ABSTRACT

This project set out to develop a flexible computer-supported interface that accommodates edutainment for several different target groups, while maintaining high levels of interest. The interface should be able to support various types of content, which would allow a customization of the interface's purpose and functionality, thus ensuring its flexibility.

Several influential scientific areas were surveyed, in order to provide a solid base for the later design and implementation of the interface. This theoretical foundation encompassed scientific areas such as cognitive development, learning style theory, cognitive strategies for learning, and interactive narratives.

During the design and implementation, a tabletop interface was developed, accepting tangible objects as input and providing audiovisual feedback from an external source, such as a television.

Testing was performed on two different target groups (2-3 years and 6-8 years) and data was gathered through observations. These observations revealed a general tendency of attentive interest in the interaction with the interface and the designed content.

On this foundation, it was ascertained that the interface was capable of maintaining high levels of interest across target groups, through a proper design of specified content.

Conclusively, a few future perspectives were outlined, meant to inspire further development of the interface, as well as the content.

PREFACE

The report you are about to read details the entire process of my Master Thesis, written during the 10th semester of Medialogy at Aalborg University Copenhagen, Spring 2010.

In relation to certain figures throughout the report, square bracketed numbers are included in the figures' captions. These are image references to external sources. The list of image references can be found in the end of the report, just before the bibliography.

An appendix is added in the very end of the report, containing documents that have been utilized, but considered unfit as actual report content.

A DVD is furthermore appended at the back of the report inside the report cover. This contains all the electronic resources related to the study, such as application developments, electronic copies of this report and more.

Citations are included in the following format (Stæhr, 2010).

An extensive effort has been exerted, not only in relation to the research and development of the project as such, but also to present to you an interesting and enjoyable read. The substantial page count is influenced by many illustrations and should therefore not be considered intimidating in any way.

Enjoy the read!

Mark Tofte Stæhr

ACKNOWLEDGEMENTS

Several people have influenced the process of this project positively and I would like to acknowledge their support.

First of all I would like to thank my supervisor, Luis E. Bruni, for his invaluable input that has guided this Master Thesis in a proper direction.

I also wish to thank my family, Ann and Oliver, for their caring support during the entire process, especially in the last stressful weeks.

Finally, I would like to thank the many dedicated developers that provide freeware applications and graphics, which have facilitated the entire process of prototyping and thus improved the final outcome of the development.

TABLE OF CONTENTS

INTRODUCTION

Gaining knowledge about the multifaceted nature of the world, in which our lives unfold, allow us to progress both as individuals and as a culture. As individuals, we undergo a personal development from infancy to adulthood, which continuously increases our conceptions of the causal relationships between various aspects of life. In essence, we evolve from novices to experts and the products of our expertise are passed on to future generations, thus developing the human culture as such. While this view is a broad and general one, development and knowledge are indisputably essential factors for achieving a state of expertise, thus justifying research that aims to accommodate these specific areas.

In a broad sense, the common denominator for development and knowledge is *learning*, an area with which both factors are inseparably interconnected. The topic in question is therefore how learning can be accommodated, in order to optimize personal development and acquisition of knowledge, and this constitutes the point of departure for this study.

The process of learning cannot readily be viewed as a definite set of rules, applicable to all target groups and contexts. Different people have different approaches to learning, and the preferences of the individual must be taken into consideration to make the learning process as efficient as possible. This suggests that the development of interfaces for learning is a question of either making specifically tailored interfaces to the different types of learners, or to make a generic one that can be customized to accommodate any of the given types, or at least the majority of these. This study is intended to pursue the latter option of developing a computer-supported, flexible and customizable interface for learning. Flexibility is meant as the ability to accommodate various target groups. As motivation is an essential factor for learning, the aim is more specifically to develop an interface that supports education and entertainment collectedly, thus an edutainment interface.

To inform the design of such an interface, the founding analyses must encompass a variety of relevant research. First, the primary characteristics of different groups of people must be identified, such as developmentally defined distinctions and learning style preferences. Second, existing interfaces, and related products in general, must be analyzed. And third, areas that directly influence the interaction design must be reviewed, such as teaching strategies and narrative structures.

To concisely define the initial scope of this study and to guide the subsequent preliminary analysis, the following initiating hypothesis is postulated.

> *"In the context of edutainment, various target groups have significantly different requirements and learning preferences, and existing common interfaces are not sufficiently flexible in terms of accommodating a wide variety of different users."*

PRELIMINARY ANALYSIS

The purpose of this preliminary analysis is to investigate the validity of the initiating hypothesis, and subsequently formulate a final project hypothesis, on the basis of the research findings. It is essentially a survey that is meant to determine if the motivating problem is relevant to address, and to define a proper direction for the further investigation.

The preliminary analysis will commence with a survey of cognitive development, encompassing the theory of developmental stages and a cognitive view on learning. Next, the vast area of learning styles will be covered in an attempt to define the key characteristics, which ultimately should facilitate an overview of the field. Then an analysis of the common sources of home edutainment will be described, which aims to settle if any currently available interfaces already offers a sufficiently high degree of flexibility.

As a conclusion on this instigating part of the report, a final project hypothesis will be formulated, followed by a delimitation that serves the purpose of guiding the further progress of the study. It should furthermore ensure that all areas are investigated with a proper amount of detail in relation to their immediate relevance to the final hypothesis.

1 COGNITIVE DEVELOPMENT

The cognitive development of the human mind is relevant to the nature of this study for several reasons, and is included here as the instigating chapter of the preliminary analysis. There are a few immediate reasons for exploring this field of research. First, cognitive development appears to influence both *if* and *how* various concepts can be learned. In other words, *what* can be learned and *how* can it be done. Second, it appears that distinct stages of cognitive development exist, which can be considered as a logical division of target groups in relation to edutainment. These target groups are of course only relevant if they are distinct in terms of learning attributes, which depends on the validity of the first reason.

While *development* and *learning* are related aspects, I find it very important to clearly distinguish the terms, in order to avoid any potential confusion. Piaget provides concise definitions of both aspects and exerts his view on the interdependency between these (Piaget, 1964). I find Piaget's account to be highly relevant, and have chosen to divide this chapter in relation to his definitions of the terms, as described in the following paragraph.

Piaget defines *development* as *"[…] a spontaneous process, tied to the whole process of embryogenesis."* (Piaget, 1964, p. 20). It is therefore linked to the physical development of the body, including the nervous system and mental functions. *Learning* is oppositely defined as generally being provoked by situations, which include input from other people (e.g. a school teacher) and other external situations in general. Finally, Piaget sees learning as a function of development, opposed to the view that development merely is the sum of discrete learning experiences. (Piaget, 1964, p. 20)

Since I share the above beliefs, the following account of the field of cognitive development will be based on these foundational assumptions.

1.1 DEVELOPMENT

Initially, I would like to clarify the previously mentioned notion of learning being a function of development, since this is an essential aspect. The belief is that development, among other bodily aspects, concerns the formation of structures of knowledge, which essentially must be considered as biological entities that founds psychological interaction. The totality of structures of knowledge therefore determines the totality of aspects that can be learned, and learning thus becomes a function of development. (Piaget, 1964, p. 20)

Operational Structures

According to Piaget, one must furthermore understand the idea of *operations*, in order to fully understand the development of knowledge, and I will therefore cover these in the following. The underlying premise is that knowledge is not simply a snapshot of reality, stored as a copy in the mind. Knowledge is classified as an encompassing understanding and I think the following quotation captures the essence well.

> *"To know an object is to act on it. To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed." (Piaget, 1964, p. 20)*

An operation can concisely be defined as an interiorized, reversible action that creates logical structures. More specifically, it is an internal action that transforms an object of knowledge in such a way that the transformation itself becomes an operational structure of knowledge, inaccessible by means of perception alone. As an example, an operation can be adding/subtracting, joining/separating or the like, which are all reversible actions. An operation is never isolated, but instead linked to other operations, which as a result creates operational structures. A basic example of an operational structure is *seriation*, which is not constituted by any single number, but instead by the existence of a series of numbers. The structure is therefore not a result of mere perception, but a result of the operational relation between several numbers. (Piaget, 1964, p. 20)

Developmental Stages

This subsection is largely inspired by the descriptions of developmental stages in *"Development and Learning"* (Piaget, 1964), and for that reason I will refrain from adding a reference for each paragraph. Where appropriate, other references will be included in addition to this main reference paper.

According to Piaget, the process of development can be divided into four main stages, namely the *sensory-motor*, *pre-operational*, *concrete operational* and *formal operational* stages. These developmental stages are always reached in the same order of succession and each stage is a prerequisite for reaching the next one, as depicted in the figure below (Figure 1).

Figure 1 - The four main stages of development.

The first of the four developmental stages is the sensory-motor stage, which is pre-verbal and lasts approximately until the age of 18-24 months. This initial stage introduces the development of various kinds of practical knowledge, which foregoes and supports the later development of representational knowledge. Among these instances of practical knowledge is *permanence*, i.e. knowing that an object exists even when it disappears from the perceptual field. Other constructions are then instigated by permanence, such as sensory-motor space, temporal succession and elementary sensory-motor causality.

In the second stage, the pre-operational stage, language emerges and given its symbolic function it brings with it thought and representation. All the developments from the sensory-motor stage must be reconstructed into the level of representational thought. Sensory-motor actions cannot readily be translated into operations (as described in "Operational Structures"), which explain the need for a reconstruction.

The third stage is the concrete operational stage where the first operations emerge. These operate on objects rather than verbal hypotheses, therefore the label "concrete" operational. Example operations are classification, ordering, numbering, spatiality and temporality, along with elementary conceptions of mathematics and physics.

In the fourth and final stage, the formal operational stage, the child progresses from the basic operations in the third stage, to formal operations that enable reasoning on hypotheses. New formal operational structures are attained, which are combinatorial, complicated group structures that are far less restricted than the concrete operations. Thus, the child enters a final stage where reasoning and complex thinking is possible to an extent that has not been experienced before.

To facilitate an overview of the attributes inherent to each stage of development, the following table (Table 1), summarizes the aspects that I have found to be the most descriptive. This table is not meant as an exhaustive collection of characteristics, but rather as a quick reference to the division of developmental stages. For further details concerning the specifics of the various stages, I refer to Piaget's papers, which have also been used as sources for the following table (Piaget, 1964)(Piaget, 1972). Each stage furthermore has several sub stages or attributes, but these have been considered to be of little relevance to the scope of this project initially. For an extensive review of the attributes inherent to each stage of development, I refer to (Piaget, 1977).

DEVELOPMENTAL STAGES		
STAGE	AGE SPAN	KEY CHARACTERISTICS
Sensory-motor	0 - 2 years	Practical knowledge is developed in the shape of sensory-motor actions.
Pre-operational	2 - 7 years	The sensory-motor actions are reconstructed to later become operations.
Concrete operational	7 - 11 years	The first concrete operations appear, which yet only operate on objects.
Formal operational	11 - 15 years	Formal operations appear, allowing reasoning on verbal hypotheses.

Table 1 - Overview of the age spans and key characteristics of each developmental stage.

It should be noted that the age spans included in the table (Table 1) are approximations based on descriptions in some of the literature by Piaget. As mentioned previously, the stages are always reached in the same order of succession, but Piaget mentions several times that the average ages of reaching these stages can vary from one society to another (Piaget, 1964, pp. 21-22). The approximations in the table are therefore based on some of Piaget's own results from Geneva, where he carried out a lot of his work (Piaget, 1972). It is assumed that these results will be representing at least the European population relatively well, which suffices in relation to this particular study. For any studies that require a higher degree of data precision, or are located outside of Europe, these age spans should be properly assessed.

Piaget mentions four factors that affect the progression from one developmental stage to another, i.e. the development from one set of knowledge structures to another. I will describe these factors concisely in the following.

The first factor, *maturation*, is rather obviously related to the whole process of embryogenesis. Maturation is clearly a defining factor in the context of development, and any bodily transformation, interior as well as exterior, is a result of this process. However, it is not in itself a sufficient explanation for the consecutive progression from one stage to another, and the reason for this is found in the previously mentioned facts concerning the average ages for reaching certain stages. Chronological diversities between various recorded average ages are as high as four years, which in other words means that the children of one society can reach a certain stage four years earlier than the children of another society. For this very reason, maturation cannot be viewed as an exclusively explanatory factor. (Piaget, 1964, pp. 21-22)

Experience is called upon as a second factor, and similar to maturation it is considered an important but not exclusively descriptive one. The idea of progressing through the developmental stages solely by means of experience is rejected on the basis of examples that suggest otherwise. One of these describes how the idea of conservation of substance, during a transformation of an object, is grasped before the ideas of conservation of weight and volume. Piaget argues that the idea of conservation of substance cannot be a result of experience, and if the ideas of conservation of weight and volume are not known, how can the amount of substance then be described? This rather odd sequence of conceptions is ascribed to the phenomenon of logical necessity, i.e. *something* must be conserved and by not knowing the concepts of either weight or volume, substance becomes that *something*. Ergo, there is a progress in knowledge, which cannot have been catalyzed by experience alone. (Piaget, 1964, pp. 22-23)

The third factor, *social transmission*, encompasses linguistic and educational transmission and refers to information that is mediated by other people. Once again, this factor is deemed insufficient as a complete description of the progressive transitions between stages of development, even though it certainly furthers the process as such (Gelman, 2009). The reason for this is that a child must be capable of assimilating any given information into existing structures of knowledge, and if no such structures exist, the information will be irrelevant in relation to the acquisition of knowledge. In other words, the principles of complex mathematics cannot be learned if the prerequisite structures of propositional logic do not exist. If the prerequisite structures on the other hand exist, social transmission is a powerful source of knowledge, and much (if not most) of what we come to know during our lives will be socially transmitted. An exhaustive investigation of the attributes of social transmission is beyond the scope of this study, but I recommend *"Learning from Others: Children's Construction of Concepts"* by Susan A. Gelman as a more elaborate resource on the topic (Gelman, 2009).

The fourth and final factor, *equilibration*, is called upon as the fundamental factor that creates order among the three previously mentioned factors. To make sense of the world, the possibly conflicting information from the other factors must be equilibrated, ultimately resulting in the acquisition of explanatory and logical operational structures. Thus, this self-regulation process establishes an understanding at one level, which consequently allows learning at another level that subsequently must be equilibrated too, and so forth. Piaget concisely describes the importance of this factor as follows.

> *"[...] in the course of these developments you will always find a process of self-regulation which I call equilibration and which seems to me the fundamental factor in the acquisition of logical-mathematical knowledge." (Piaget, 1964, p. 24)*

A brief compilation of the essence of each factor is produced in the following table (Table 2), with the intent of facilitating an overview.

TRANSITIONAL FACTORS	
FACTOR	KEY CHARACTERISTICS
Maturation	The process of bodily transformation, interior as well as exterior, e.g. development of the nervous system.
Experience	The process of obtaining knowledge about objects and concepts through interaction with the physical reality.
Social transmission	The linguistic or educational information mediated by other people in the individual's environment.
Equilibration	The process of acquiring logical operational structures by means of self-regulation among the other factors.

Table 2 - Overview of factors that influence the transition from one developmental stage to another.

As a crude conclusion on the findings in this first section, it seems obvious that the method of acquiring knowledge depends on the current developmental stage of the individual, i.e. learning *is* truly a function of development. Any aspirations to facilitate the process of learning must therefore take into consideration the developmental foundation of the target group(s) and strategize the learning methodology accordingly.

1.2 LEARNING

This second section will engage the topic of learning, not in the sense of learning styles and teaching strategies, but in relation to development. It is meant to provide a concise description of a more biologically related view on learning, which can be considered as the induction of knowledge on the basis of development on the one hand, and elements of learning on the other hand.

A traditional view on learning is that the acquisition of knowledge is based on the stimulus-response schema, which essentially states that a response is generated on the basis of a stimulus. In other words, the stimulus is what causes the response. This rather one-sided view on the causal relationship between stimuli and responses is questionable, especially in relation to some of the aspects mentioned in the previous section regarding development.

