation, visual materials recorded (video recorded and photos taken) the children's reactions and the whole process. The participants were four year aged twins (a boy - D and a girl - N) and their mother (only peripheral).

After the installation of the experimental setup, they approached to the area. They were really curious about what they were going to do, and interested in the paints and the covered area. They were highly motivated to start immediately. They started to experience and played nearly 15 minutes till the paint finished and the specified area was covered with traces of children's movements.

The observations made possible to get insights about their experiences and play with the analog physical setup environment. As a result, the questions to be answered:

How do they approach the playground, and what are the origins of engagement?

What kinds of interaction become apparent during the play?

During play, can we observe different social formations and behavior?

4.3.3 Findings

A general visualization of preliminary setup – presenting time and specific points – shows the flow of the process, providing the information on how children approached, experienced, built reasoning and more importantly played with the physical setup –the analog prototype- (Figure 4.4). The following sections will readdress the main issues.

Approach and Engage

Even before their arrival, it was obvious that the two participating children were very interested in the setup. As they approached the setup, they immediately asked many questions. The questions were mostly related to the purpose of the specified experimentation area – *"What is this area for?", "What are these sponges for?"* – And about what one can do with them – *"How will we use them?"* – After explaining general rules and limits of the setup, they were allowed to explore and play freely on their own. – *"You can try on your own and explore/act as you wish."* – They only received physical help from the experimenter for their balance during paint refill for their traces.

From the beginning, they were not shy, but very curious about the setup. First, they visually explored from the distant, continued with tactile identification, concentrated engagement in the setup, followed by the development of the process, and lastly the social behavior and the free exploration.

(a) First approach

(b) Tactile exploration

(c) First trials

(d) Checking the other

(e) Collaborative trials

Figure 4.4 : The progress of the preliminary setup.

Explore and Play

After the first approach, the children started to explore the playground on their own.

D was the first to explore the playground. Right after getting paint in his shoes, he made a big run reaching to the limits of the playground, and when his shoes run out of paint, he stopped to see the whole traces he made. On the other hand, N started by examining the traces her shoes leave, and only after that she started to wander (Figure 4.5).

The affordance of leaving visual traces that allows observing one’s own movements was found very interesting by both participants, but especially N. Perceiving these as helpful tools, they accepted the environment and played extensively to experience and explore more.

Figure 4.5 : The first trials.

Despite being very interested in the shoes at the beginning of the experiment, later it gave its place to leaving traces and the potential that holds as emerging functionalities. The visual affordances became more accepted as the base of the play, further explorations experienced during this timeline on this basic preliminary setup.

Interact and Socialize

This preliminary attempt was noteworthy, as children strongly bonded with the setup, the environment started to facilitate emerging social engagement. Apart from the children's physical activity within the environment, as they were focused on their play, it was a remarkable thing to see that the children also influence themselves. Many behaviors emerged during play, such as influencing, suggesting alternative ways, collaborative building, and synchronized moving with each other (Figure 4.6).

From the beginning, both children did not show any sign of shyness. D was the first to step onto the playground, and quickly run to the limits, while N started within a smaller circle, examining her own traces. After the first cycle, they switched their attention. They were looking at the traces of each other to see what he/she did. Later on, for a short period, they played tag. As a result, they leaved similar traces. Soon to the end of the play, N suggested that they can hold hand hands and together they tried to move synchronized. -*"Shall we try holding hands?!"*-

Figure 4.6 : The children playing tag.

4.3.4 Conclusion

Key features of the study can be itemized as follows:

1. The children developed first impressions of the setup from afar to then come close and start examining it in detail.

2. They collaborated in the given task, most probably because they are used to doing things together in their daily lives.

3. They soon thought of alternative ways to use the setup.

4. The boy started wandering the entire setup from the beginning whereas the girl started at first with experimenting within a small circle to then explore the entire canvas.

5. The basic forms, i.e. footsteps, facilitated faster explorations.

6. The space supported both singular and collaborative actions.

7. The simplicity of the setting triggered the children's imagination.

Building an analog prototype helped to examine the ideas and assumptions from the background knowledge, like the environment can become the play, which they simply interact with/within and provide more for a child’s mind.

The analog prototype enabled the clear observation of how children approach an unknown environment, object or material, how they interact with them, and how they engage in play. Furthermore, other than the conceptual findings, the observation of the development of social interactions was also important during play, within the preliminary setup phase. Figure 4.7 shows the flow of the preliminary setup and observed emerging conditions.

The children in this age group build an interest in other children and the things happening around them. The environment embodies the potentials. It could give clues through visual appearance regarding desired functional performances, yet still depending on a child's imagination.