Piaget argues that stimulus and response have a mutual causal relationship, or as he puts it: *"I would propose that the stimulus-response schema be written in the circular form – in the form of a schema or of a structure which is not simply one way."* (Piaget, 1964, p. 24). The premise for this statement is one already suggested in the previous section, namely that a relevant structure must be present, which can assimilate the stimulus.

The suggestion of writing the stimulus-response schema in a circular form seems to be relevant, and such a schema is depicted in the figure below (Figure 2).

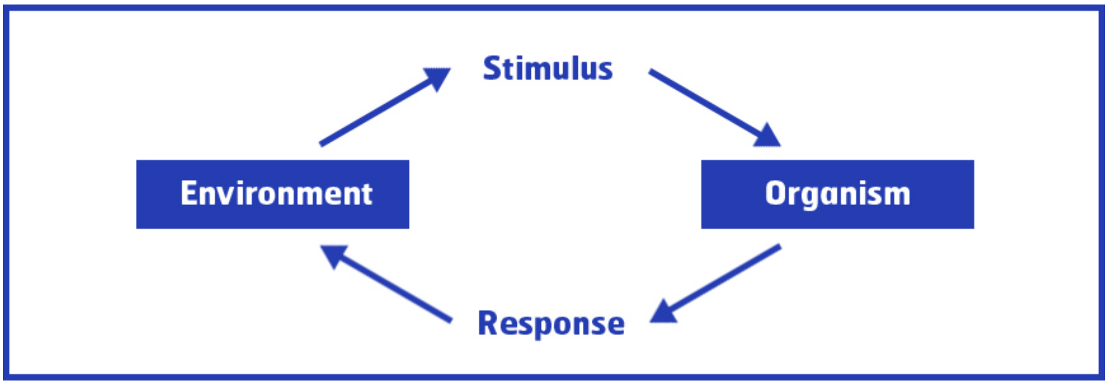

Figure 2 - The stimulus-response schema in a circular form.

The above stimulus-response schema, or cycle of interaction, includes four basic constituents. The *environment* transmits *stimulus* that can be assimilated into the structures of an *organism*, which subsequently creates a *response* on the basis of the given stimulus. This cycle can be exemplified by a student-teacher relationship, where the teacher (environment) explains a concept (stimulus) to a student (organism) who then replies (response). This does, as previously mentioned, require that the organism possess the structures necessary for assimilating the stimulus.

The substantial focus on assimilation is general to Piaget's view on the process of learning, while the concept of association is considered as a much lesser priority in this relation. Learning is, according to Piaget, a matter of active assimilation, and rather than analyzing discrete states by means of external reinforcement (such as measuring and weighing with equipment), one must focus on the operative aspect. This operative aspect, or the understanding of transformations, is the essence of equilibration, where contradictions and incompatibilities are eliminated through reasoning on several factors (e.g. by comparison between personal experience and socially transmitted statements).

As a concluding remark, I will emphasize an aspect that seems essential in relation to the aspirations of this study. The quality and frequency of intellectual stimulation from adults, or possibilities that allow children to engage themselves in spontaneous activity, affects the speed with which a child can progress to a higher stage of development. Poor stimulation and activity will slow down the process, while rich stimulation and activity conversely will speed it up. An interface for learning, which offers children the opportunity to engage themselves in spontaneous activity, therefore seems to hold great promise. (Piaget, 1972)(Gelman, 2009, p. 116)

2 LEARNING STYLES

Defining learning styles is unfortunately not a task that can be accomplished in a straightforward and universally acceptable manner. A substantial amount of opinions and models of learning styles exist, and while some of these theories are more influential than others, there is no consensus of a singular definition (Becta, 2005). But despite the fact that a true definition may be unachievable, a survey of the broad collection of theories can paint a rather detailed picture of learning styles, albeit in a conceptual rather than scientific manner.

It should be noted that an exhaustive review of the various positions on learning styles would constitute an entire study in itself. Such a complete coverage of this scientific field is therefore well beyond the scope of this study, and I will instead seek theories and inspirations that can found the further progression of the project at hand. The overarching aim of this chapter will therefore be to describe the various theories and models that seem applicable to the context of this study.

To ease the process of understanding this complex topic, I opt to break it down into its key constituent elements, although this could be viewed as an overly simplified approach. The following table (Table 3) describes three interrelated elements that can be viewed as a foundation of learning styles. (Becta, 2005, p. 2)

KEY ELEMENTS OF LEARNING STYLES	
ELEMENT	DESCRIPTION
Information processing	Habitual modes of perceiving, storing and organising information (e.g. pictorially or verbally).
Instructional preferences	Predispositions towards learning in a certain way (such as collaboratively or independently) or in a certain setting (e.g. environment or time of day).
Learning strategies	Adaptive responses to learning specific subject matter in a particular context.

Table 3 – Three interrelated elements of learning styles, reprinted from (Becta, 2005, p. 2).

According to this component-view, humans essentially have inbuilt modes of processing information, preferences for the context of learning and an ability to adapt to particular learning situations. The latter element is especially interesting, since these particular learning situations (subject matter and context) could be contrary to the individual's preferences for information processing and instructional settings.

An essential conflict between the many theories is the degree to which learning styles can be viewed as stable entities in the minds of people. Some theories state that learning styles are genetically founded, while others believe that external factors, such as experience, environment and curriculum design, are influential (Becta, 2005, p. 2). Common to both sides of the dispute is the minimal body of scientific evidence to support either of the beliefs, and assuming a firm position will therefore eventually become a matter of persuasion by literature and personal conviction. The remaining part of this chapter is meant to investigate these various views, and my personal belief will eventually be based on the outcome of this research. While such a *"personal belief"* surely is more subjective than it is scientifically justifiable, I find it important to take a stand in relation to the ultimate aim of this study.

A basic concept within the field of learning styles is *learning modalities*, which refers to a person's preference for obtaining and storing information by means of one or more of the sensory modalities, namely visual, auditory and kinesthetic (Becta, 2005, p. 3). Most people learn most effectively through one primary modality and has a tendency to miss, or in certain cases ignore, information that is presented to the other ones (Felder & Silverman, 1988, p. 676).

> *"Visual learners learn best from either pictures or written text, auditory learners prefer the spoken word, and kinaesthetic learners think in terms of actions and bodily movement." (Becta, 2005, p. 3)*

The existence of these preferences has considerable scientific support, but the implications for the design of educational material is unclear. Generally, the issue concerns the correlation between the learner, the subject matter and the presentation. Some theorists believe that the subject matter should be presented in a way that matches the learner's preferences, while others believe that a correlation between subject matter and presentation will produce a better outcome, regardless of the learner's preferences (Becta, 2005, p. 3). At a glance, the latter statement appears to be more achievable in terms of practical implementation, since the assessment of learner preferences, as well as the subsequent design to accommodate these, may prove to be a substantial task.

Another aspect of learning styles is *cognitive styles*, which again refers to personal preferences regarding learning, but this time in terms of representation and organization. Again, a multitude of opposing and overlapping theories exist, and several different terms are used throughout, sometimes denoting the same thing. But two types of cognitive styles are generally accepted, namely the *verbal-imagery* dimension and the *wholist-analytic* dimension (Riding & Read, 1996).

The verbal-imagery dimension concerns the representation of learning material. *Verbalisers* learn best from words or text, while *imagers* prefer to learn from pictorial representations of the information. (Becta, 2005, p. 3)

The wholist-analytic dimension concerns the organization of learning material. Wholists prefer a top-down approach to information where an overview of the topic is presented first, and further details are introduced subsequently. Analytics conversely prefer to break the information down into components, and sequentially explore each of these in depth. (Becta, 2005, p. 3)

As with the learning modalities, there is a disagreement concerning the implications for content development, i.e. whether learning materials and instruction should be matched to the cognitive style of the individual or not.

Some theorists argue that matching will improve both performance and satisfaction (Sternberg, 2006)(Felder & Silverman, 1988)(Dunn, 1990), while others claim that mismatching will aid the development of a balanced approach to learning (Becta, 2005). The latter claim is based on the assumption that learning styles are not purely genetically determined, but can change over time on the basis of experience. Several authors support this view, and emphasize the interaction between learner, context and task nature, instead of focusing on the learner alone (McLoughlin, 1999)(Becta, 2005, pp. 3-5).

Conclusively, there is a crucial distinction between those who believe in either fixed learning styles or flexible learning strategies. In other words, it is a matter of either adapting the content and presentation of the learning material to the preferences of the learner, or to let the learner choose an approach that is appropriate in relation to the given task at hand (Becta, 2005, p. 5). The question is therefore whether learning, over an extended period of time, will gain most from one approach or the other. As mentioned earlier, there is no conclusive scientific support for either of the beliefs and choosing a side is nearly equivalent to a coin toss. I do though believe that the approaches are not mutually exclusive, and that they very well can be related to both developmental stages and levels of education. Matching of learning material to learner preferences could, as I see it, be beneficial for learning the basic concepts and facts of life, which is the process inherent in the earlier stages of development. This sort of preferential learning may be effective for specific knowledge such as colors, shapes and other object names. Conversely, mismatching may prove effective for higher education where students are more aware of how they come to know, and are more capable of abstract and complex thinking. At this stage, the students' capabilities for creative reasoning could be facilitated by the introduction of multiple learning styles, and the strengths and weaknesses of each. But as this notion will constitute an entire study in itself, I will leave it as an aspect to contemplate.

An abundance of learning style models exist, and the majority of these have similar foundations, and even similar meanings when abstracting from the many reinvented terms that essentially denotes the same thing. In the remainder of this chapter, I will therefore only include a few models to exemplify the generally accepted dimensions of learning styles.

Felder and Silverman propose a learning style model that bridges the preferred learning style of a student with a corresponding teaching style to be applied by a teacher (Felder & Silverman, 1988). While the model is intended for learning and teaching in engineering education, I consider it relevant to this study for two reasons. First, the model's dimensions of learning and teaching styles appear to be generally applicable with little or no modification. Second, considering the approaches in higher education is important, even when designing learning experiences for children. To explain the latter statement in more detail, there seems to be a risk involved if specific learning styles are accommodated during childhood, but not in later education. Students may be struck by apathy if their learning styles are incompatible with the teaching style, a situation that appears to be common in the present system of education (Felder & Silverman, 1988).

Again, it is up for discussion whether the students or the teacher should adapt their styles. The following table (Table 4) describes the dimensions of the model.

DIMENSIONS OF LEARNING AND TEACHING STYLES			
PREFERRED LEARNING STYLE		CORRESPONDING TEACHING STYLE	
Sensory Intuitive	Perception	Concrete Abstract	Content
Visual Auditory	Input	Visual Verbal	Presentation
Inductive Deductive	Organization	Inductive Deductive	Organization
Active Reflective	Processing	Active Passive	Student participation
Sequential Global	Understanding	Sequential Global	Perspective

Table 4 – Dimensions of learning/teaching styles, reprinted from (Felder & Silverman, 1988, p. 675).

Most learning style models build upon Carl Jung's theory of psychological types (Jung, 1921) and this is no exception, although it has been elaborated. The essential parts of Jung's work, included in learning style theories, are the dimensions of *perception*, *judgment* and *attitude*. The perception dimension contains the two functions *sensing* and *intuition*, while the judgment dimension encompasses the two functions *thinking* and *feeling*. These two dimensions can furthermore be modified by the attitude functions *extravert* and *introvert*.

In the following, the model proposed by Felder and Silverman will be explained as concisely as possible. For additional detail about the different dimensions I refer to the Felder & Silverman paper, which also constitutes the literary foundation for the following descriptions (Felder & Silverman, 1988).

First there is the *perception* dimension, which contains the sensation and intuition functions, as defined by Jung. Sensors gather data through their senses by observing and experimenting, while intuitors prefer speculation, theories and principles. This dimension is paired with the *content* of the teaching style, which should be concrete for sensors and abstract for intuitors. It should be noted that the characteristics mentioned now and in the following are behavioral tendencies and not strict, genetic patterns. A sensor can occasionally display signs of intuition and vice versa.

The *input* dimension corresponds to the previously mentioned learning modalities, but only the visual and auditory functions are included in the model, given that the perceptual qualities of kinesthetic learning are only marginally relevant to engineering education. I agree to the extent that taste and smell may be of little relevance to most groups of learners and that touch, as a means of input, will have little importance to students in higher educations, compared to the visual and auditory modalities. Kinesthetic perception is though irrevocably tied to, at least, our first years of development, and with a broader perspective than just engineering education, kinesthetic perception is likely to be influential on learning. The corresponding teaching style for this dimension is *presentation*, which relevantly should be visual for visual learners and verbal for auditory learners.

Then there is the *organization* dimension, which classifies learners as either inductive or deductive. These functions are both reasoning processes, and induction concerns the progression from particular data to general theories, while deduction conversely utilizes theories to define something particular. The corresponding teaching style is likewise *organization* and encompasses induction and deduction. The learning and teaching dimensions therefore appear to be simply matched, but Felder and Silverman state that they usually conflict, since induction is considered the natural learning style of humans, while deduction is considered the natural teaching style. This clash between learning and teaching styles has severe implications, and I will therefore cover this dimension in a little more depth in the following paragraph.

First of all, the deductive teaching method presents the learning material in an orderly fashion that concisely defines the subject matter, even if this is of a remarkably complex nature. Not presenting the precursory process of trial-and-error, which ultimately founded the neat structure, may mislead students to think that the author simply and internally thought out such a model. Students may be discouraged by not being capable of such thinking themselves, which leads to apathy and eventually the risk of dropping out of school. Secondly, this method of teaching classifies errors as something that should be avoided at all costs, and students will therefore try to avoid the very trial-and-error process that has founded all the neat and concise definitions, proofs, models etc. In other words, we become afraid of making mistakes rather than accepting their occurrence and learning from them. This reminds me of an inspiring talk by Sir Ken Robinson on ted.com, with the title *"Ken Robinson says schools kill creativity"* (Robinson, 2006). In his presentation, he talks about how the school system frowns upon mistakes rather than embracing them as steps in a creative process, and as a consequence our inherent sense of creativity is stifled. He suggests that creativity should be accommodated, and that this will bear fruit for education in several ways. To return to the points made by Felder and Silverman, the following quotation outlines the possible benefits of an inductive, rather than deductive, approach to teaching. The numbers in superscript are references from the reference source, which are included for the sake of correct quotation, but not further detailed for the sake of readability. For an elaboration of the following postulation, I refer to the references in the cited paper.

> *"Much research supports the notion that the inductive teaching approach promotes effective learning. The benefits claimed for this approach include increased academic achievement and enhanced abstract reasoning skills;[22] longer retention of information;[23,24] improved ability to apply principles;[25] confidence in problem-solving*

abilities;[26] and increased capability for inventive thought.[27,28]" (Felder & Silverman, 1988, p. 678)

From this minor digression I will continue with the next learning style dimension, which is *processing* that encompasses either active or reflective learners. Active learners are experimentalists that process information best by actively discussing and testing this information in the external world. Their reflective counterparts conversely prefer to process the information introspectively by means of reflection. Active learners are therefore weak in passive situations and reflective learners are weak when given no time to reflect on the presented information. The corresponding teaching style is *student participation*, which should be either active or passive according to the processing preference of the individual. There seems to be a substantial correlation between the processing and perception dimension, where sensory-active and intuitive-reflective could be considered appropriately matched pairs. But while the commonalities within each pair are evident, they are still independent categories. A learner that exploits sensory perception will therefore not necessarily process the information actively.

The last dimension in the model is *understanding,* which comprises sequential and global learners. This is correlated with the teaching style *perspective*, which contains the same functions. Sequential learners exhibit linear reasoning processes and solve problems in a logically consecutive manner. Global learners are conversely more non-linear in their reasoning processes, and take substantial leaps during problem solving rather than the stepwise approach of the sequential learners. The sequential learners prefer that material is presented as a consecutive progression of complexity, starting with a simple foundation that gradually can be improved. The global learners can benefit from being prematurely introduced to complex subjects that afterwards are broken down into segments. It can structure-wise be considered as a question of preferring a bottom-up or a top-down approach, while the terms have other unique attributes, as described in the previous part of the paragraph. A sequential approach to teaching is the predominant perspective currently, and global learners can sometimes struggle when enrolled in higher education. This increases the risk of global learners dropping out of school, but they should not be regarded as less capable than their sequential counterparts. The following quotation highlights their strengths and emphasize why the schools should not neglect this type of learners.