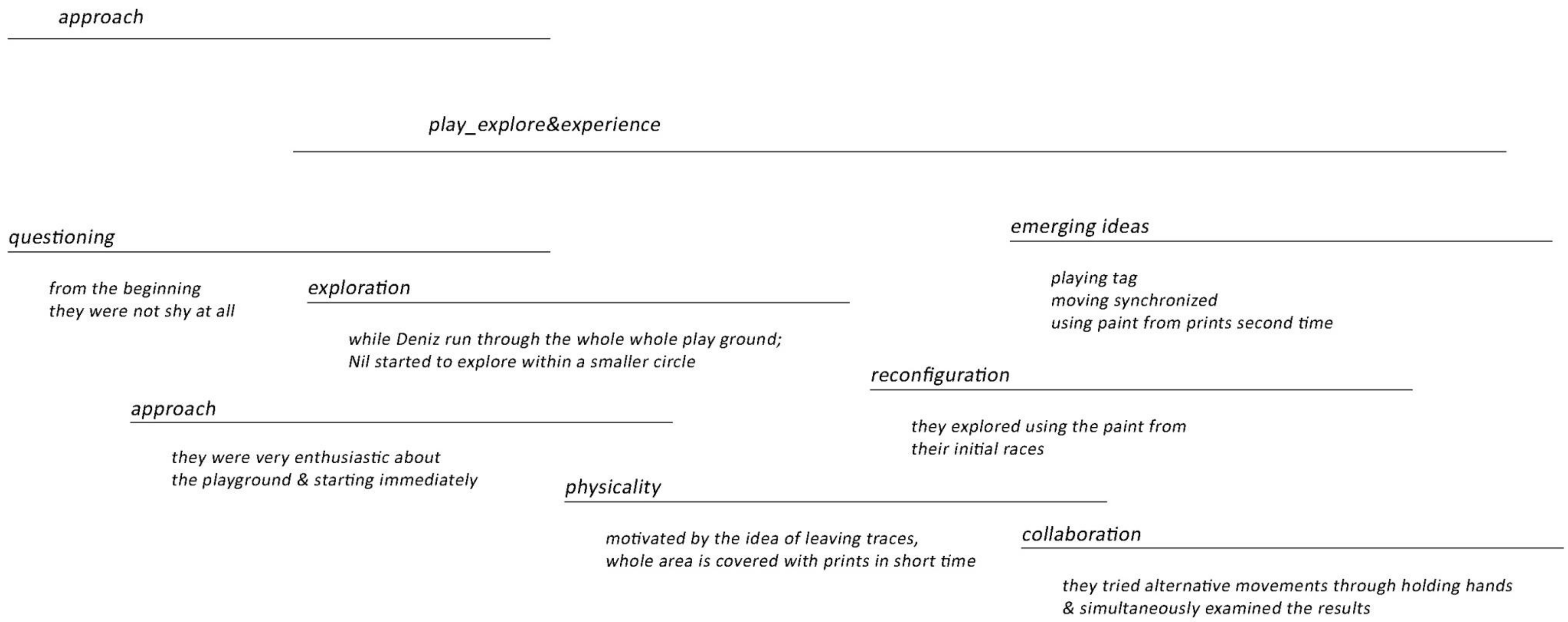

Figure 4.7 : The overview of the preliminary setup.

5. A PROTOTYPE WITH PIEZOELECTRIC SENSORS AND A SCREEN

"Perception forms the portal between reality and knowledge." (Kellman & Arterberry, 2000)

As supported by the cited literature and the narrated initial study, children manipulate their surroundings, objects and materials, and convert them into play things. Moreover, the preliminary setup showed that they can come up with a resolution and accept undefined spaces to integrate them in their play.

To build an approach for playful learning, this thesis presented the surrounding environment as the unified medium of the physical and the digital worlds, where one or more children can freely interact. The preliminary setup stands as the physical part while the proposed prototype investigates the outcomes of the learning process in an interactive environment.

5.1 Design Requirements

The second part of our study introduces an interactive object rather than a playground. Despite being a table-top box, this prototype is designed to mimic an environment embodying kinesthetic and visual interactions.

The main idea of this interactive prototype is to encourage children in joining play. Letting the children act and explore on their own naturally motivates them for interaction and active exploration. As a result, the design requirements are identified as affordances in the manipulation of input and output data and affordances of interpretation of feedbacks.

5.2 Affordances in Manipulation

The interface of an interaction is mainly constructed by the input and the output. There is continuing research in the field of tangibleinteraction to find proper ways to transform an input data into output data, and to materialize an aesthetic feedback. This process of identifying and defining the relation between the input data and the output data is expressed as *mapping*. Mapping is used to respond to design requirements and leads to the appearance of a feedback.

Bateson and Mead (1976) state that the feedback is generally formed by the input and the output, but is notably a matter of *subjective interpretation* and *context*.

Embedding the input and the output into the environment opens up new possibilities in space. By embedding, new relations and ways of interactions emerge between the children and the environment, defining the basis of the children's playground. The playground with enhanced features becomes the ground where children can explore, experience and build changing interactions with and within the play environment. As in this thesis, they can interpret the results of their movements and build basic reasoning.

Numerous research has already been reported on the explorations of the interaction stimulating the children's senses. In the preliminary setup, the potentials related to the affordances of the space have been explored and observed by the author. In further phases, through sensors the output will be embodied in space.

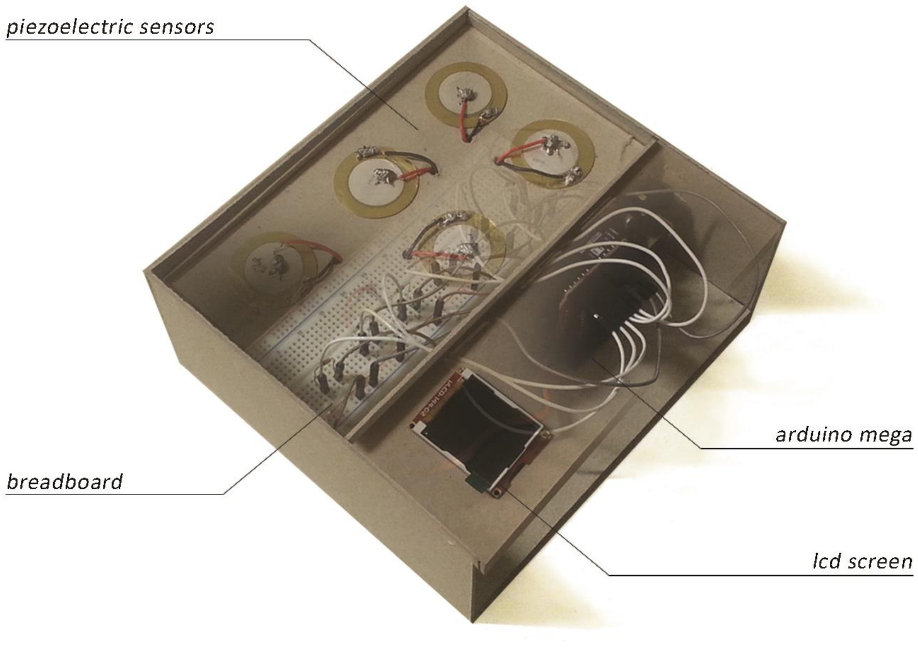

Figure 5.1 : The final state of the prototype presented.

In this setup, kinesthetic refers to applied force and movement, while visual refers to color. The output of this data is visualised through a screen. The screen is a mockup feature that we reverted to within the limits of this study whereas the original design futures interactive piezoelectrically capacitated floor boards previously simulated as the walkable area of the first phase (Figure 5.1).

5.3 Affordances of Interpretation

To encourage children in interpreting the system in an explorative way, a connection should be established between the input and the output, digital and the physical, the user and the environment. Mainly, the connection can be constructed via cables and plugs to interpret data by joining components together in the physical setup.

In this thesis, with embedded interaction, children have the freedom of manipulating and transforming the data and the freedom of exploring the results of their movements as scale, position and color. As a result, they build basic reasoning skills through active play. These aspects are going to be explained in the following sections of this chapter in detail.

The children are able to connect the pressure of their movements that create different outcomes as paints spread in the preliminary setup, or as lights presented on the ground, in this way the design of these kinds of environments holds numerous possibilities. It is possible that more connections and relations can be defined and produced regarding the environment. But, within the scope of this thesis, the qualifications of the prototype remains related to scale, position and color for a simple and playful experience (Figure 5.2).

Every movement children make, triggers a mapping route in the code of prototype: vibration due to movement to scale, movement to position, movement to color, vibration due to movement to color, vibration due to movement in position.

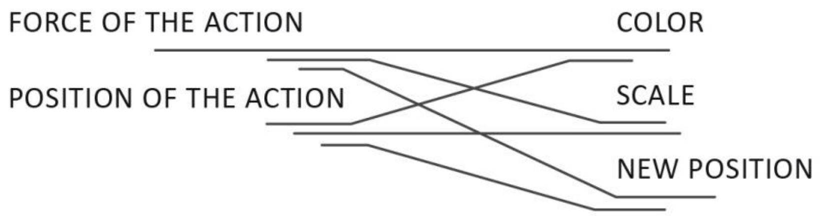

Figure 5.2 : The basic relations that are mapped in the code.

In the prototype, transforming the inputs into meaningful outputs may occur in different levels – some to be easier or more complex. For example, mapping movement to a response that identifies the position of the geometric element is rather simple. The movement is directly related to the output.

Mapping both the movement and the strength of the movement onto a response –for example onto a color– is more complex than usual. Because they are different types of inputs, the output becomes harder to build basic reasoning (Figure 5.3).

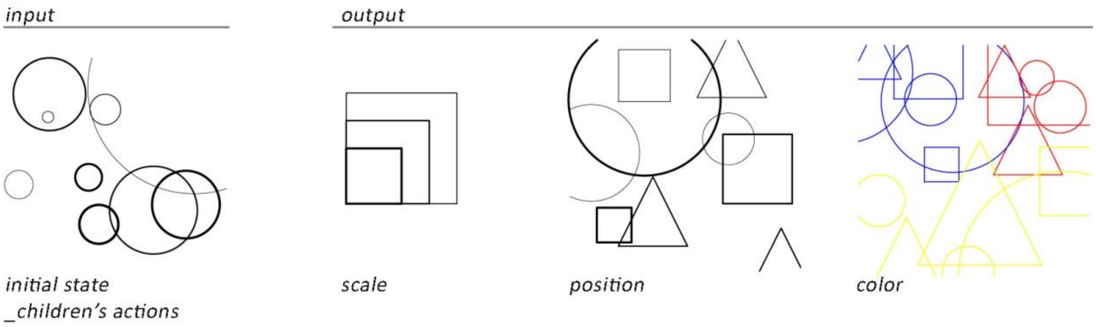

Figure 5.3 : The movement data (input) mapped as different aspects (output).

5.4 The Interactive Prototype

When building the prototype physically, Arduino platform has been used to embody the aspects of the sensing and actuation. The representation of the interaction ground – its appearance, size and the style of connection – were also designed (Figure 5.4).

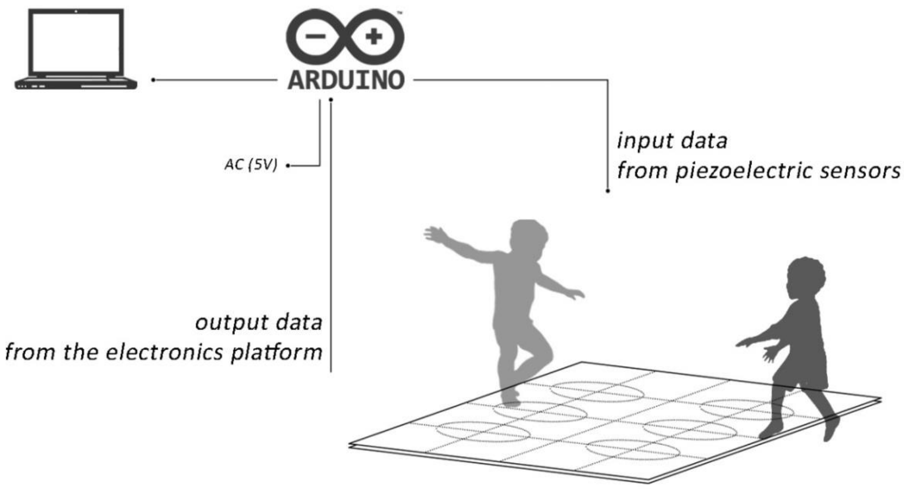

Figure 5.4 : The overall setup.

5.4.1 Hardware

The basis of the hardware is an Arduino Mega 2560 R3 microcontroller, an Arduino Display Module and an Adaptor Shield to visualize the data with piezoelectric sensors (Figure 5.5).

Arduino Mega 2560 includes 16 analog input channels, which enabled the use of the children's physical movements as the input data. The input data is collected through piezoelectric elements, and transferred to Arduino for the mapping. In this manner, Arduino Mega enabled the integration of analog input and the digital and analog output.

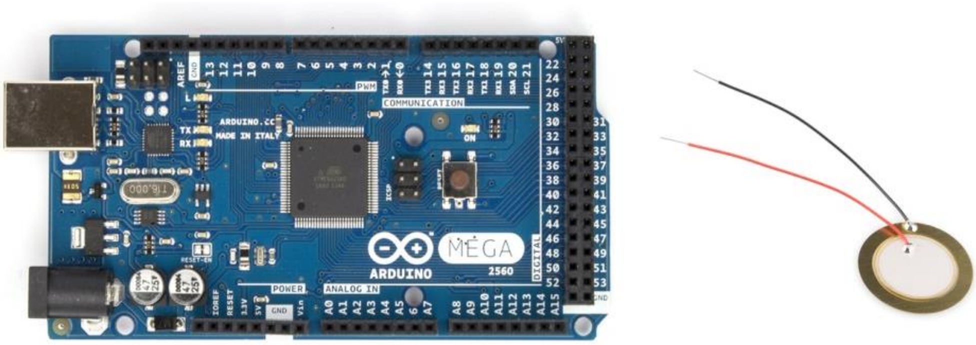

Figure 5.5 : (a) Arduino Mega (URL-1) (b) Piezoelectric sensor (URL-2).