> *"[…] global learners are the last students who should be lost to higher education and society. They are the synthesizers, the multidisciplinary researchers, the system thinkers, the ones who see the connections no one else sees. They can be truly outstanding engineers – if they survive the educational process." (Felder & Silverman, 1988, p. 679)*

This concludes the descriptions of the various entries in the learning/teaching style table (Table 4), and I will progress to describe another model of learning styles. It must be noted that the following descriptions are inspired by an article, for which I have been unable to identify the author(s). I therefore find it appropriate to tie a few words to the decision of including an otherwise scientifically invalid source of information.

First of all, the article includes and combines established theories of the mind in a manner that I find appropriate. Second, the article is retrieved from a forum for African-American school administrators (www.breakfastwithapurpose.org) that seek to improve academic achievement through the sharing of information, resources, support and the like. And third, the article is not used here as a fundamental building block in a theoretical framework, but rather as an inspiration in the process of defining the multifaceted subject of learning styles.

The article proposes a model that initially combines the perception and judgment dimensions, as described previously in the chapter. The model can thus classify people in four distinct ways of processing information, based on their positions in the *sensing-intuiting* dimension and the *thinking-feeling* dimension. The model is reprinted in the following figure (Figure 3).

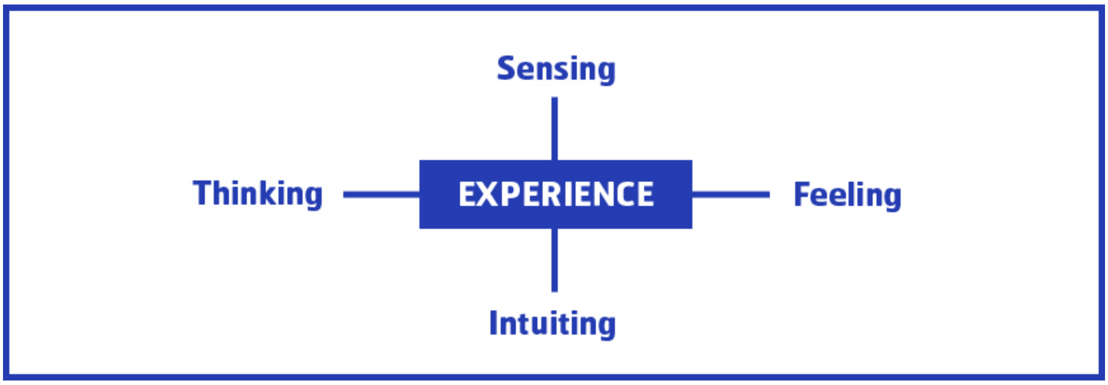

Figure 3 - The Thinking Model based on (Jung, 1921), reprinted from (Unknown Author, 2009, p. 1).

This basic pairing of dimensions does not differ significantly from the findings of Jung, which continues to be the case, even for the article's later addition of the attitude dimension (extravert/introvert) as a modifier for any of the possible learning styles. Where the article distinguishes itself, and in my opinion becomes interesting, is when it suggests that the learning style model (or thinking model) can be analyzed with respect to the theory of multiple intelligences, as defined by Howard Gardner (Gardner, 1983). A person's psychological profile (in relation to learning) may therefore be influenced not only by the thinking style, but also by the tendency toward a certain type of intelligence. A logical/mathematical sensing thinker is therefore not necessarily the exact same type as a linguistic sensing thinker. The article includes examples of professions that adhere to the different styles of thinking in relation to the different intelligences. These are included in the appendix in the back of the report (Appendix A: Thinking/Intelligence Styles) for the mere sake of exemplification.

The article supports the previously mentioned statements concerning the presence of a mismatch between learning and teaching styles in school, and acknowledges the issue of accommodating all possible learning styles. The suggestion in the article is in favor of teaching the students various approaches to learning, rather than matching the instruction to each individual.

Another esteemed researcher within the area of learning styles, Rita Dunn, also sets forth her view on this matter. She refers to research which states that 60 percent of learning styles is biologically founded and claims that learning styles therefore generally are inflexible (Dunn, 1990, pp. 15-16). Dunn therefore supports the view that people should be taught according to their learning style preferences, which she concisely states as follows.

> *"When students cannot learn the way we teach them, we must teach them the way they learn" (Dunn, 1990, p. 18)*

Interestingly, I believe that this quotation can be considered as having two different meanings, although I am confident that Dunn only supports the first one of the following. First, it can mean that we must accommodate the learning style preferences of the individual, i.e. tailor the teaching material to facilitate the process of learning for several distinct types of learners. Second, it can mean that we must inform people about the methods of how they learn, i.e. the strengths and weaknesses of different learning style preferences and approaches to learning. Consequently, the individual will be capable of adapting the best possible approach to a given situation, given that learning styles can be adapted in the first place.

Since none of the preceding research has ruled out any of the two conflicting beliefs, and I feel incapable of providing an answer myself, I see no other way but to acknowledge the plausibility of both. Luckily, both sides of the conflict have implications for the design of content, and since this study concerns the development of an interface that *supports* the development of content, it has no direct effect.

A brief conclusion and summary of the chapter, with consideration of the further progression of this study, must be that certain requirements for the desired interface already has surfaced. It seems apparent that the learning style theories and models, despite their many different terms and beliefs, provide several relevant variables, which can support the design phase. The learning modalities, or perception dimension, set forth the requirement that all three modalities (visual, auditory and kinesthetic) must be accommodated by the interface. They do not necessarily need to be active at all times, but they should definitely be available means for content designers. It must furthermore be possible to develop both active and passive applications for the interface, thus accommodating the respective types of learners. Supporting these two modes of activity will make the interface more flexible and usable in a wide variety of situations, while accommodating both the experimentally minded people and the reflective minds. Finally, it seems essential to enable the development of both top-down and bottom-up control, to support the inductive, deductive, sequential or global learners respectively, or possibly collectedly.

3 SOURCES OF HOME EDUTAINMENT

Several possibilities for home edutainment appear to be generally available to us, the citizens of the 21st century. This chapter is meant to survey these options, to provide knowledge about the products and applications that people are exposed to in their everyday settings, and therefore spend several hours with. Any appliance that already gets a substantial amount of attention is a strong candidate for becoming an excellent vessel of learning experiences. When home appliances are used regularly, it is likely due to a good motivational background, since the users interact with these products on a voluntary basis. The remainder of this chapter is dedicated to an investigation of the strengths and weaknesses of some commonly utilized home edutainment equipment, namely *computer*, *television* and *tangible products*.

3.1 COMPUTER

In the following, the term "computer" will encompass both regular personal computers and game consoles.

One of the notable strengths of the computer is the versatility of its content, which can be chosen to accommodate a given task or desire. Microsoft Word facilitates the process of writing, Adobe Photoshop helps correct or transform images of any kind, and the latest Fifa game from EA Sports spellbinds the children. This "one-box-does-it-all" ability is definitely appreciative and it furthermore enables the inclusion of variable complexity and difficulty, thus allowing a tailoring of the content to several groups of users.

The Internet is naturally also an indisputable strength of the computer, as it provides connections among users, access to vast resources of information, enables updating of existing content and much more. Further elaboration on this topic should not be necessary to prove the value of the Internet.

Yet another potent attribute is the possibility of creating rich content that intertwines images and sound into a powerful hybrid, both in relation to immersing the user in vivid 3D games, but also in relation to productivity and the like, where multiple feedback can aid the user. Haptic and force feedback is also possible through the addition of peripheral input devices, and while this type of action-and-reaction devices are less common than mouse and keyboard, they certainly offer possibilities.

These peripheral input devices are, in my optics, both the strength and the Achilles heel of the computer. The ability to choose the means of interaction, in relation to the given task at hand, is an obvious strength whether the aim is entertainment or productivity. And in some cases, a simple modification of an existing input device is sufficient for creating illusively new means of interaction. This is exemplified by the success of the Nintendo Wii game console, where the same input device takes on different roles when positioned in a specific container. The versatility offered by such a simple customization of one and the same input device is illustrated in the following (Figure 4).

Figure 4 – Different containers for the Nintendo Wii controller [1][2][3].

In the above examples, the addition of a simple plastic shell transforms the controller into a game specific entity. The versatility of the computer's content can in this way cross the border of the computer screen, and bring the specificity into the real world, or domain of interaction.

The above examples are obviously examples of strengths, but there are also severe weaknesses related to the area of input devices. While the specific devices, mentioned above, are interesting and has a certain directness of interaction, other devices are conversely indirect and less intuitive. Joysticks, gamepads, keyboards and mice all belong to a vast category of abstract input devices that have no, or only little, direct relation to the content that it is meant to control. The interaction with computers is therefore often indirect in nature and the interfaces, in the shape of input devices, have steep learning curves. In the pursuit of a flexible interface, as is the desire of this study, learning curves should be diminished and interaction should be made intuitive. The following figure (Figure 5) depicts a few input devices that are used abstractly for several types of applications, although they are made for only one application, or none.

Figure 5 - Common abstract input devices for computers (mouse, gamepad and keyboard) [4][5][6].

These input devices create an indirect and non-intuitive interaction, which in the case of the gamepad can be exemplified by the restricted control of movement that eliminates a proper one-to-one mapping (the 8-way control button/stick can only be pushed to a certain point, at which a maximum speed is reached).

As a concluding remark, the contemporary computer must be online in order to fully unfold its potential, not only in the sense that it must be connected to the Internet, but also in the sense that it must be connected to a power socket.

Although both electricity and Internet presently is available almost anywhere, it can be a constraining factor in certain situations.

3.2 TELEVISION

As a device, the television is fairly simple in structure and is not a jack-of-all-trades like the computer. However, it does share some attributes with the computer as it offers rich audiovisual content and needs to be online. The term online, in relation to television, refers to a connection to a power socket (as with the computer), but also a connection to a TV signal. The television is therefore, like the computer, dependant on peripheral factors in order to function properly.

However, the television is a passive device and do not offer the possibility of interacting with the content. A few notes should be tied to this statement in order to avoid confusion, since one could argue that the television does have interactive capabilities. First of all, I will not concern myself with the introspective interaction that may be claimed to occur when watching certain television programs. Second, I choose to disregard any interaction that takes place through mobile services (SMS voting and the like) as this is neither instant nor personalized, and therefore not of interest.

There are though television shows that I would call pseudo interactive, which are interesting although they plausibly only function for the younger target groups. The concept of these shows is that the main characters address the spectator and ask suggestive questions that prompt a certain answer. A minor delay then allows the spectator to answer before the character responds to this. This is obviously not true interaction, and there is a potent risk of having awkward pauses in the story on the screen if the spectator is nonresponsive. But *if* the show can trigger a response, this simple response can have an effect on learning (increasing information retention through repetition), which is a valid reason for mentioning this type of television content. The following figure (Figure 6) depicts a television show called *"Ni Hao, Kai-Lan"* (Nick Jr., 2008), which utilizes this type of pseudo interaction.

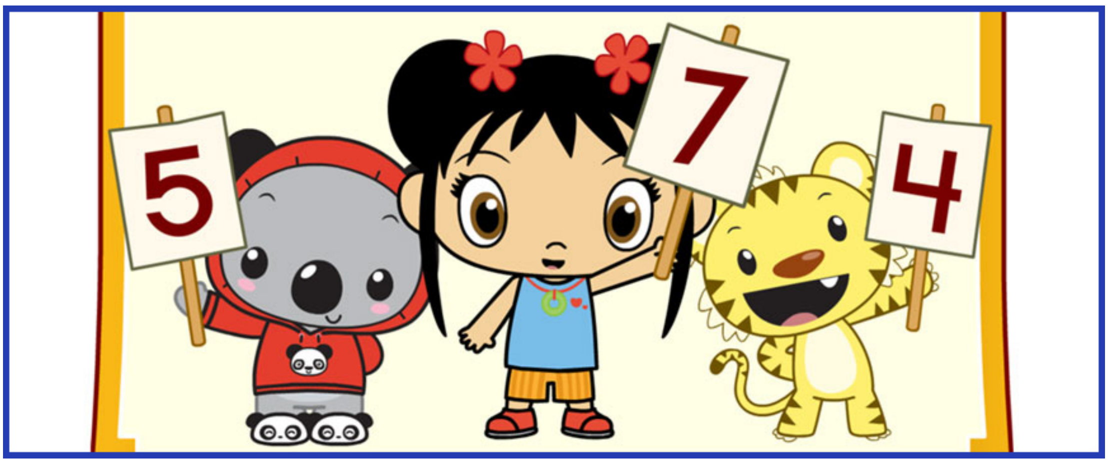

Figure 6 - Three of the main characters in the television show "Ni Hao, Kai-Lan" [7].

The show basically teaches children a few Chinese words and explains moods, emotions and behaviors in various situations. And as mentioned previously, it seems relevant to exploit repetition, at least in the process of teaching words to the children.

Otherwise, the television is a great source of information, ranging from news networks to animal programs, and this may be why it is often turned on and runs as either the primary center of attention or as a secondary provider of information that runs in the background.

3.3 TANGIBLE PRODUCTS

In this section, tangible products encompass books, board games, building blocks, puzzles, tangible toys in general and much more. In essence, it concerns everything that is tangible and resides in the majority of contemporary homes. It is quite contrary to the other categories in several ways, which should become obvious in the following.

Tangible products can generally be defined as being static, in relation to both content and complexity. A tangible product is what it is and do not upgrade or transform into a new and improved version of itself. It is the same in appearance, the same difficulty throughout and it is in large parts predictable. There are surely tangible products that exploit both visuals and audio, but these can be divided into two categories that determine if they belong within the group of computers or tangible products. If the addition of visuals and audio is of a complex and rather profound nature, it is likely that a computer controls all the aspects. In this case the computer can be considered the essential part, while the tangible product can be considered the interface. It thus belongs within the computer category. The alternative, that will place products within the group of tangible products, is to have simple or few audiovisual components, which is the tendency of many tangible products (plausibly due to production costs).

When something is labeled "static" it readily connotes boredom, but tangible products have something that the previous categories do not, namely offline usability and exploratory interaction.

Figure 7 - Building blocks with colored letters [8].

Contrary to both computers and television, tangible products do not have technological dependencies (besides some occasional shifts of batteries, which I choose to see past). They can therefore be brought and used anywhere at any time, which is invaluable in many situations. This is what I refer to as offline usability.

Furthermore, the tangible products afford exploratory interaction that can satisfy the otherwise too often overlooked kinesthetic modality. The products can be turned, combined, transformed, moved, tossed and much more. These actions facilitate the process of getting to know a product's attributes, and this exploratory investigation does not exclude other types of input. Consider for example a set of building blocks depicting colored letters (see Figure 7). Not only can a child explore the blocks kinesthetically and get to know that they are made of a hard material, have pointy corners and stack easily. The child can furthermore get input from a collocated parent, which can provide the child with knowledge about the letters and the colors. The last part obviously requires the presence of an adult and cannot be credited to the nature of tangible products, but the exploratory method of grasping functionality seems invaluable in itself.

To me, it seems obvious that tangible products, although they are often overlooked and referred to as old-fashioned, possess some capabilities that the contemporary, technological wonders do not.

3.4 COMPARATIVE ANALYSIS

While the title sounds profound and comprehensive, the actual intention with this section is to simply gather all the impressions from the previous three categories into a coherent conception of home edutainment equipment and its inherent possibilities. It is the aim that this analysis of commonly available equipment should inspire the creation of a conceptual foundation for this study. In other words, it should provide a foundation for an appropriate project direction, both in relation to a potential product and in relation to further aspects that require investigations.

I see an extremely interesting possibility in the correlation between the three categories. This possibility is to use the tangible products as means of interaction and the television as audiovisual feedback. The reason for this conception will be explained in the following, but before continuing, I find it proper to emphasize that the idea of a tangible user interface obviously is not a concept that I have just conceived. Many such interfaces exist, especially within the scientific domain of development, but I foresee (perhaps prematurely) that such interfaces can be accessible to the majority of the 21st century citizens if a proper design strategy is devised. So with no further ado, I will briefly explain the instigating stepping stone for this concept.