For the visualization of the output, Arduino Display Module Pack (Figure 5.5) includes a uLCD-144-G2 1.44" LCD Display, a 4D Arduino Adaptor Shield and 5 way interface cable (Url-1). The shield stands as an interface connecting the LCD screen and the Arduino Mega. The uLCD presents its own library with numerous commands from the Arduino, making a drawing, displaying, playing and logging data easier .

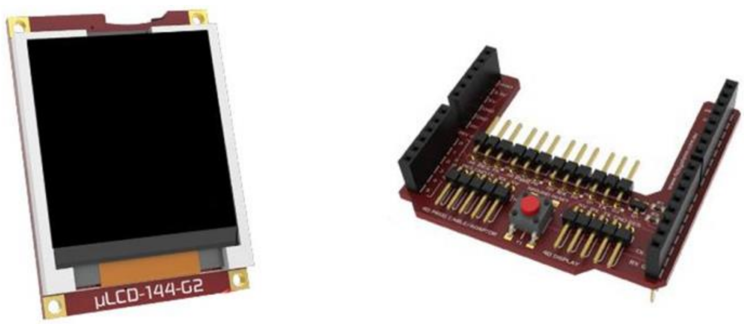

Figure 5.6 : uLCD-144-G2 1.44" LCD Display and 4D Arduino Adaptor Shield (URL-3).

A representation of basic connections between the Arduino and the piezoelectric sensors can be seen in Figure 5.7.

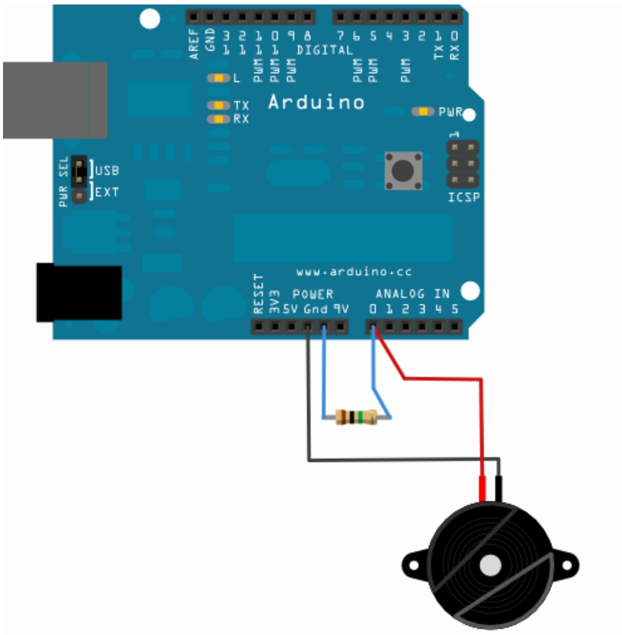

Figure 5.7 : The basic connections between Arduino and the piezoelectric sensors (Url-4).

In the project of this thesis six analog inputs are connected to Arduino mega and Arduino Mega to LCD screen with the shield. All in all, Figure 5.8 and Figure 5.9 can be examined to general setup of the hardware.

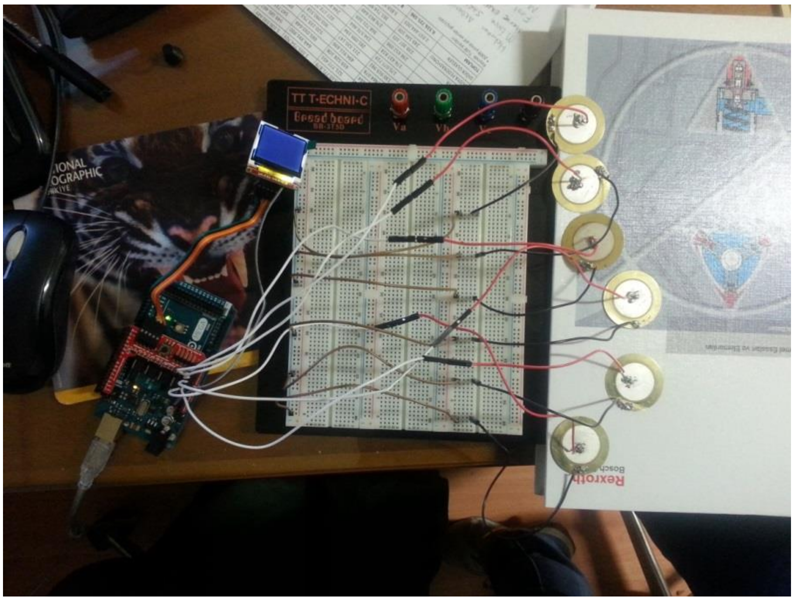

Figure 5.8 : The preliminary setup of the project, showing Arduino, the shield, LCD screen and breadboard connecting six piezoelectric sensors.

5.4.2 Software

The software of the project is also written in Arduino. Arduino supports many libraries, stands as a real platform for unifying different elements and is open source. Moreover, because the code of the program can be transferred to the memory of Arduino, it enables working with a suitable power supply, during the absence of a computer connection.

The code starts with reading the analog data from six inputs *(sensorReading).* Since analog ports were used to connect, instead of just seeing the digital representations of "1" and "0" for the actions, the volumes of the movements have become detectable with the help of Arduino.

Analog inputs on the Arduino are limited to 5V. This means that Arduino automatically transforms the input limit of 0V-5V range into 0-1023 range in digital medium. Consequently, the action on the piezoelectric sensors and the level of applied force can be observed through the screen by introducing the values to the code as integers and characters.

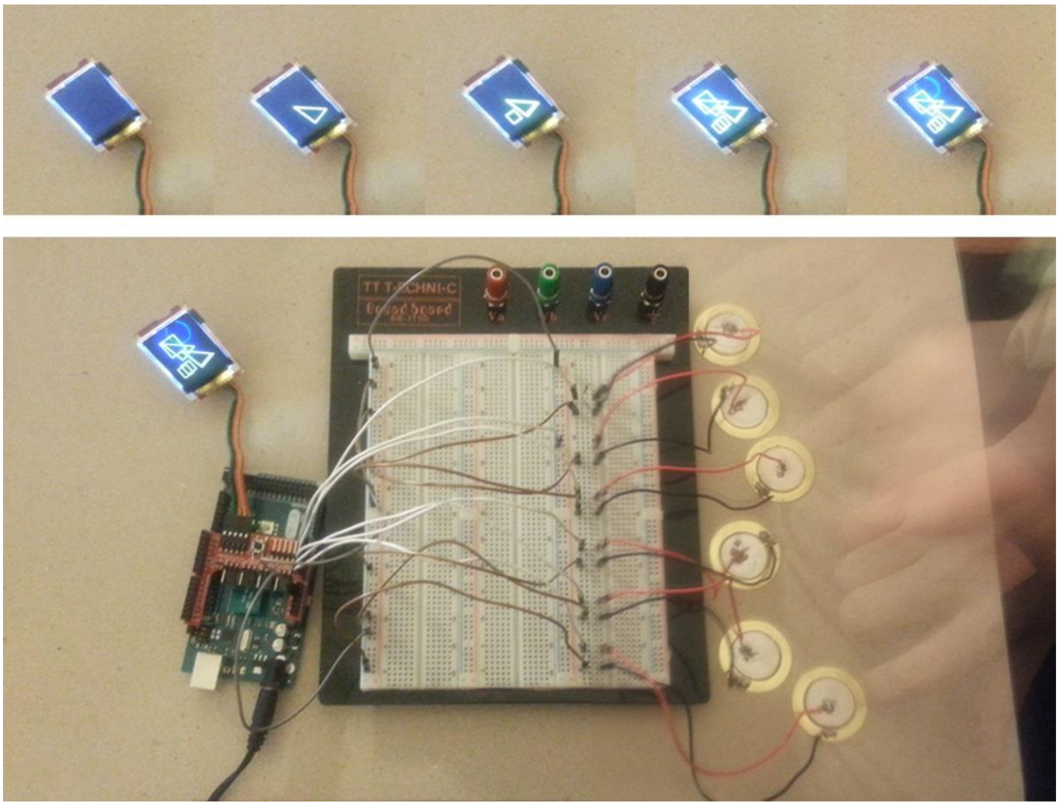

Figure 5.9 : Experimenting with the initial prototype.

Since piezoelectric materials produce energy from the physical actions, the process of this transformation continues to trigger the dynamic in itself for a while. This uncontrolled decrease in the voltage – and relatively data – causes misinterpretations in the system. To eliminate unwanted noises, a lower limit is defined in the code at 250 in 0-1023 range to exclude a 0V-1V range.

During the specification of the optimal limits, it is observed that piezoelectric sensors can overwhelm the system when voltage values are bigger than 5V. Later on, voltage experiments are conducted to identify the optimal range for the system. Moreover, it would be easier for children to comprehend the output with more refined outcomes, when they explore the setup. Their actions were reaching to limit of 1023 so fast and causing complications in the code. As a result, controlled experiments are conducted on the assembled system to identify the best suitable range with more controlled increases and decreases (Table 5.1).

Table 5.1 : Trials to identify the optimal range.

	increasing reaching to 1023	decreasing reaching to 0	impact to other inputs
1MΩ resistor	↑	↓	—
zener diode	↗	↘	—
zener diode + 1MΩ resistor	↗	↓	—
none	↑	→	

In the experiment, the value read from the analog inputs varied based on using a resistor, a Zener diode, both or none of them. As seen from the Table 5.1, in the case of the 1 MΩ resistor, the value read from the input escalated so fast to the 1023 limit, while the trials including the Zener diode not. On the contrary, the value declined to the 0 limit so fast in the absence of the Zener diode. As a result, the Zener diode is included in the current system, as it enables the slow decrease and increase in the values read.

The analog input data were used for creating two new kinds of knowledge (see Figure 5.10):

The first one identifies the average strength *(ave_sensorReading)* by calculating the six analog inputs. By doing so the average value represents the force applied on the surface meaning children's movements.

The second one identifies the position *(x, y)* of the average strength, using both the coordinates and the strength. As a result, the current value of the input data is represented with the actual positioning on the surface with weighted mean.

Depending on the position of the average value, the LCD screen has been divided into color zones. With *"If... Else if"* commands, calculated analog inputs are correlated with the position and focusing on the particular area, results as a change of color of the drawn geometric object. This way, children can build simple reasoning and see that intense data from particular areas gives feedbacks as mapped color transformations.

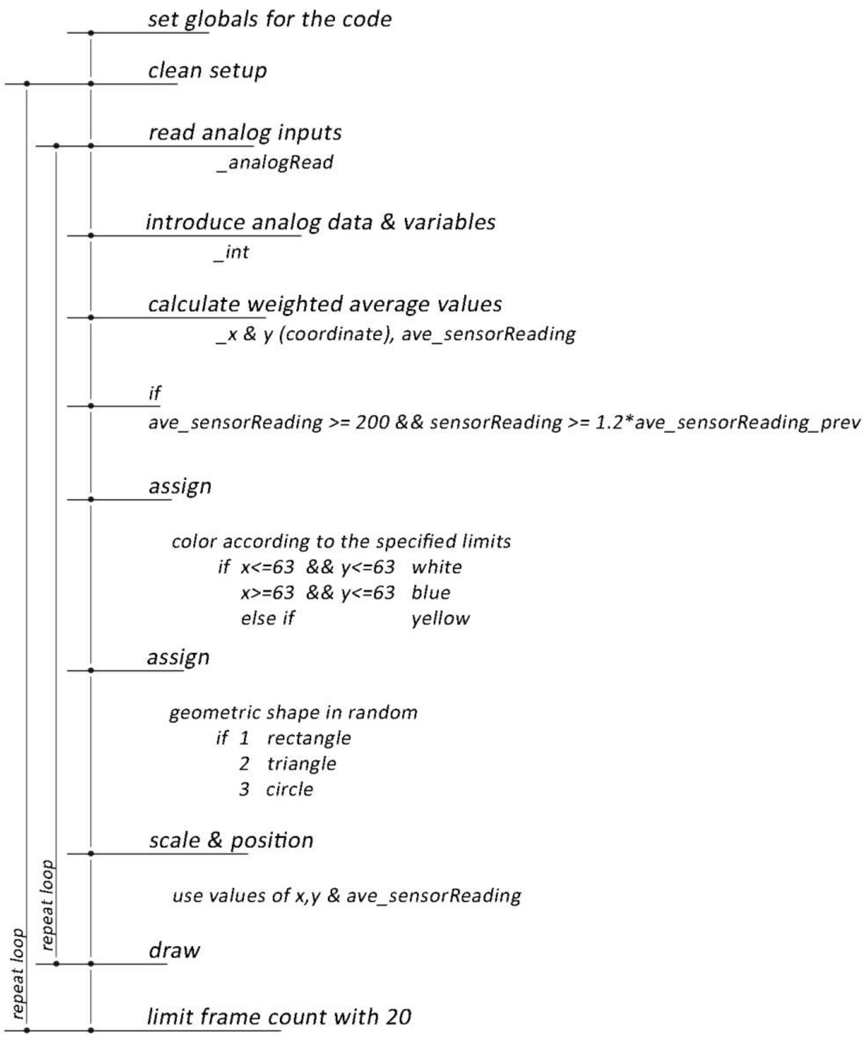

Figure 5.10 : The organization of code.