The computer is an extremely capable piece of machinery that generally has just two letdowns, namely its input and feedback systems. Here I think in terms of hardware and not software implementation. The problem with the input system concerns the previously mentioned learning curve of the interface, as well as its non-intuitive functionality. The other issue, concerning feedback systems, actually only becomes an issue by comparison with the television category. As flat screens have dropped enormously in price, the everyday living rooms have adopted television sets with a fairly large screen real estate. A computer screen will seldom be able to compete with a television when the variable is size. The sound system (if any) will also almost always be of a better quality in the living room than it will be next to the computer.

Considering the statements above, I propose that the computer itself is given the task of being the central hub between devices, i.e. the mathematically and performance-wise grandmaster that receives, calculates and distributes. The audiovisual feedback should be handled by the living room system (television and potential sound system), as this system likely will be both bigger and better in terms of both quality (image and sound) and location (the living room is where people are). The interface, or means of interaction, should then comprise tangible products, since these facilitate exploratory and kinesthetic interaction.

In essence, the computer should be put in the center of the action and delegate the various functions to the means that are most suitable. The keyboard and mouse should then be substituted by tangible products, and thus diminish the learning curve of the abstract input devices. While still in an infant stage of development, this will be the instigating concept for further investigation.

4 FINAL PROJECT HYPOTHESIS

The preliminary analysis has established that various target groups have significantly different preferences and approaches concerning the topic of learning. Both the developmental stage and the learning style profile of the individual define how certain types of teaching will be received, and in the case of severe conflicts between learning and teaching style, there will be little success for neither learner nor teacher.

Seemingly, none of the commonly available edutainment interfaces accommodate these differences to an extent where they can be said to be fully flexible, although traces of useful and relevant functionality can be found in any of the three main categories surveyed in the previous chapter.

Based on the preceding research, I therefore find it safe to consider the initiating hypothesis as being acceptable, and it is thus appropriate to formulate a final project hypothesis that can guide the remainder of this study. Inspired by the findings in the initial chapters of this report, and the possibility of using various tangible products as means of interaction, the final project hypothesis is formulated as follows.

> *"A single interface, which supports content that can be modularly customized to different types of users, can accommodate edutainment across target groups and still maintain high levels of interest."*

5 DELIMITATION

This delimitation is included to guide the further progress of the study, and to paint a genuine picture of how the report will be structured. In relation to the scope of the study, it is my intention to emphasize and cover the primary aspects, while still paying the necessary attention to secondary, yet influential, aspects.

The development of a flexible and customizable interface, especially one like this that addresses the topic of learning for a diverse range of target groups, necessitates the inclusion of various fields of expertise in the process. A psychologist can define the characteristics of several target groups; a hardware engineer can build a technologically functional prototype; a narratologist can provide the proper narrative content; a designer can create the graphical identity; and a programmer can implement it all into a unified and codified structure. In this rather exhaustive list, many potential contributors are already neglected, such as usability designers, test designers and the like. This proves the necessity of having diverse perspectives on the entire development process.

With a limited time span, I can of course not as a one-man-army cover all fields satisfyingly, given that other scientists spend their entire lives studying just one of these in infinitesimal detail. I can, on the other hand, not justify a discarding of the many influential areas and a compromise must therefore be made, in order to solve this apparent conundrum.

I believe that the best perspective on the final project hypothesis can be found in the development of a concept that represents the final product, albeit in a prototypical manner. In other words, the aim must be to develop a prototype that includes elements from all, or at least many, of the influential areas. This should enable an evaluation of the concept's usability, and provide a design suggestion that afterwards can be refined by a collaborative effort of experts within the specific fields.

Compromises have already been made, both in the *Cognitive Development* chapter and the *Learning Styles* chapter. Certain subareas that have been considered less important than others have been cut short, simply because of the impossibility of covering all areas in detail. As mentioned, I believe that this is a necessary sacrifice that in the end will result in a better and more complete outcome.

In the remainder of the report, certain areas will therefore be included in a rather superficial manner, because they on the one hand are considered influential, and on the other are considered less essential to the prototype design than other areas. I will in all cases attempt to cover the primary elements of the area, and provide references to explanatory sources.

ANALYSIS

The overarching aim of the analysis is to research several essential and intriguing areas, with an ultimate goal of providing a solid theoretical foundation for the subsequent design and implementation of the targeted interface. It is meant to explore the final hypothesis and discuss the findings in relation to the aspirations of this study.

The analysis part will commence with choosing a proper platform for interaction, followed by a review of the state of the art. Next, the common architecture of tabletop interfaces is briefly surveyed, then cognitive theories for learning that may be applicable in the context of this study, and subsequently the nature of virtuality and narrativity is discussed. Finally, some appropriate target groups are chosen before the entire analysis part is concluded.

6 CHOICE OF INTERACTION PLATFORM

The primary requirements for the prototype are input by means of tangible objects and output in terms of visual and auditory feedback. The interaction platform must therefore enable these possibilities, and the following paragraphs are meant to briefly describe the constituents that are considered necessary for a fulfillment of the stated requirements.

The process of providing visual and auditory feedback is fairly straightforward, and a monitor and a set of speakers should provide these respective types of feedback. The required resolution/quality of these means of feedback cannot readily be asserted, and this choice is therefore ascribed to the design phase where any issues in this relation must be coped with.

In relation to the requirement of accepting tangible objects as input, I regard an interactive tabletop interface as being an appropriate and effective solution. I therefore choose this approach for the recognition of tangible objects, and will briefly define the concept of an interactive tabletop interface. In essence, the concept is to have a table that is reactive to input, either in the sense placing fingers on the table (multi touch interface) or in the sense of placing objects on the table (tangible user interface). In relation to this study, the latter option is the most appropriate one and will be subject to further development. The following figure (Figure 8) depicts the reacTable (Jorda, Kaltenbrunner, Geiger, & Bencina, 2005), which constitutes a good example of a functional interactive tabletop interface.

Figure 8 - The reacTable interactive tabletop interface for music creation [9].

Having a table as an interface creates a definite space that frames the area of interaction. Thus, the area where interaction is possible becomes apparent, and this should immediately make the general management feasible.

A more detailed description of the functionality of interactive tabletop interfaces will be given in a later chapter (Chapter 8 – Interactive Tabletop Architecture) and the objective of this brief introduction is simply to forego and found the following descriptions of the state of the art.

7 STATE OF THE ART

This chapter will describe the state of the art within the two main influential areas concerning the scope of this study, namely interactive *tabletop interfaces* and interactive *educational interfaces*. The intended outcome of this survey is to obtain inspiration regarding the present technological capabilities, innovative design choices, educational goals and the like.

7.1 INTERACTIVE TABLETOP INTERFACES

In this first section, several interactive tabletop interfaces are investigated. Since an abundance of such interfaces has appeared during the past decade, and the majority of these principally are similar, I opt to survey some that excel in one way or the other. I therefore weigh the functionality and concept higher than a 2010 product tag, which in this area of technological development not necessarily means that the product is more advanced. The three examples in this category are selected for *commercial appeal*, *educational relevance* and *conceptual design*, respectively and are presented in that specific order in the following.

Microsoft Surface

"Surface" is the simple but descriptive label for Microsoft's attempt at creating a commercially successful tabletop interface that accepts input from both the touch of fingers and objects. It is a fairly large table (108 x 69 x 54 cm) that offers the user several nifty possibilities of interacting with digital media, and this subsection will describe the key features of this product, based on information from the official website (Microsoft, 2008). The descriptions of Surface are most certainly severely embellished in this source, but for technical facts and the like it should be sufficiently reliable. The following figure (Figure 9) illustrates the appearance of Surface.

Figure 9 – The Microsoft Surface interactive tabletop interface [10].

The size of the table has made space for an impressing 30-inch viewable area that sports a 1024 x 768 pixel resolution, which maximally can be considered acceptable. The computer that controls the components of the table roughly corresponds to an average laptop these days, which for dedicated work must be considered a fairly substantial hardware foundation. A camera tracks the input, while a DLP projector manages the visual feedback, and that should suffice as a brief and introductory presentation of the hardware foundation.

The key attributes of Surface, according to the official data sheet, is *direct interaction*, *multi-touch*, *multi-user experience* and *object recognition*. As an elaboration, users can "grab" digital information with their hands, exert multiple inputs at one time, collaborate or compete with other people and use objects as input devices directly (almost) on the table.

Concerning the two means of input, multi-touch and object recognition, Surface can track 52 fingers on the table simultaneously with no markers needed, while objects must be tagged with labels in order to be recognized. These tags come in two variations, 8 bit and 128 bit, which provide a position, an angle of rotation and an identification number. For the latter variation there are an almost infinite amount of unique tags available. Touch input provides information about the finger's position, direction and force applied to the table. The input data is as such highly detailed and provides a solid foundation for the development of various types of applications.

The intention is surely to support a host of applications, and among the ones introduced by Microsoft are arrangement and traversal of photos, exploration of the globe and a lagoon where you can "play" with fish in the water (like you would in an aquarium).

I wrote initially that Surface was chosen for its *commercial appeal* and it most certainly have this, as most people at the least will consider it as being "pretty cool". However, it does not come with a price tag that suits the average consumer, and an experience with Surface is likely to be the result of a business campaign from one of the large multinational companies. Presently, Surface costs 11.000€ in Europe, which unfortunately rules out the device as an average household appliance. It should though be noted that the product is directed at businesses, and that average consumers are meant to experience the product as a link in a business model. Either way, Surface is a potent and hip platform that comes at a high price.

SMART Table

The SMART Table is a less flashy version of an interactive tabletop interface, compared to Surface, but dimension-wise it is similar (91.5 x 74 x 65.4 cm). It similarly presents a 1024 x 768 pixel resolution and utilizes a camera for tracking inputs on the table. The SMART Table does though not recognize objects that are placed on the table, but relies solely on multi-touch input. Still, this enables collaborative use of the table, and with its aim of supporting educational material for children this is a crucial factor. Furthermore, the company behind the SMART Table (SMART Technologies) has a wide range of products that are meant for educational use, and this table can be coupled with several of these to create an integrated solution across products. The following figure (Figure 10) illustrates the table in action. (SMART Technologies, 2008)

Figure 10 - The SMART Table interactive tabletop interface for educational use [11].

An essential feature of this product is the inclusion of a toolkit that enables teachers to design educational material for the table without too much of a hassle. Besides the standard applications, the table can therefore be used for several specific purposes tailored to the given curriculum. Additionally, ready-made applications can be downloaded for the table, and thus provide extended functionality.

I have not been able to get a reply from the company, concerning the price of the unit, but various Internet resources mention a price that lies in the neighborhood of 7.000 to 8.000$. While dollars should not be confused with euro, this price tag is still a substantial one that rules out the average consumer. It is targeted at schools for educational use, but the inaccessibility to general consumers is a pity regarding the possibilities offered by such a product.

As a conclusive remark, the SMART Table appears to be the less pricey and less flashy version of Surface, which offers the necessary functionality needed to be included properly in an educational situation.

Generation Random

This last example, called “Generation Random”, is included as an outsider and could even be regarded as the odd one out in relation to the previously mentioned products. There is also far less information about this than there is for the others, but as mentioned in the introduction to this section, it has been chosen for its conceptual design. The aim of looking into this type of product is therefore to consider the functionality, rather than admiring a commercialized boy wonder. The rather limited information has been gathered from these sources (interactiondesignblog.com, 2009)(LUST, 2007), and the following figure (Figure 11) illustrates the product.

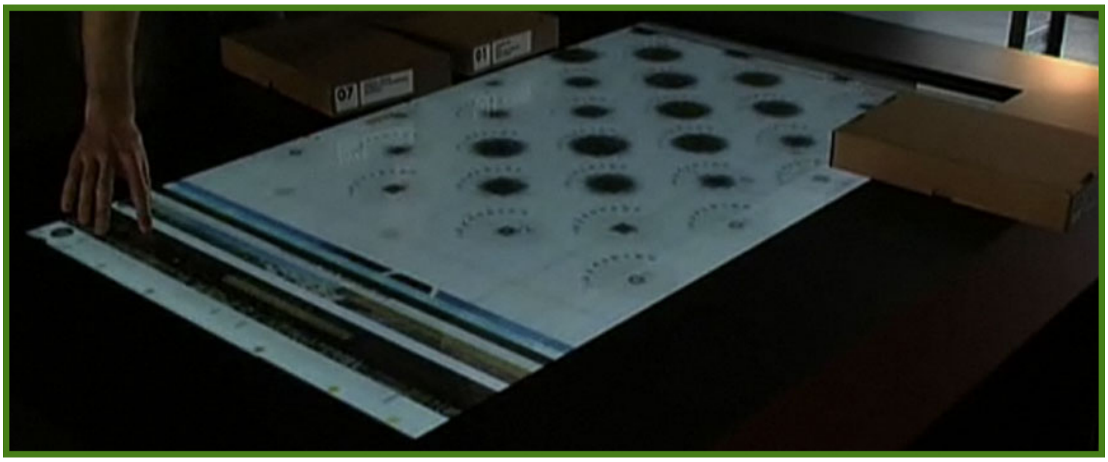

Figure 11 - The Generation Random interactive tabletop interface [12].

As little concrete information is tied to this product, concerning specifications and the like, I will simply describe the appealing concept in a brief manner.

The basic functionality is similar to the previously described products, but this one does not recognize objects on the surface and it does not track multiple fingers. It is in other words a single-touch interface. But functionality-wise it works really well, at least judging from the videos, and thus proves that technological supremacy not necessarily is the key to good functionality.

And then there is the grand function that I found really interesting; it takes archive boxes as input. The table is meant as an interface for exploring the contents of archive boxes, which contain the work that has been carried out in the past decade of the developer-company. A multitude of archive boxes are equipped with RFID (radio frequency identification) tags, and simply placing a box next to the table allows the user to browse the contents on the interactive table. This mixture between real and virtual, in the given context, makes perfect sense to me. I therefore consider this product/project as being a good source of inspiration, albeit its minimal documentation and scientific validity.

7.2 INTERACTIVE EDUCATIONAL INTERFACES

Interactive educational interfaces appear in many shapes and in the following, three examples are selected that represent innovative ideas for the design of educational products. I choose to survey interfaces for children, since inventive design of learning experiences plausibly has greater bearing on this segment, compared to the adult one. The conception behind this statement is that adults are adept at gathering knowledge from several sources, specific as well as abstract. Adults can for example seek information from the Internet by means of the present computer interface, a privilege that the youngest children do not have. This younger segment, where abstract methods of obtaining knowledge have not yet been learned, can therefore benefit profoundly from innovative approaches and interfaces for learning.

Ely the Explorer

Ely the Explorer is an educational aid that enriches the learning process in several ways through computer supported collaborative learning (CSCL). The concept includes a tabletop interface, tangible dolls and cards, and a digital camera. Ely the Explorer is a well-developed concept that is admirable in many ways, e.g. for its refined physical product design or its engaging interactive narrative. The concept's constituent elements will be detailed in turn, based on the information in the scientific paper that is connected to the product (Africano, Berg, Lindbergh, Lundholm, Nilbrink, & Persson, 2004).

Figure 12 - From left to right: an Ely doll, the teleporter and insertion of Ely into the teleporter [13].

The concept is that children must help the Elys with certain tasks as the Elys travel to different places in their teleporter (see Figure 12). The Elys are soft dolls that carry a backpack with a PDA inside, which can display information about the place that the Elys have visited. The teleporter is a tabletop interface with a touch-screen and three control dials on top, and compartments for the Elys on the side. When inserting an Ely into one of these compartments, it is teleported somewhere. It is visualized on the screen and the children are given some tasks that they must solve collaboratively. The screen is divided into three personal areas and a shared area in the middle, and the dials are used to navigate and control the onscreen events, alongside the touch-screen (see Figure 13).

Figure 13 – The touch-screen and control dials (left) and collaboration by the teleporter (right) [13].

Different cards that are equipped with RFID tags can be used to input information into the graphical user interface (GUI) or the backpack. Another source of input is the digital camera, which is used to input the children's own images into the system. Certain exercises require that the children take pictures and use them to solve the task at hand. Collectedly, Ely the Explorer provides several opportunities to engage in activities by means of different input methods, and the information that should be learned is presented and manipulated in various ways. As such, the product provides an interesting and engaging learning situation that encourages the children to solve problems both collaboratively and independently, in the sense that the group predominantly operates autonomously. The teacher can therefore be a helper, rather than an enforcer, which should improve the overall learning atmosphere.

The main inspiration that can be taken from this example is, in my opinion, the creation of an engaging interactive narrative that combines real and virtual aspects into a single coherent story. The use of physical, tangible objects in the narrative affords explorative interaction and provides a simple and intuitive interface, especially compared to the keyboard and mouse approach.

Shadow Box

The Shadow Box is a conceptually simple product that intends to teach preschoolers about words through visual association and auditory clues. The interface is easy to grasp and consists of a box, some word blocks and some picture blocks (see Figure 14). The box is equipped with a RFID reader and the blocks are equipped with RFID tags, which enable the box to recognize if a block is inserted into the box. (Sung, Levisohn, Song, Tomassetti, & Mazalek, 2007)

Figure 14 - The Shadow Box with word and picture blocks [14]

The children are meant to insert the blocks into the box and close the lid. If a picture block is inserted, the system will describe it and prompt the child to find the corresponding word block. The same goes for the inverse scenario. If a matching set of blocks is inserted into the box, the child is rewarded with an animated sequence that depicts the given type as a shadow play (hence shadow box). Since the lid is closed and the animation is presented as a shadow play, the child should get the idea that the object (animal, car or the like) has been brought to life inside the box.

I really like the simple functionality of this project that, despite its simplicity, guides the child through the experience and rewards successful interaction.

Lali

This last example is also the least complex, which is the exact reason for including it. It exemplifies how even simple products can add to the enjoyment of certain activities, and any attempt to spread joy is indisputably justifiable.

Lali is a plush toy that resembles a lion and is meant for preschool aged children. This physical version of Lali also has a virtual correlate that responds to certain actions that physical Lali may be exerted to (Bruikman, van Drunen, Huang, & Vakili, 2009). The real and the virtual versions are similar in appearance as can be seen in the figure below (Figure 15).

Figure 15 - Virtual Lali to the left, and physical Lali to the right [15].

Physical Lali encompasses a series of sensors that detect certain actions, such as hugging, tickling, squeezing and the like. When one of these sensors is triggered, the virtual correlate reacts accordingly, e.g. when touching physical Lali's nose, virtual Lali will sneeze.

Observations of Lali in use showed that the youngest children (younger than 2,5 years) did not, or only partially, understand the connection between real and virtual. The older children (3 years of age or more) mostly understood this connection. (Bruikman, van Drunen, Huang, & Vakili, 2009)

I think that Lali is an interesting interface to the computational possibilities, which is aimed at the youngest children that otherwise often are neglected. The simplicity of Lali makes it accessible, but naturally also limited in relation to potential usage scenarios. A sophistication of the Lali concept could very well be beneficial for the knowledge acquisition of children that are at the toddler stage.

8 INTERACTIVE TABLETOP ARCHITECTURE

This chapter will cover the essential architecture of interactive tabletop interfaces, thus providing the necessary foundation for an informed design that builds on the experiences of others. The chapter is divided into a *hardware* and a *software* section, which describes the essentials of building the physical setup and the programming procedures respectively. The design suggestions and guidelines in this chapter are primarily based on past experiences with this type of setup and the literary foundation that describes the engine (reacTIVision) behind the previously mentioned reacTable (Kaltenbrunner & Bencina, 2007).

8.1 HARDWARE

The hardware part of an interactive tabletop interface is a mixture of several components, and the prerequisites depend on the specific type of interface that is desired. A setup that requires visual feedback projected directly onto the table surface has fundamentally different prerequisites than a setup that solely concerns recognition of input. Whether multi-touch capability or object recognition is the aim can also influence the design. Besides the apparent need of building a physical table of some dimension, there are three quintessential aspects to the development of an interactive tabletop interface, namely *fiducial markers*, *surface design* and *camera/projector setup*. These aspects will be sequentially explained in the following.

Fiducial Markers

There are generally two types of input, namely fingers or objects that touch the table surface. While fingers inherently are "input-ready" as they basically are required to provide information about their positions, objects are more difficult to use, as they must be determined in terms of position, orientation and object type. This subsection will therefore solely concern this issue of distinguishing different types of objects.

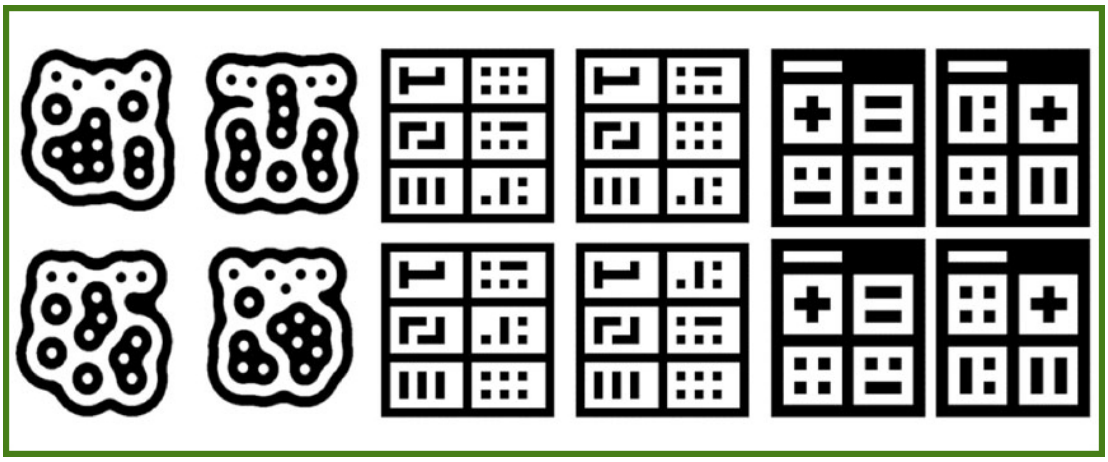

Figure 16 - Fiducial marker types. From left to right: amoeba, classic and d-touch styles [16].

A fairly simple and effective approach to object recognition is to label the objects with a marker that is easily recognizable by the tabletop system. One such family of markers is fiducial markers, which based on a brief personal experience seems to be a both accessible and reliable method of object recognition. Fiducial markers exist in various amalgamations of which the "amoeba" type is considered to be both most precise and reliable (see Figure 16 for an illustration of the different types). The basic functionality of fiducial marker recognition is as follows: 1) A fiducial marker is attached to an object. 2) The object is placed on the tabletop interface. 3) A camera recognizes the fiducial marker. 4) The relevant information is extracted from the camera vision system and is passed on for further processing, depending on the nature of the interface system.

Fiducial markers can simply be printed to paper and cut out with a pair of scissors, which makes both prototyping and development a breeze. The default set of fiducial markers (amoeba) contains 216 distinct markers and this should be sufficient for most applications. The only drawback of this type of homemade markers is the vulnerability to tearing and smudging, which is imminent given that the marker mostly will be placed facedown on the table surface. To overcome this issue, the fiducial markers can be coated with transparent self-adhesive foil. This will protect the marker and additionally make the occasionally necessary cleaning more feasible.

Surface Design

The tabletop surface may be considered secondary in importance, but it is in fact an essential factor. Preferably, the tabletop surface should be a semitransparent and diffuse one, and there are a few reasons for this.

First of all, the camera that tracks the fiducial markers is usually positioned underneath the table surface, while the objects, and therefore also the fiducial markers, are placed on/above the table. If the surface is fully transparent, the objects can be tracked even above the table, but if the surface is semitransparent the objects can be tracked only if they lie on the table. For most applications, tracking should only occur when something is touching the table surface and not above it.

The second reason is that many interactive tabletop interfaces use the table surface as a screen that provides visual feedback. This feedback is provided by a projected image and a semitransparent surface is a perfect canvas for projection. A proper surface can therefore serve two purposes, namely to ensure that tracking only occurs when desired and to provide visual feedback of a good quality.

Camera/Projector Setup

The camera is obviously a core component for this type of interface, since it is responsible for all input. The projector is a core component in most setups, as it provides the visual feedback, but it is not a necessity like the camera. Both components should be positioned inside the tabletop interface and point upwards to the surface where the interaction will take place. This setup is depicted in the following figure (Figure 17).

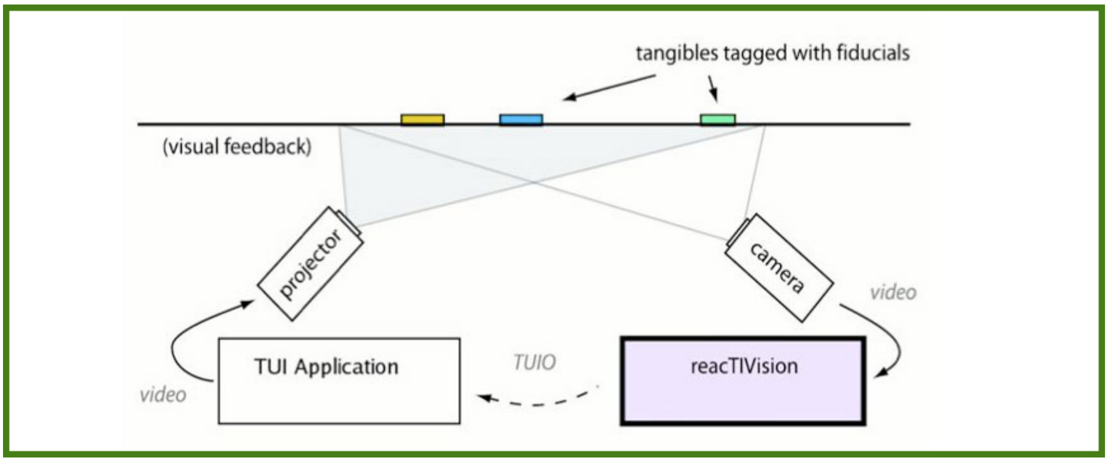

Figure 17 - Interactive tabletop interface setup, reprinted from (Kaltenbrunner & Bencina, 2007).

Besides the camera and projector setup, a few other components are illustrated in the figure (*TUI application* and *reacTIVision*), but these adhere to the software category and will be described there instead
Whether or not visual feedback is included by means of back projection directly to the table surface has implications for the camera installation. Projecting an image to the surface will effectively mean that the camera cannot track any input by means of imagery within the visible spectrum. To elaborate, the visual feedback uses the visible spectrum of light, which interferes with the camera's tracking of input if this too uses the visible spectrum. If a projector is included in the project, the camera should make use of a different spectrum of light, and for this infrared light can be used.

Using infrared tracking, instead of visible, necessitates a few modifications. Cameras usually have inbuilt filters that blocks infrared light, and such filters must therefore be removed. Furthermore, all visible light should be blocked instead, and an infrared pass filter must be placed in front of the camera to block all but the infrared light. Finally, infrared light must light up the table from inside to enable proper reflections from any input on the table. For this task, an infrared LED (light emitting diodes) array is perfect. With these modifications, the projected image and the one that tracks input, will be separated and thus not interfere with each other.

Illumination is generally an important aspect, whether the tracking is infrared or not, as is other photography related factors. People that know a bit about proper composition of photographs, in terms of shutter speed, aperture and ISO settings (to name a few), will acknowledge the importance of proper illumination. There is though an issue when placing light sources within the table, and that is the reflection that is made in the table surface. The camera will be unable to track anything if affected by a reflection, and the positioning of light sources is therefore crucial. In this relation, a significant amount of voices claim that light can be emitted *into* the surface plate, and thus avoid reflections. The theory is that light will reflect internally in a plate if this is illuminated from the edges. I have found these illustrations quite helpful for understanding the concept.

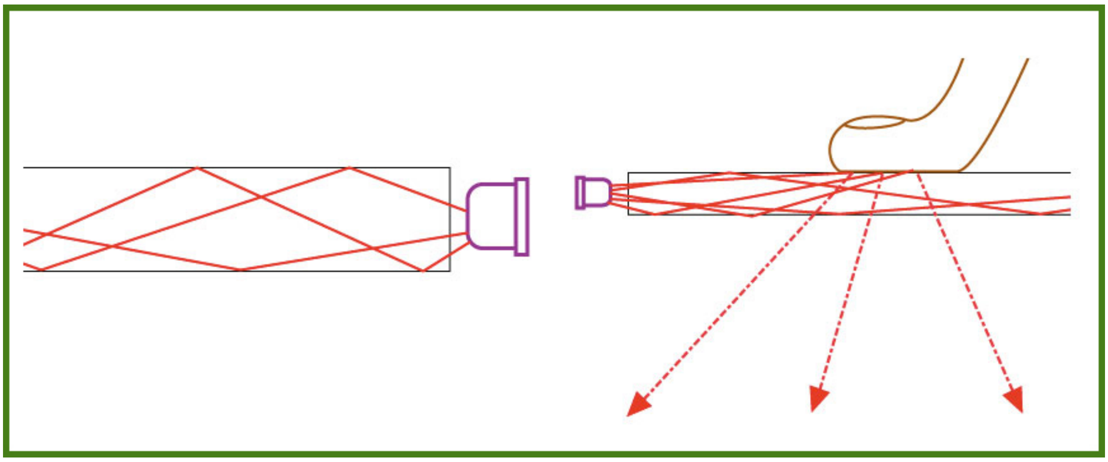

Figure 18 - An LED sends light into an acrylic plate (left), which is reflected by a finger (right) [17].

This approach to illumination appears to be a far better solution than placing light sources within the table, thus risking reflections.

Conclusively, there are just two aspects that furthermore should be considered, namely resolution and frame rate. For the projector, resolution is a matter of image quality, while it for the camera is a matter of enabling detection of small means of input (such as fiducial markers). The greater the resolution of the camera, the smaller fiducial markers can be tracked, which expands the possibilities for the design of applications. Frame rate is additionally important, as it determines if fast motion can be detected. The faster frame rate, the faster movement can be detected.

8.2 SOFTWARE

The software part of an interactive tabletop interface is what determines the functionality that will be offered to the users. There are two basic components in the software design, which are the ones mentioned prematurely in relation to the previous illustration of a typical setup (Figure 17). While these components are illustrated as *reacTIVision* and *TUI application*, it should be noted that these are specific terms from the reacTIVision framework. Other frameworks that can manage input recognition and responses exist, but specificity may help the understanding of the interrelation between the components, and I will therefore explain the functionality in terms of the reacTIVision framework.

ReacTIVision, or the software application that detects input, analyzes a video stream from a camera algorithmically to recognize either fingers or fiducial markers. The software is open source and the source code is therefore available alongside precompiled platform-specific applications. The specifics of the algorithmic foundation for the software will not be described as they are of little relevance to the broader scope, and I refer to the provided literature for further details (Kaltenbrunner & Bencina, 2007).

The reacTIVision framework detects all relevant input from the video stream and extracts all relevant information, such as position, id and angle of rotation, depending on the type of input (finger or fiducial marker). This information is then bundled into a TUIO (tangible user interface object) that can be transmitted over a network. The resulting TUIO stream, containing information about the input, can then be picked up by the second component, the TUI (tangible user interface) application (see Figure 19).

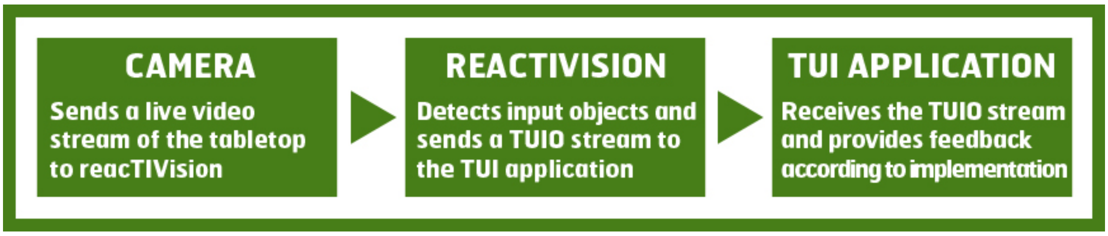

Figure 19 - The flow of information from camera, through reacTIVision, to a TUI application.