Figure 5.11 : The installation steps.

The LCD screen shows three basic geometric figures: a square, a circle and a triangle. They are appointed randomly by the code *(random)*. Yet, the scale of the geometric elements changes accordingly to the actions of the children. Also, the coordinates are calculated through mean values and relatively their color depends on the positioning.

The code is run for 20 times, and after that, the screen turns to its initial state to start over *(Display.gfx_Cls)*. The readings have been limited to 20 frames, because it lasts long enough to enable the perception of the idea, and at the same time, not overwhelm the system.

5.5 An Interactive Prototype For Playful Learning

5.5.1 Documentation

The experiments provide data with regards to how children build basic reasoning skills via playful learning in an interactive environment. Can they explain the correlations in a meaningful way, or understand the mapping logic works?

The twins (aged 4) from the preliminary setup were the participants of this experiment also. The observation took place in one of the offices of the Yildiz Technical University Department of Architecture. A table and chairs were provided. The experiment was visually recorded, and also numerous photos had been taken for later inspections (Figure 5.12).

Passive observation is chosen for this setup. It was important to observe how long they stayed engaged with the prototype, and whether they will be able to figure out new possibilities on their own.

(a) first investigation of Deniz (b) demonstrating a trial (c) in search of how the system connected (d) collaborative trials

(e) exploring via both hands (f) applying non-point force 1 (g) applying non-point force 2 (h) Nil applying full-force

Figure 5.12 : N and D (age: 4) exploring different insights via prototype.

5.5.2 Observations

Before presenting the prototype, the children were again not shy, on the contrary, very interested in the thing they see and what they are going to do with it. –*"How will we use them?"*– To get their attention, the experimenter showed them how it reacts to action in brief and verbal explanations were also added. Then, they were asked if they want to try on their own. – *"You can try on your own and explore/act as you wish."* –

The box seemed strange, especially to D. – *"What is this for?"* – He started with opening the box and seeing what is it inside, causing the lights appeared on the screen during instruction. –*"What is inside?"*–

After warming up, N and D tried many approaches. They started exploring individually, yet not long after, they figured out that they can manipulate the results together and at the same time. Moreover, they tried using their both hands at the same time, which can contribute to their motor activities. Right after, they tried bigger actions, applying all the force they have. It is observed that D identified this mapping *(force to scale)* and controlled the results from the screen.

The social behavior while exploring the prototype varied depending on the circumstances and cannot be compared. Such as, after understanding that both can play at the same time, they played with the prototype together for a limited time. Due to the proportions of the prototype, they soon started saying –*"It is my turn!"* – *"I want to try too."* –

5.5.3 Findings

In the beginning, demonstrating simply how these relation works were very important. Both of the children were interested in how the prototype works. After focusing on this issue, they started trying new applications and ideas (Figure 5.13).

The main difference between the preliminary setup and this trial was the shift in approach. The twins were focused on the idea faster, in the initial setup. But they spent time on figuring out the mapping and relations. As Ackermann states, interactive objects challenge one's mind of how things work (Ackermann. 2005).

Embedding different uncommon features into an object or the environment captures their attention, where in fact it can be explained with a simple logic.

Because this phenomenon captures their attention, they keep playing until they understand the mapped relation, namely the learning outcomes. On the other hand, if the mapped phenomenon was very hard for them to figure out, then they lose their attention towards the play.

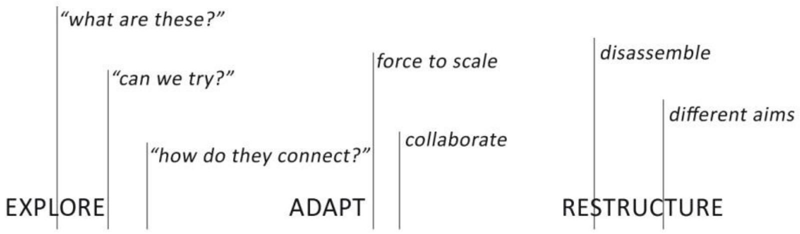

Figure 5.13 : The classification of children's actions in the second study asobserved.

5.6 Discussion

The thesis questions the potentials of space in playful learning setting for children, using the embedded interactivity as a potential affordance to increase their reasoning skills, motivation and collaboration. In this regard, interaction stands as the major parameter for enhancing the relation between the children and the environment.

The preliminary setup revealed that the children are more open and enthusiastic about the things they do not know and eager to find out. Parameters such as collaboration, motivation and reasoning have been observed during the preliminary setup with the children. Yet, since the experiments were conducted with twins, results regarding collaborative acts must be investigated with stranger

Digital experiments, which are coded in Arduino platform, are used for simulating the existing observed situations and possible alternative cases. Later on, the addition of analog inputs and the output into the system enabled interaction with the environment. Consequently, varying input data collected and their aspects mapped to become the output, which enables the feedback and the interaction required for the playful learning environments.

On the other hand, observing both the preliminary setup and the experiment with the prototype, the children did not talk much during the latter experiment and it became harder to observe the reactions of them from their mimics. In addition to observing participants, it could have been better to ask questions to the children to make them aware of something about what happened, or what caused with questions such as “Why do you think it did not work?” or “What do you think about this outcome?”.

Since the interaction occurs as the result of children’s actions and not limited to secondary devices, if provided in the surrounding, they could have included other objects in these trials that leading to create potential new insights in children.

In the second trials, the mapped data of the children’s movements is visualized through a rather small LCD screen. The level of engagement was lower than the first experiments, since the sense of large scaled outputs vanished. Still, the motivation created via instant interaction with the physical environment shows that if correctly applied, embodied interaction promotes both playful learning and physical activity.