A TUI application can be any application that supports the client-side scripting needed to receive TUIOs. The reacTIVision framework provides several examples of sample code in various programming languages (C++, C#, Java etc.). Setting up the TUI application to receive TUIOs should therefore be a fairly straightforward task, which basically requires the implementation of a TUIO listener that defines several callback methods to be used in the programming. There appears to be six primary callback methods, namely three concerning TUIOs and three concerning cursor objects (the term for touch inputs). The three methods for each type include *add*, *update* and *remove*, which despite the simplicity should be sufficient for the development of an interactive tabletop interface. The callback methods are described in the following table (Table 5).

KEY CALLBACK METHODS FOR A TUI CLIENT

CALLBACK METHOD	TRIGGERED WHEN…
addTuioObject(*)	A fiducial marker is placed on the tabletop.
updateTuioObject(*)	An existing fiducial marker is moved/rotated.
removeTuioObject(*)	A fiducial marker is removed from the tabletop.
addTuioCursor(*)	A finger is placed on the tabletop.
updateTuioCursor(*)	An already recognized finger is moved.
removeTuioCursor(*)	A finger is removed from the tabletop.

∗ Each callback method includes the information from the TUIO, which is presented as either a TuioObject or a TuioCursor, depending on the type of callback method.

Table 5 – The key callback methods for a TUI client, which are triggered by input from reacTIVision.

How the application responds to inputs on the tabletop is therefore a matter of how the callback functions are being managed. A simple example of a likely scenario could be to attach a fiducial marker to an object, and to visually illustrate that object on a screen whenever the object is placed on the tabletop. Further, and more sophisticated, functionality could then include moving the representational object in relation to the physical object on the tabletop.

9 COGNITIVE STRATEGIES FOR LEARNING

This chapter will provide brief descriptions of several aspects that can influence the design of learning applications. A proper strategy is key to the development of a proper outcome of a learning experience, and considerations of human cognitive functions can be supportive in this relation. As mentioned in the report's delimitation, the scope of this study optimally calls for a multidisciplinary effort, involving several specific areas of scientific inquiry. Among these necessary inputs of expertise is an insight into the cognitive aspects that support the acquisition of knowledge. The following descriptions are therefore introductory in nature, rather than exhaustive, and for a potential full-scale development, experts should definitely be included in the process.

9.1 EXPLICIT/IMPLICIT LEARNING

Explicit and implicit learning is basically respective terms for conscious and unconscious learning, although such a simple account surely is ill favored among the scholars in that specific area of expertise. Put differently, explicit learning is what we know we learn, while implicit learning is what we do *not* know we learn. The study of these concepts regards both the processes of acquiring knowledge and the interrelationship between the two. Some theorists regard them as separate entities, while others believe that they intermingle.

Hayes and Broadbent define that selective (explicit) learning produces verbally describable knowledge, whereas unselective (implicit) learning produces knowledge that cannot be described verbally (Hayes & Broadbent, 1988). Despite the alternative terms, and later questionability of the definition's founding experiments (Green & Shanks, 1993), I find the distinction easy to comprehend, which is valuable for this type of survey. It must be noticed that the possibility of accounting verbally concerns the produced *knowledge*, and not the learning experience itself. A distinction must be made between the knowledge and the learning, and while explicit/implicit knowledge may be considered separately, it is entirely possible that explicit/implicit learning can occur in parallel or in connection with each other.

Several theorists claim that the two types of learning often functions in conjunction with each other, and I share this conception. Experiments have established the parallel functioning of the two types of learning (Willingham & Goedert-Eschmann, 1999), and the occurrence of a synergy effect between the two has additionally been suggested (Sun, Slusarz, & Terry, 2005). Scans of regional brain activation during explicit/implicit learning tasks, obtained by means of fMRI (functional magnetic resonance imaging), provides additional insight. These results suggest that the explicit and implicit learning processes are overlapping and executed in parallel, although they still can be viewed as partially distinct (Aizenstein, et al., 2004).

It is argued that individual IQ (intelligence quotient) has an effect in explicit learning situations, whereas there is no effect in relation to implicit learning

(Reber, Walkenfeld, & Hernstadt, 1991). This supports the respective attributes of the types, namely the conscious and the unconscious approach to the task at hand, as IQ can be correlated with active, rather than passive, reasoning processes.

A study has shown that sequences can be learned implicitly, and that this can decrease the reaction time in a SRT (serial reaction time) test (Stadler, 1992). While such a performance improvement surely is desirable in certain situations, I find it more interesting to correlate this finding with Piaget's conception of operational structures and knowledge. My point is that a sequence is an operational structure, and if sequences can be learned implicitly, then operations can be learned without instruction about the nature of the operations. In other words, operational knowledge can be acquired by means of purposeless exploration, which suggests that simple play can foster operational knowledge. This conception is neither groundbreaking, nor novel, but it surely has implications for the validity of including play-like exercises as a means of educational development.

9.2 DISTRIBUTED COGNITION

Distributed cognition is a cognitive theory that expands the notion of what can be considered a cognitive system. According to the theory, cognitive processes are not confined to internal interactions in the brain of an individual, but can be present in the interactions between the members of a group, or even between people and the environment. Cognition is therefore not exclusive to the black box of our minds, but can be distributed among several cognitive entities. Hollan et al. mentions three kinds of distributed cognitive processes, which are reprinted in the following. (Hollan, Hutchins, & Kirsh, 2000)

- Cognitive processes may be distributed across the members of a social group.
- Cognitive processes may involve coordination between internal and external (material or environmental) structure.
- Processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events.

To exemplify these entries, a social group can be considered as a collected unit of analysis, i.e. a functional cognitive system that is constituted by the processes that unfolds between the members of the group. Furthermore, placing your car keys on the drawer next to the door may help you remember them at a later time. The latter is interesting in the sense that a "dead" object suddenly is enabled to influence the cognitive process

> *"The material world also provides opportunities to reorganize the distributed cognitive system to make use of a different set of internal and external processes." (Hollan, Hutchins, & Kirsh, 2000, p. 176)*

A main principle of distributed cognition is that cognition is embodied. Internal and external processes are not separate entities that function independently of each other, but rather intertwined mechanisms that must be coordinated. Our tools thus become part of our cognitive system and affect the way we think and act. Hollan et al. exemplifies this matter very well, which can be seen in the following quotation. (Hollan, Hutchins, & Kirsh, 2000)

> *"Just as a blind person's cane or a cell biologist's microscope is a central part of the way they perceive the world, so well-designed work materials become integrated into the way people think, see, and control activities, part of the distributed system of cognitive control." (Hollan, Hutchins, & Kirsh, 2000, p. 178)*

Two other interesting aspects are mentioned in the same literature, namely that *"people establish and coordinate different types of structure in their environment"* and that *"people off-load cognitive effort to the environment whenever practical"* (Hollan, Hutchins, & Kirsh, 2000, p. 181). We can therefore use the environment to structure and facilitate given tasks, and I believe that an accommodation of these possibilities can have positive implications for learning. Again, I refer to Piaget's concept of operations and see a great potential in combining the aspects into a singular application. One where operational structures can be explored by reorganizing objects in the environment. This will furthermore allow the user to off-load cognitive effort, as already organized objects need not be considered.

Conclusively, it appears that organization and manipulation of the environment is a natural way for humans to support thought and memory, and this concept can very likely be beneficial to learning as well.

9.3 COGNITIVE ERGONOMICS

Ergonomics concerns the improvement of human interaction through an understanding this very same interaction. Although this formulation may appear cryptic, it essentially means that ergonomists must examine the nature of interaction, detect aspects that can be improved, and finally implement changes that ensures the improvement. Wilson provides the following, more elaborate, definition of ergonomics.

> *"Ergonomics is the theoretical and fundamental understanding of human behaviour and performance in purposeful interacting socio-technical systems, and the application of that understanding to design of interactions in the context of real settings." (Wilson, 2000, p. 560)*

Wilson emphasizes the need for combining the separate subfields of ergonomics, in order to properly define, and thus understand, ergonomics as a scientific area. While this very likely is a good approach for true ergonomists, I will consider the theory in terms of cognitive ergonomics, as physical and social ergonomics are prioritized lower at the given stage of the project. But make no mistake. Ergonomics, in general, is definitely an important aspect to most aspects of life, and should be fully considered in the case of a full-scale development scenario.

Cognitive ergonomics can superficially be described as the study of *"[...] how work affects the mind and how the mind affects work."* (Hollnagel, 1997, p. 1171). Like conventional ergonomics concerns the quality of work in general, cognitive ergonomics concerns the quality of work that actively includes the cognitive system. There are two main aspects to the concept, namely the condition of the human at work and the outcome or result of that work. These aspects are interdependent, as a poor quality of either aspect will affect the quality of the other. (Hollnagel, 1997)

The ever-increasing complexity of technology has at least two implications for humans in work situations. First, machines are taking over certain functions in work situations, given their supremacy in certain areas (speed, precision, consistency etc.). Our tasks are therefore modified, and where the need for physical skills were once prevalent, the need for cognitive skills may be greater presently. Second, the complexity of technology may render us incapable of satisfyingly controlling the machines. This will in turn render us useless or result in a low quality of the work situation. (Hollnagel, 1997)

While the first issue is difficult to address with any immediate effect, the second issue is surely a matter of design. When developing any sort of interface that includes a substantial degree of technological complexity, thoughts concerning cognitive ergonomics can therefore be beneficial. These benefits may include ease of use, improved quality of the experience, and better final outcome of that experience.

9.4 COLLABORATIVE LEARNING

Collaborative learning, or CSCL (computer supported collaborative learning) in relation to this study, concerns the quality of socially interactive learning. This quality can refer to different aspects, e.g. in a professional work space the quality may be based on an end result, while the quality of children's collaboration may be measured in terms of motivation and enjoyment. Either way, CSCL is likely to have implications for the design of educational products and possibly the method of teaching as well. As stated by Vygotsky, cognitive development depends on either guidance by an adult (traditional teaching) or collaboration with other, more capable, peers (collaborative learning) (Vygotsky, 1978, p. 86). Whether to opt for either of the approaches, or a combination, is definitely an essential consideration.

A very broad definition of collaborative learning is *"[...] that it is a situation in which two or more people learn or attempt to learn something together."* which Dillenbourg labels as unsatisfactory (Dillenbourg, 1999, p. 1). I acknowledge that this generic definition is rather worthless in relation to specific applicability, but in relation to the development of a flexible interface for learning, such a generic definition may be exactly the sort of inspirational foundation needed.

Crook mentions three aspects that have been interpreted as positive factors of collaborative learning, namely *articulation*, *conflict* and *co-construction* (Crook, 1998, p. 238). Dillenbourg mentions four aspects within the same category, namely *induction*, *cognitive load*, *(self-)explanation* and *conflict* (Dillenbourg, 1999, pp. 10-11). There is a convergence of terms here, which results in four distinct factors, as described in the following table (Table 6).

POSITIVE FACTORS OF COLLABORATIVE LEARNING	
FACTOR	DESCRIPTION
Articulation or (self-)explanation	Collaborators are usually motivated to articulate their thoughts in public, thus reinforcing their own emerging understanding of the learning material, while providing additional information to their peers.
Conflict	"Conflict" between collaborators is considered valuable in the sense that these negotiate to reach consensus on a given topic. Ergo, understanding through discussion.
Co-construction or induction	Collaborative problem solving or creation is said to inspire the process of creativity, and co-construction within the group is likely to be beneficial to all members.
Cognitive load	The possibility of dividing tasks among group members can decrease cognitive load, while other interactions may increase the load, such as explaining concepts to others. Even the latter increases learning, and is for that reason still considered a positive factor of collaborative learning.

Table 6 – Four factors of collaborative learning (Dillenbourg, 1999, pp. 10-11)(Crook, 1998, p. 238).

Crook furthermore claims that the quality of a productive collaborative situation depends on the presence of external resources, as well as the interpersonal relationship between the collaborators (Crook, 1998, p. 241). Concerning the first aspect, the claim is that external resources may function as referential anchors that support the construction of a shared understanding among the collaborators. The second aspect prescribes the profound influence of interpersonal relations, whether these are positive or negative. Likes, dislikes, friendships and expectations in general, are all aspects that collaborators are likely to bring to any experience that involves a group. And these preconceptions affect the quality of any collaborative learning experience. (Crook, 1998)

A distinction is furthermore mentioned between *cooperation* and *collaboration*; defining the two terms as respectively work where tasks are divided among group members and subsequently assembled, and work that is done together (Dillenbourg, 1999, p. 8). The argument is though partly broken down by the notion that the division of labor and subsequent assembling into a coherent piece of work can be considered as both cooperation and collaboration. In relation to this study, I find the distinction to be of little relevance.

9.5 METACOGNITION

Being an area of thinking about thinking, metacognition is defined in several more or less philosophical ways. The reason for including this area in the survey of cognitive strategies for learning is not to contemplate on these definitions, but rather to reflect on the broader notion of metacognition in relation to edutainment. I therefore opt to simply consider metacognition as knowledge or cognition that regards cognitive phenomena, which is an introductory description of the topic by Flavell (Flavell, 1979, p. 906).

Considering the nature and effects of cognitive processes seems to me important, and the inclusion of metacognitive support in learning applications can likely have a positive influence on the outcome of the learning experience. An example could be a child that is less capable of reading and writing than his friends, but better at mathematics. Knowing that he and his friends have different understandings of the concepts, and understanding that this may be due to genetics, parental guidance or the like, could help the child to accept the fact rather than get upset. It could even motivate an extra effort to improve reading and writing skills, as these obviously are not inaccessible but just more difficult.

Another metacognitive aspect that seems interesting is knowledge about how you learn best, i.e. which learning style you inherently employ when faced with a learning situation. This links back to the discussion about learning styles and the possibility of adapting and strategizing learning approaches. An example scenario could be a visual-active learner who is faced with an auditory-passive learning situation. With little metacognitive consideration the learner will most likely not fit into the learning scenario and therefore struggle severely. Conversely, if the learner knows that this inherent learning style is incompatible with the teaching style, it is possible to affect the learning experience, whether this include an adaption to the teaching style or a request of changing the teaching style.

I am confident that metacognition has great applications within the area of education, and the area is also widely applied to intelligent tutoring systems presently (Bull & Kay, 2008). There is no doubt about the complexity of the area as such, but even the general concept of teaching people how they learn best and why this is, seems capable of bearing fruit over a period of time.

10 VIRTUALITY AND NARRATIVITY

In this chapter, I will discuss the areas of virtuality and narrativity in relation to the edutainment interface that is the aim of this study. The propriety of discussing these areas is founded by the potential attributes of the final product. It has already been determined that the final interface will include audiovisual feedback, and the nature of computer-mediated images and sound makes a discussion of virtuality appropriate. And since the interface furthermore will concern learning experiences, i.e. the path from not knowing to knowing, narrativity will be discussed as well.

Again, these respective topics are profound areas of research, especially narrativity, which makes a complete coverage of the fields insurmountable. I therefore prefer to include the ideas and concepts that seem most applicable, and discuss their relevance to an edutainment interface.

Several slides from a course on *"Narratives in Interactive Systems"* that I attended during the 8th semester of Medialogy have been inspirational. These are referred to as follows: ("filename", "slide number") e.g. (2.1 NIS Virtuality I.ppt, s. 21).

10.1 VIRTUALITY VS. ACTUALITY

Several opinions exist on the nature of virtuality, ranging from the scholastic view of the virtual as potential, to a more negative view of the virtual as fake (Ryan, 2001, p. 28)(2.2 NIS Virtuality II.ppt, s. 13). From a design point of view, virtuality must be considered as potentiality, since the aim is to accommodate learning, and not to create a virtual reality experience. In other words, the virtual is meant to enhance an actual learning experience, rather than mimic reality, and this aim should emphasize the potential of virtuality rather than the risk of a fake appearance.

In relation to the above, it is not the goal to obtain transparency of the medium in an attempt to immerse the user in the learning experience (2.1 NIS Virtuality I, s. 25). The virtual correlates of the physical means of interaction are meant to be additional sources of information, and the user's awareness of the medium as well as the virtuality of the representations is not an issue. In fact, the user *should* be aware that the extension of the learning scenario is provided by the interface.

What the interface should strive to achieve is an application of hybrid reality where actual objects (input) and virtual representations (feedback) are associated by means of relations. This relational bond between the actual and the virtual is created in the mind of the user, and the interface must therefore facilitate the construction of these relations. This can, as examples, be achieved by ensuring spatial and causal coherence. (2.3 NIS The trouble with the virtual.ppt, ss. 10-14)

Access to virtuality is granted only by anchorage to the perceptible, i.e. through the physicality of actual objects. In order to perceive the virtual it must be accessible to the senses, thus necessitating physical correlates. Considering the chosen interaction platform, this project appears to have a proper foundation for creating a meaningful interaction between that which is actual (physical objects) and that which is virtual (representational objects). (2.3 NIS The trouble with the virtual.ppt, ss. 19-20)

The very essentiality of these methodological considerations appears to lie in the creation of proper relations, without which the physical objects and virtual representations are to be considered as two separate entities.

10.2 INTERACTIVE NARRATIVES

The desire to include interactivity and a narrative structure simultaneously introduces complications that commonly are referred to as the narrative paradox. This paradox occurs at the convergence of proper unrestrained interaction and pre-authored plotlines, i.e. at the collision between freedom of movement within the narrative and the Aristotelian notion of articulated plot events that are firmly associated with a given timeline (Aylett, et al., 2006). This clash is an obvious concern in relation to the addition of narrative content in the interface that will be developed in this project, which will afford high levels of interaction. A narrative in the Aristotelian sense therefore seems irreconcilable with the idea of a highly interactive tabletop interface, and alternative structures must be considered if narrative coherence is to be accommodated.

Before discussing applicable aspects of narrativity I wish to share a distinction that to me seems important to this very discussion. Edutainment is twofold by nature as it comprises education and entertainment, and although these aspects should be entwined into a coherent application they are still separate entities. As such, a narrative can be considered a progression from A to B via a series of events. In the light of this simplified description, the respective constituents of edutainment can be considered as separate narratives. Education is a progression from not knowing to knowing via a series of educational events. Likewise, entertainment is a progression from one mode of enjoyment to another via a series of affective events. I believe that these separate narratives can be, but not necessarily have to be, combined into a singular instance.

It has already been established that immersion is of little importance to this project, and this naturally includes narrative immersion. A complete absorption in the (entertaining) narrative may distract the user from the educational context, which obviously is ill favored. I do not argue against the strength of narratives, but rather suggest that they in this project are aimed at making education more entertaining. The narrative embellishment thus becomes a motivational factor for learning, increasing both enjoyment and total time spent learning.

Interactivity can roughly be divided into three levels, namely *reactive*, *selective* and *productive* interactivity (Ryan, 2001). I choose to neglect reactive interactivity, as it resembles the present educational paradigm where students are expected to sit passively and absorb the stream of instructional information. This lack of deliberate action does not correlate with the scope of developing an interactive edutainment interface. It will probably prove difficult to avoid instances of selective interactivity, as this is an inherently human method of assessment and navigation, but the pinnacle of the intended interface is certainly productive interactivity. I will therefore discuss this aspect in further detail.

Productive interactivity is classified as the fullest type of interactivity, involving productive actions where the user leaves durable marks on the world, actual as well as virtual (4.2 NIS Interactivity II, s. 5). There are a few aspects to this. First of all, "the fullest type of interactivity" tell me that the possibilities of interaction are unrestricted, or at least only so to a mild degree. Secondly, "durable marks" can be regarded as additions to the virtual world of representations or the permanent retention of the learned knowledge, both of which can be considered as storing information in a "database". A correlation between the retained knowledge and the virtual storage could, through assessments, provide the user with a perceptible, quantitative representation of his/her educational progression. In other words, a provision of areas that have already been grasped mentally, as well as areas that still have not been covered and thus are open for exploration and consequently understanding. Such a delineation of progression must be supplied with caution, since few people wish to be faced with a questionable feat, such as "you are 0,7% clever".

Several narrative structures have been proposed to overcome, or circumvent, the narrative paradox and reconcile interactivity and narrativity (Ryan, 2001, pp. 246-258). These structures exploit varying degrees of top-down and bottom-up control, i.e. the overarching design of the storyteller (or system) and the partially unpredictable input provided by the user (4.3 NIS Interactivity III, s. 10). There must be an appropriate division between these opposing forces of system and user control, in order to accommodate both full interaction and proper narrative progression. This balance is surely difficult to find, but the following quotation provides good inspiration towards a partial solution to this conundrum.

> *"As electronic authors design the reader's encounter with the text, they should concentrate on those truly magic moments when the click of the mouse provokes a response from the system." (Ryan, 2001, p. 257)*

Although the format of the narrative in the quotation is different from that which is targeted in this study, the core principle of the statement should be directly transferrable. Emphasis on such microevents could induce short-term instantaneous enjoyment in the user, and thus sustain the dramatic interest of the overarching narrative. The inclusion of such "cheap thrills" seems like a relevant approach to the design of a concept that accommodates interactivity and narrativity collectedly.

11 DEFINING THE TARGET GROUPS

The target groups must be chosen appropriately in relation to the final hypothesis of this study, since it is their experiences that will enable an evaluation of said hypothesis. The reason for choosing more than one target group is that the flexibility of the interface cannot be evaluated by means of a single target group. The criterion for the choice of target groups is therefore to pick out two that are sufficiently distinct, thus enabling the possibility of evaluating their respective experiences. The decision is predominantly based on the theory of developmental stages that was described in the first chapter (Chapter 1 – Cognitive Development). On this foundation I choose to address a group of daycare children (2-3 year-olds) and a group of children at the preliminary grades of school (6-8 year-olds).

11.1 THE DAYCARE GROUP (2-3 YEARS)

The daycare group is selected on the basis of its position at the transition between the sensory-motor and the pre-operational stage. Remember that the age classifications are approximations and therefore not unconditionally reliable. Another important criterion for choosing target groups is therefore to have a sufficient span between them, thus ensuring that the individuals in each group in fact are distinct. This should be the case with the ones chosen here.

This target group is expected to be a very hands-on collection of individuals, given that their knowledge predominantly has been the result of sensory-motor actions so far. Now at the verge of the pre-operational stage of development, the children are facing a complete reconstruction of their knowledge structures. It is therefore expected that the daycare group will be one in a state of flux, potentially displaying fluctuating mood and behavior, but generally exhibiting an exploratory and physical attitude towards new discoveries.

11.2 THE SCHOOL GROUP (6-8 YEARS)

The school group is, similar to the daycare group, selected on the basis of being positioned at the verge of a transition between stages. In this case, the step is taken from the pre-operational to the concrete operational stage. It can therefore with reasonable certainty be expected that these children will be able to solve tasks that include concrete operational knowledge, e.g. grouping or ordering physical objects.

These children are plausibly still very hands-on, given that their reflective capabilities have not yet been internalized, but I expect that the individuals of this group may exhibit radically different behavior in this relation. The age deviations within categories, and the proximity to the formal operational stage, makes it entirely possible that some of the children may display signs of formal operational knowledge. This is not necessarily relevant to the test scenario, but aids the ascertainment of a proper stage span between the target groups.

12 ANALYSIS CONCLUSION

The conclusion that can be drawn from the analysis section is the establishment of the multifaceted nature of this project. Several different areas and topics have been surveyed and discussed, all satisfyingly in relation to the desired acquisition of general knowledge that can facilitate an overview, but dissatisfactory in the sense that much more research could be made. Upon contemplation, I do though consider the analysis a success and acknowledge that further specificity and breadth within the reviewed scientific areas, requires not only additional group members, but also additional years of research.

In continuation of the above, I am truly satisfied with the approach of preferring quantity to quality. Not in the sense that I regard the quality of the preceding chapters as low, but rather in the sense that a proper multidisciplinary approach has been simulated, albeit in a low-resolution version. I genuinely feel that the preliminary analysis and analysis have covered the major aspects, and among the potential omissions there should be no crucial areas. This statement is obviously rather bold, as the majority of the field of cognition (to name one) has not been included in this report, but most certainly would provide valuable information. The term "crucial" should therefore be considered lightly here.

Above all, I believe that the scope of the study has been properly "framed" by the analysis, and the essential foundation for the instigation of the design phase has been developed. Part of this foundation is the choice of target groups, which provides two distinct groups that are appropriate in relation to both the following design and implementation phase, and the subsequent test scenarios.

DESIGN

The purpose of this design part is to provide a detailed set of guidelines for the subsequent implementation phase of the project. All aspects should be delineated to an extent that enables a proper implementation with no, or at least only few, alterations to the described design.

The part is instigated by a brief description of the general concept, partly as a reminder of already mentioned aspects, and partly as a compilation of these into a coherent and collected description.

Then follows a chapter that deals with the design of the interface, which encompasses the physical construction of the table, a delineation of the interconnections between the various required components, and finally an explanation of the chosen software platform.

In the following chapter, the designs of 4 different puzzles (two for each target group) are described. These descriptions include exemplifying concept drawings and tables that delineate the visual and auditory responses to certain events that occur during the progression of the attempt to solve the specific puzzles.

Finally, the design part is evaluated in the design conclusion chapter, where different isolated illustrations are gathered in a collected, explanatory interaction model.

13 CONCEPT DESCRIPTION

Before describing the design considerations, a proper explanation of the general concept is in order. It has been developed mentally alongside the analysis and although several conceptual aspects have been noted previously, a coherent account of the intended functionality is needed.

The concept is to develop a tabletop interface that takes physical objects as input and provides audiovisual feedback as output. Tracking of input and mediation of feedback (interface) should be generic entities with a fixed functionality, while the physical objects and software (content) should provide an opportunity to customize the purpose/functionality of the product at any given time. The flexibility of the product therefore lies in the design of a sufficiently capable interface that accepts a wide range of diverse content for different target groups.

The goal of developing a flexible interface that accommodates a variety of different target groups has more implications than just the necessity of supporting versatile content. In my opinion, true flexibility also implies that the interface, as well as the content, is accessible to a significantly broad amount of people. This accessibility has several aspects to it (e.g. price range and medium), and these aspects must be considered if a wide audience is to be reached. To exemplify the belief, you can develop a supreme product that accommodates all potential target groups, but if its price tag is too heavy, only few people will ever be enabled to buy it and thus have access to it. For this reason, it is not only a matter of developing a well functioning flexible interface with properly appealing content, but also a matter of its accessibility to the targeted users.

The essence of the concept is therefore to make a flexible, cost-effective and easy-to-use product, which can be accessed by and tailored to a variety of users with different requirements, preconceptions, capabilities and much more.

In continuation of the previous paragraphs, an idea that has been maturing during the analysis research is that things, which are already available to the average contemporary consumer, should be considered in relation to this study. In other words, if certain products are generally available to the target groups, and these can be used in conjunction with the interface proposed here, there is no need to include them as a part of the interface. The interface should then rather be able to interconnect with these products, thus creating a fully functional unit at a decreased cost. As an example, there is no need to include means of audiovisual feedback if a television can be connected to the interface. Most people own one or more televisions, which provide a commonly accessible source of audiovisual feedback that can be exploited.

The specific design considerations, concerning the outcome of this concept, are described in the following chapters, which address *interface design* and *content design* respectively.

14 INTERFACE DESIGN

This chapter concerns the design of the actual interface, i.e. the functional foundation upon which diverse types of content can be developed. The development of this interface encompasses both hardware and software, and there are consequently several aspects that must be defined.

14.1 PHYSICAL TABLE CONSTRUCTION

The physical construction of the tabletop interface has a few requirements attached to it, which I will cover in this section in order to produce the desired design outline needed for the later implementation. The section is divided into appropriate subsections, which should emphasize the mentioned requirements.

Materials and Dimensions

Since the interface is meant to target a variety of users, including children of all ages, a certain requirement for the tabletop construction is *durability*. The prototype must be able to withstand the occasionally rough interactions exerted by the users. These include pushing, kicking or resting on the table, as well as forceful positioning of objects on the table. The choice of materials must therefore support the durability of the prototype.

Plexiglas, plastic or similarly durable materials are appropriate considerations, which additionally will facilitate mobility, given the moderate volume/weight ratio of these materials. Wood is of course also a durable option, but it weighs more and could give a bulky impression. Plastic-like materials furthermore have the strengths that they are cheap in production and can be mass-produced by utilizing standardized molds. This accommodates the aim of developing a cost-effective and accessible interface, but in relation to this study the primary concern is to develop a durable prototype to exemplify and prove the concept. The cost-efficiency and mass-production capabilities of the chosen materials are therefore of little concern in this relation, but should be kept in mind for any larger production.

I have previously developed prototypes that were made of aluminum and polycarbonate, and these have proven to be resistant even to heavy-handed interaction. These materials are not especially cheap, but they are very suitable for prototyping as they are easy to manipulate and afford modularity. I therefore opt to build the prototype from these materials.

The potential size of the area where objects can be recognized is determined by the viewing angle of the camera used for tracking and its distance to the tabletop surface. A PlayStation Eye camera will be used for the prototype, which has an adjustable lens that affords either a 56-degree or 75-degree field of view. Thus, the potential area of recognition becomes a matter of the distance between surface and camera. As the height of the table is constrained by the fact that small children must be able to use it, the area of recognition will likewise be limited. In relation to the height of my 2-year-old son's play table, 55cm appears to be a reasonable height, enabling a 50cm x 37,5cm area of recognition with the camera lens set on 75 degrees. The aspect ratio of the area is correlated with that of the camera (640 x 480 pixels = 4/3 aspect ratio).

Besides the active area where objects can be recognized, additional space should be available along the edges for placing any objects that are not currently needed. This space is determined through assumptive approximations as it is not of paramount importance. The following figure (Figure 20) depicts an initial concept drawing, which is succeeded by a brief description of the measurements.

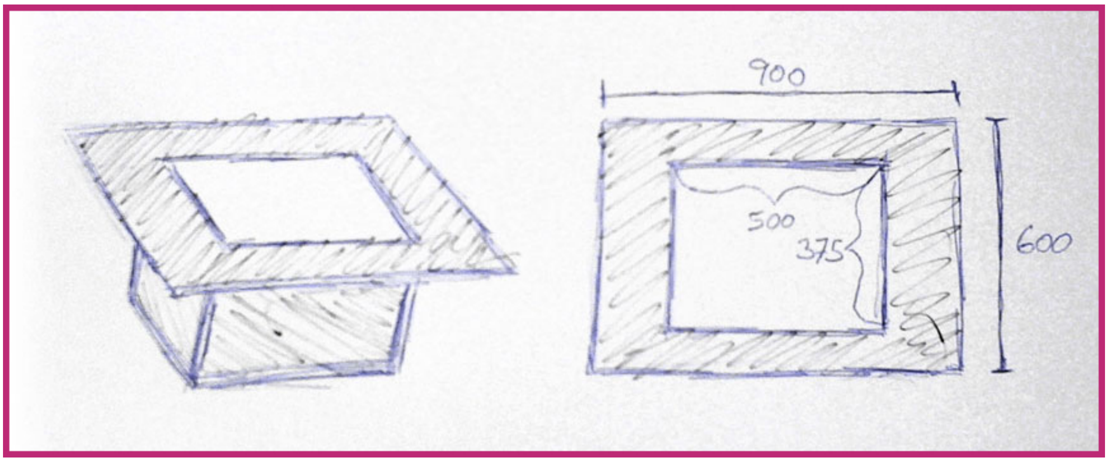

Figure 20 - Concept drawing of the tabletop interface, with measurements in mm.

As depicted in the figure, the tabletop surface should be 90cm x 60cm with an active area of recognition in the middle, measuring the 50cm x 37,5cm as mentioned previously. The height of the table should be 55cm in accordance with the height of my son's play table, and the internal measurements of the table stand/legs should be equal to the active table area, i.e. 50cm x 37,5cm.

Surface and Lighting

The surface and lighting of the table are both quintessential aspects for the functionality of the interface, as mentioned in the chapter about tabletop architecture (Chapter 8 – Interactive Tabletop Architecture).

A semitransparent coating must be applied to the active part of the tabletop surface, in compliance with the general tabletop architecture, to avoid tracking of objects that are above the tabletop surface. Tracing paper or self-adhesive foil are both relevant possibilities to accomplish such a coating.