In spite of not being able to represent all the features of preliminary setup in the digital medium, since the focus of this thesis is studying the relation between both mediums in play environments, main issues concerning this setup are revisited to discuss the outcomes in the light of experiments conducted. In this regard, the identified main aspects are: interaction context -spatial interaction, tangibility and embodiment-, playful learning context –reasoning, motivation and collaboration-.

5.6.1 The context of interaction

Using Arduino enabled the transformation between the physical world and the digital world by creating unique ways for interaction spread and started to influence each other.

When people move in physical space, the mapped data of them can be represented in the digital realm. Within embodied systems, both the digital and the physical mediums merge and turn into a unified system. As a result, any of them can give form to the interaction and to the overall system.

Embodied interaction styles could define the movements of users. Within specified environments, limitations and rules can be infused as well. The surrounding can restrain or enhance the physical relations and arrangement directly. For instance, a formation can support collaborative work or on the opposite, and individual interaction among children.

Because interaction embedded in space, spatial interaction is an inherent inseparable aspect. The children used their bodies as the origin of their perception. In the preliminary setup, children needed to move in space to interact. Significantly, this interaction in space is also to be categorized as tangible interaction. Using this sense strengthens the relation between the children and the perceived. Despite the 3D spaces in virtual realities, technology in the physical realm can enrich the perceived space better than a window and a pointer device.

5.6.2 The context of playful learning

Current generations are being raised up in an environment hosting all kinds of technology, since it has many opportunities to offer (e.g. Communication, data acquisition) including virtual environments, which attract children. Because free play does not hold meaning from the beginning and does not restrict their use and idea, as a result, they present novel, and not predesigned interactions and outcomes. Children could have the freedom of reconfiguring any environment as their playground.

Similarly, Fisher (2002) writes that children are active learners and given opportunities, they find support to explore and play. She adds that the presence of an environment capable of offering active participation is crucial. As a result, it is not surprising that in a learning environment, learning by doing and learning with active involvement are the leading elements.

With the enhanced environments, through the children's imagination and engagement, unexpected outcomes are most likely to occur. Because, both the digital and the physical world become the medium for the children's play, realization of interaction triggers cognitive development, collaboration, social communication and even competitive encounters to be experienced.

In the first experiment, the participants had the chance of free physical activity, while in the second experiment, they were limited to an interactive space as the prototype was small. As a result, the enthusiasm in the physical activity changed, exploration and collaborative work also decreased with the lack of enough space to act on their own. In the case of larger groups, trying prototype would be inappropriate for playing with this scaled prototype.

In the second experiment, they were not sure how exactly the mappings worked out. This level of mapped data may lead to varying results, if applied to different age ranges.

For free play, children need places where they can be less limited. These places haven’t been specified as playgrounds particularly. As children need physical spaces rather than virtual worlds, embedded interactions work in an effective manner in this regard.

Also, as observed in the preliminary setup, children are enthusiastic about exploring all the area given. Consequently, the embedded interaction may motivate children for more physical activity.

6. CONCLUSION

An interactive playground has been developed as a case that enable the environment to become the medium for investigating children's playful learning. Three main issues were emphasized within this regard: Playful learning, embodied interaction and the relation of physical and the digital worlds that children manipulate and restructure. Within this research, examining the playful learning theories and precedent studies enabled identifying the preliminary structure of needed information for learning through play research.

When they get response from the environment as a result of their actions, children were more engaged and motivated to explore and experience these aspects (movement, color, scale) and secondary results of their actions. These trials showed us that playing with the prototype also advanced the level of social interaction. These aspects are mentioned and discussed because they help in defining the overview of interactions took place.

From the beginning of the first trial, the children were so engaged and enthusiastic about exploring and experiencing proving that even the most primitive setups hold the potential to encourage children to play. In this study, through background knowledge, observations and trials, the main idea of this thesis can be asserted again that the environment, children inhabit, can be the interaction medium for children to learn through play. The simple logic behind this is the unified behavior of the physical and the digital worlds as space.

The interactivity in the prototype made possible experiencing and exploring for children. As a result, embodied interaction becomes the driving force for playful learning within the real world. Embedding features of reasoning in an interacted environment enables the unification of digital and the physical with affordance more than a screen can offer.

Children are curious by their nature. They try everything mostly without preliminary thoughts. Consequently, since they do not judge how things should be or not, their basic exploration instincts become their advantage.

Moreover, with further research new relations between designs, user behavior and cognitive processes can emerge and/or be discovered. As important as design, the evaluation is also needed to be balanced to fully explain the effects of interaction and learning outcomes. Because the research field is broad and have numerous variables to study, systematic studies would eventually open up new arguments on the subject, additionally increase our level of understanding and knowledge of learning outcomes, interaction, collaboration, user behavior and related challenges as focused topics.

Due to the limitations of time and extends within the scope of this thesis, the study should be continued to improve. Future studies would benefit from experts from the field of developmental psychology in the discussions of better mappings of learning and behavioral materials regarding children. Since the experiments conducted with two children, the situations with less or more users from different backgrounds and age ranges can be investigated. Future studies would benefit from the application of piezoelectric materials to 1:1 scale in the form of a surface that children can walk on similar to the set-up in the preliminary setup. Moreover, both experiments are conducted within a short period. The results may change if children have the chance of exploring for longer time.

In the end, by exploring background approaches and experiments conducted, the study provides perspectives which in fact led the starting question of this project: How these spaces should be designed to encourage children in playful learning, the active exploration and reasoning process? Designing a learning space that supports the child's curiosity and playfulness involves envisioning it as an interactive medium which unifies digital and physical features in fostering the possibility of their manipulation, transformation and reconstruction.

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APPENDICES

APPENDIX A: Bibliography
APPENDIX B: The developed code
APPENDIX C: Consent form for children to participate in research

APPENDIX A

Books

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Videos

Howard Chudacoff *giving a talk about his book*: http://www.youtube.com/watch?v=201hGBiFdjY&feature=player_embedded

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

Mihaly Csikszentmihalyi giving a talk on Flow Theory

http://www.ted.com/talks/mihaly_csikszentmihalyi_on_flow?language=tr#t-28665

APPENDIX B

```
//read & name the analog input

sensorReading = analogRead(A0),
sensorReading_1 = analogRead(A1),
sensorReading_2 = analogRead(A2),
sensorReading_3 = analogRead(A3),
sensorReading_4 = analogRead(A4),
sensorReading_5 = analogRead(A5),
ave_sensorReading2=ave_sensorReading,
```

```
// globals for this program
// introduce analog data & other variables

int sensorReading = 0,
int sensorReading_1 = 0,
int sensorReading_2 = 0,
int sensorReading_3 = 0,
int sensorReading_4 = 0,
int sensorReading_5 = 0,
int x,
int y,
int ave_sensorReading,
int ave_sensorReading2=0,
int i=0,
```

```
// convert number into string

char buff[12],
  itoa(sensorReading, buff, 10),
  //Display.putstr(buff),
  //Display.putstr("\n") ,
  char buff_1[12],
  itoa(sensorReading_1, buff_1, 10),
  //Display.putstr(buff_1),
  //Display.putstr("\n") ,
char buff_2[12],
  itoa(sensorReading_2, buff_2, 10),
  //Display.putstr(buff_2),
  //Display.putstr("\n") ,
char buff_3[12],
  itoa(sensorReading_3, buff_3, 10),
  //Display.putstr(buff_3),
  //Display.putstr("\n") ,
char buff_4[12],
  itoa(sensorReading_4, buff_4, 10),
  //Display.putstr(buff_4),
  //Display.putstr("\n") ,
char buff_5[12],
  itoa(sensorReading_5, buff_5, 10),
  //Display.putstr(buff_5),
```

```
// definitions of mean values

x =
(1.0*sensorReading+64.0*sensorReading_1+127.0*sensorReading_2+1.0*sensorRea
ding_3+64.0*sensorReading_4+127.0*sensorReading_5)/(sensorReading+sensorRea
ding_1+sensorReading_2+sensorReading_3+sensorReading_4+sensorReading_5),
```

```
y =
(1.0*sensorReading+1.0*sensorReading_1+1.0*sensorReading_2+127.0*sensorRead
ing_3+127.0*sensorReading_4+127.0*sensorReading_5)/(sensorReading+sensorRea
ding_1+sensorReading_2+sensorReading_3+sensorReading_4+sensorReading_5),

ave_sensorReading =
1.0*(sensorReading+sensorReading_1+sensorReading_2+sensorReading_3+sensorRe
ading_4+sensorReading_5)/6.0,

char poff[12],
  itoa(ave_sensorReading, poff, 10),
  //Display.putstr(poff),
```

```
// define a lower limit to draw

if(ave_sensorReading>=200 && ave_sensorReading>=1.2*ave_sensorReading2)
```

```
// assign color according to the specified limits

char color,
  if (x<=63.0 && y<=63.0) {
    color= 0xFFFF,//white
  //  Display.putstr("0") ,
  } else if (x>=63.0 && y<=63.0) {
  color=BLUE,//blue
  //Display.putstr("1") ,
  } else if (x<=63.0 && y>=63.0) {
  color=YELLOW,//???
  //Display.putstr("2") ,
  } else {
  color=YELLOW,//
  //Display.putstr("3") ,
  }
```

```
// assign shape according to the specified limits

int rs = random(1,4),
char boff[12],
  itoa(rs, boff, 10),
  //Display.putstr(boff),
  if(rs == 3) {
  Display.gfx_Rectangle(x-ave_sensorReading/20.0, y-ave_sensorReading/20.0,
x+ave_sensorReading/20.0, y+ave_sensorReading/20.0, color),
  } else if (rs == 2) {
  Display.gfx_Triangle(x-ave_sensorReading/12.0, y-ave_sensorReading/12.0,
x+ave_sensorReading/12.0,y+ave_sensorReading/20.0, x-
ave_sensorReading/20.0, y+ave_sensorReading/12.0, color),
  } else {
  Display.gfx_Circle(x, y, ave_sensorReading/12.0, color),
  }
```

```
//define frame count

 i++,
  if(i==20) {
  Display.gfx_Cls() ,
  //Display.putstr("\n") ,
  i=0,
  }
```

APPENDIX C

CONSENT FORM FOR CHILDREN TO PARTICIPATE IN RESEARCH

Research Title: Embodied Interaction: A Case For A Playful Learning

Researcher's Name: Ozde Ozdal

Explanation and Purpose of the Research

You are being asked to participate in a research study for researcher's master thesis at Istanbul Technical University. The purpose of the study is to examine affordances in user interaction within playful learning environments.

Research Procedures

For this study the researcher will provide information about the research, consent form before physical experimentation. Your maximum participation in this study is estimated to be approximately 30 minutes.

Potential Risks

Potential risks related to your participation in the study may include physical discomfort during conducting trials. If experience physical or emotional discomfort regarding the experimentation, you may stop at any time.

For confidentiality, instead of your real names, aliases will be used in research. Data containing your experimentation data will be kept confidential meticulously and will be destroyed in three years from the completion of the thesis. The results of this study may be published in research publications. However, no names or any identifying information will be included in any publication.

To prevent any problem that could happen because of this research and help; if there is a problem; you should immediately let the researcher know.

Participation and Benefits

Your involvement in this study is completely voluntary, and you may withdraw at any time.

The findings of this study could be used to reevaluate the current use of play and help improve the affordances of playing environments.

If you have any questions about the research study, please feel free to ast the researcher. Additionally you will be given a copy of this signed and dated consent form to keep.

Author's Signature ____________________________________ Date ___________

1

APPENDIX C

CONSENT FORM FOR CHILDREN TO PARTICIPATE IN RESEARCH

Research Title: Embodied Interaction: A Case For A Playful Learning

Researcher's Name: Ozde Ozdal

I have read the participation information sheet and have had the opportunity to ask the researcher any questions I may have had. I understand explained to children whom I am responsible for that the participation in this research is voluntary and can withdraw any time from the study.

I understand and explained that the risks are minimal in this study. I understand and explained that they will be involved in 30 minute video recorded experiments with photos will be taken of their movements and their work during trials. Their name and personal information will not be used identify in any means.

By signing below I am consenting to my children to participate in this 30-minute experimentation, video record and having their photos taken as work samples.

I understand that information from this experimentation will be used for a thesis research and possibly other published studies and I consent for it to be used in this manner.

I gave my permission for my child ______________________ to participate in this research.

I gave my permission for my child ______________________ to participate in this research.

Parent Signature_____________________________________ Date ____________

Name ____

Child's Signature____

Child's Signature____

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