Besides the coating of the surface, the active area of recognition should be lowered in relation to the remaining part of the tabletop. The reason for lowering this area is to avoid that objects are accidentally pushed outside of the active area. Such occurrences could lead to perceived system malfunctions, which obviously is undesired. The polycarbonate plates that are accessible to me and intended for the tabletop surface are 6mm thick. A lowering of 6mm therefore seems relevant, since the tabletop edges and the active surface area then can be made in two pieces and placed on top of each other, i.e. the active surface area below the remaining table plate.

In relation to lighting, four arrays of LEDs should send light into the polycarbonate plate used for the active area, in compliance with the notion mentioned during the survey of the general tabletop architecture. The intended positioning of these LED arrays along the edges of the surface is depicted in the following concept drawing (Figure 21).

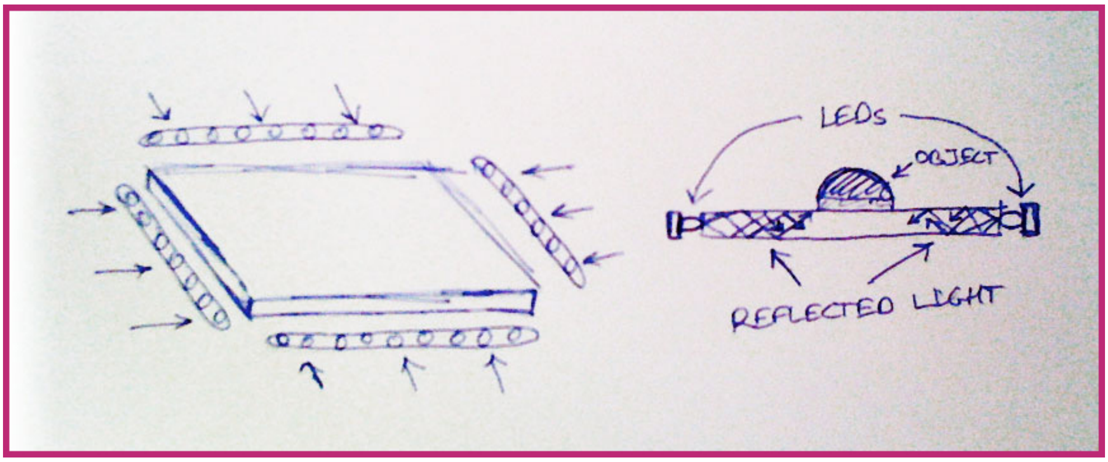

Figure 21 - Concept drawing of the placement of LED arrays to light up the surface.

This concludes the design guidelines for the construction of the physical table, and I will therefore proceed to the description of the interconnections between the various necessary system components.

14.2 COMPONENT INTERCONNECTIONS

As described and depicted previously (see Figure 17 p. 41 and Figure 19 p. 43) several interconnected components constitute the interface, and while the previous descriptions were general in nature, these are supposed to found the later implementation by being specific.

Figure 22 - The flow of information through the components of the interface.

The preceding figure (Figure 22) illustrates the components and the way they are interconnected. This flow of information will be the point of departure for the following descriptions of each specific component. The software component essentially manages input and output and is constituted by subcomponents. I will describe the software platform in the following section of its own, as this aspect requires a bit more specificity.

Objects

The objects that are to be used as input for the system can be any object with a fiducial marker attached to its bottom. A requirement is that the object is large enough to enable the attachment of a sufficiently large fiducial marker. Since the minimum size of the fiducial is dependent on the resolution of the camera, this prerequisite is easily assessed.

Since the development of the table surely will provide leftovers of polycarbonate, some or all of the objects could be made out of this material. Objects made of polycarbonate will be sturdier and weightier than the cardboard alternative that often is used for prototyping, which is appropriate as the aim is durability. Besides attaching a fiducial marker to the bottom of the object, a figure or image can be attached on top of the object to create a recognizable identity. Details concerning the specific objects for this study's prototype applications are provided in the next chapter (Chapter 15 – Content Design).

Camera

The PlayStation Eye camera that will be used for the tracking of the abovementioned objects is capable of tracking VGA quality (640 x 480 pixels) at 30fps, which according to my informal research should be sufficient. The lens should be set to 75 degrees field of view and the camera should be placed at the bottom inside the table, facing up towards the tabletop surface. The camera should preferably be mounted in a way that makes it possible to adjust the position of the camera slightly in all axes, thus making it possible to get the best possible coverage of the surface.

The camera is simply connected to a computer via a USB cable, and the video stream is passed on for processing by the software, which will be covered separately in the next section.

Television

The use of a television as the means of audiovisual feedback is what sets this project aside from the vast majority of other tabletop interfaces. In fact, I have not stumbled upon a single interface that did not include visual feedback as part of the table itself. Thereby not said that this will become a better or more capable tabletop interface than the others, since it actually is quite contrary. Not having visual feedback directly on the surface can only be considered as a limitation of the interface when compared to those who have this built-in.

"So why would you ever consider an exclusion of this feature?" you might ask. It is in fact quite simple. As mentioned previously, flexibility and accessibility is also a matter of product pricing, and since the visual feedback in tabletop interfaces is provided by expensive projectors, I opt to eliminate this costly asset.

The recipe for a tabletop interface then gets to look something like the following.

- A camera (a webcam should suffice for a more than acceptable tracking)
- A plastic casing of some sort, with a semitransparent surface on top.
- Some LEDs to illuminate the table from inside.
- A computer for the management of software (built-in or external)
- A television to provide audiovisual feedback.

The last two entries are expensive but present in the average contemporary home, and the first three are not costly at all. I cannot provide a specific price range, but my hope and expectation is that this type of interface can be as affordable as other regular toys in an ordinary toy store (board games, radio controlled cars, LEGO etc.). Well, enough about entrepreneurial dreams.

The television will be connected to the computer as an external monitor and to the audio output, thus functioning as the audiovisual feedback of the interface. This feedback is determined and provided by the application software and I will therefore move on to the next section that regards this important aspect.

14.3 SOFTWARE PLATFORM

The software platform comprises two aspects, namely the software that handles the recognition of objects and the software that manages the audiovisual feedback in relation to the input from said objects. The reacTIVision framework (Kaltenbrunner & Bencina, 2007), mentioned in the chapter on tabletop architecture, is chosen for the recognition of objects (fiducial markers), while Unity (Unity, 2005) is chosen for the management of feedback. The relationship between the two entities is illustrated in the figure below (Figure 23).

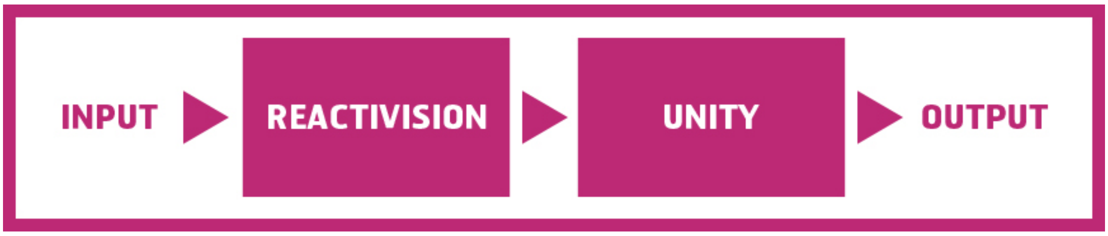

Figure 23 - The flow of information from input (objects) to output (feedback).

ReacTIVision comes as an executable application that detects the fiducial markers from the video stream and broadcasts this information locally. Unity must then be set up to receive this information, which can be done by means of the sample scripts that are bundled with reacTIVision. Unity is chosen for its prototyping abilities, as it affords drag and drop management of graphics (2D and 3D) and audio clips, as well as scripting of these virtual entities. Unity will effectively handle all virtual representations related to the prototype applications, which will be described in the forthcoming chapter.

15 CONTENT DESIGN

Given the scope of the project, the content for the interface must be designed specifically for each target group, thus enabling an assessment of the validity of the final hypothesis. Puzzles have been chosen as an overarching topic for the content design, given their physical, logical and exploratory nature. It is the assumption that several different types of puzzles can be tailored to match the profile of each target group. As a further general guideline, I opt to develop both a *concrete* and an *abstract* puzzle for each target group, since educational material roughly can be divided into these broad definitions.

It is not the intention to develop puzzles that are comparable across the target groups in terms of the given tasks, but rather to design content that is similar in nature, but tailored to the specific segment.

I must emphasize that the aim is to create scenarios that enable learning (education) and then assess the user's interest and enjoyment (entertainment). It is implicitly assumed that the scenarios enable learning, as this aspect will not be assessed in the test sessions. This is naturally a foundation for discussion, but it is considered a necessary delimitation since an assessment of the learning outcome requires a longitudinal study, which is beyond the scope of this project.

A content specification that outlines the attributes of each puzzle is included in the appendix (Appendix B: Content Specification (Puzzles))

15.1 CONCRETE PUZZLE: ANIMALS (DAYCARE)

The concept of this puzzle is to have a puzzle board with holes where specifically carved out pieces can fit. The pieces will depict 5 commonly known animals, while the puzzle board will illustrate the natural habitat of the animals. The animals are lion, elephant, hippo, giraffe and monkey, and the habitat is a grassy field. A concept drawing (Figure 24) is included for illustrative purposes.

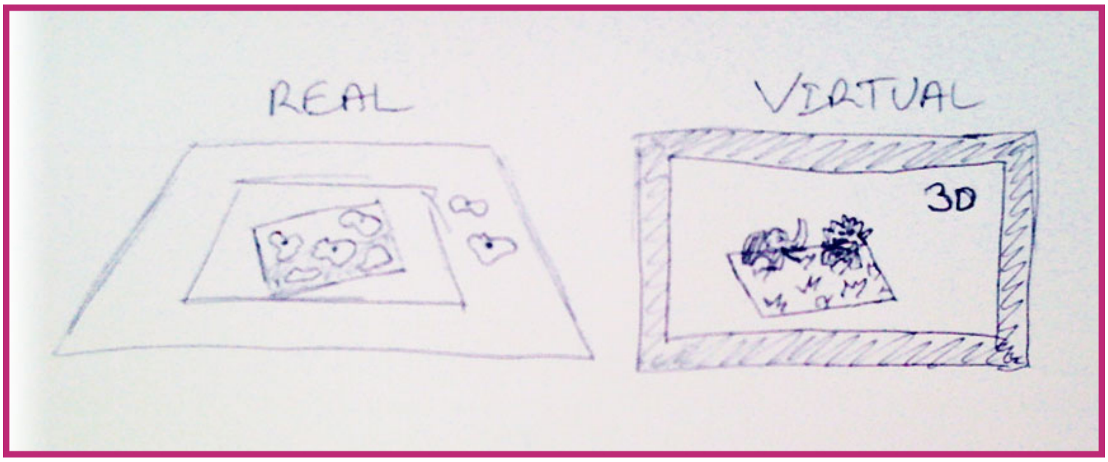

Figure 24 - Concept drawing of the concrete animal puzzle.

When the board or a piece is placed on the table, feedback must be provided. This is also the case if all pieces are successfully positioned in the matching holes in the puzzle board.

The following table (Table 7) describes the responses that should be triggered when certain pieces of the puzzle are placed on the table, or when the puzzle is successfully completed. The responses are meant as guidelines and can be altered slightly during implementation. They are presented in English here, but will of course be implemented in the natural language of the target groups (Danish).

VISUAL/AUDITORY RESPONSES TO EVENTS: ANIMAL PUZZLE		
EVENT	VISUAL FEEDBACK	AUDITORY FEEDBACK
Puzzle board placed	Grassy field	-
Lion placed	3D lion	"A dangerous lion"
Elephant placed	3D elephant	"A big elephant"
Hippo placed	3D hippo	"A chubby hippo"
Giraffe placed	3D giraffe	"A tall giraffe"
Monkey placed	3D monkey	"A hungry monkey"
Puzzle completed	3D mouse	"Well done. You have helped all the animals with finding their home."

Table 7 – Visual/auditory responses to events in the concrete animal puzzle.

The reason for including a mouse when the puzzle is completed is to have a well-known character (in this case an animal) that can evoke a response from the target group, which can be observed. The auditory feedback, which will be presented as if it was uttered by the mouse, provides an additional reward for the successful completion of the puzzle.

15.2 ABSTRACT PUZZLE: SHAPES & COLORS (DAYCARE)

The materialistic appearance of this puzzle is similar to the animal counterpart to the extent that it features a puzzle board with holes where specifically carved out pieces can fit. But it distinguishes itself by being abstract in nature, illustrating shapes and colors rather than concrete animals or the like. Four differently colored shapes will be included as part of the puzzle, and these are a blue square, a green hexagon, a red circle and a yellow star. A concept drawing (Figure 25) is included in the following.

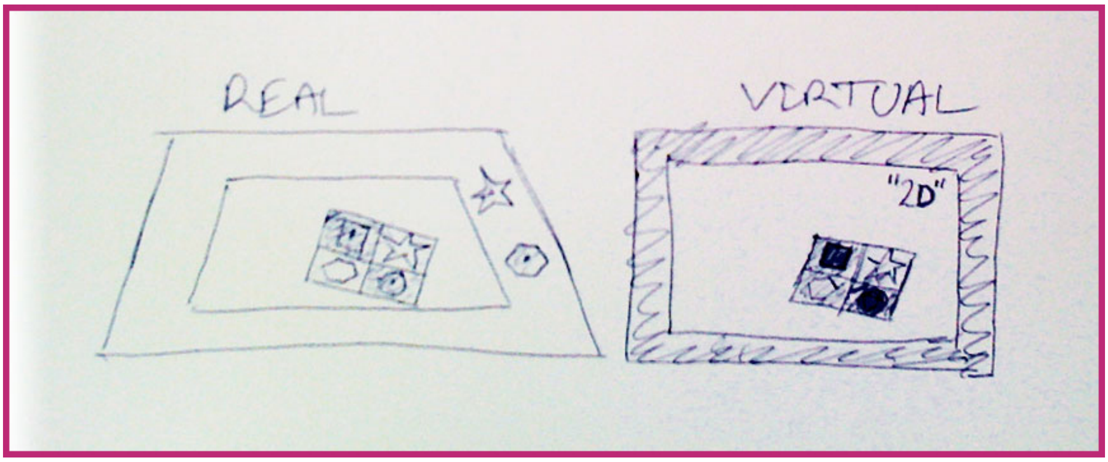

Figure 25 - Concept drawing of the abstract shapes and colors puzzle.

The visual feedback is meant to be a replication of the tangible puzzle pieces. I find it interesting to be able to compare the responses to the concrete and the abstract puzzle, which differ greatly in terms of appealing appearance. The responses to events of this puzzle are described in the following table (Table 8).

VISUAL/AUDITORY RESPONSES TO EVENTS: SHAPES & COLORS PUZZLE		
EVENT	VISUAL FEEDBACK	AUDITORY FEEDBACK
Puzzle board placed	Puzzle board replica	-
Blue square placed	Blue square	"A blue square"
Green hexagon placed	Green hexagon	"A green hexagon"
Red circle placed	Red circle	"A red circle"
Yellow star placed	Yellow star	"A yellow star"
Puzzle completed	3D mouse	"Well done. You have placed all the shapes correctly in the board."

Table 8 – Visual/auditory responses to events in the abstract colors and shapes puzzle.

Again, the mouse is included as a rewarding character that is assumed to evoke responses from this young target group.

15.3 CONCRETE PUZZLE: SPORTS CAR (SCHOOL)

Given this target group's assumed capability of concrete operations (see Chapter 1 - Cognitive Development), the complexity of the puzzles are increased to include appropriate challenges. This puzzle is designed to be a 20-piece puzzle (5 by 4) that illustrates a car seen from above. The puzzle pieces will simply be squares with a fragment of the whole image depicted on top of it. The tangible pieces will therefore constitute a 2D image of the car when combined properly. The visual representations of the pieces are meant to be fragments of a 3D model, which means that the virtual pieces will constitute a 3D model of the car when combined properly. This is illustrated in the concept drawing (Figure 26).

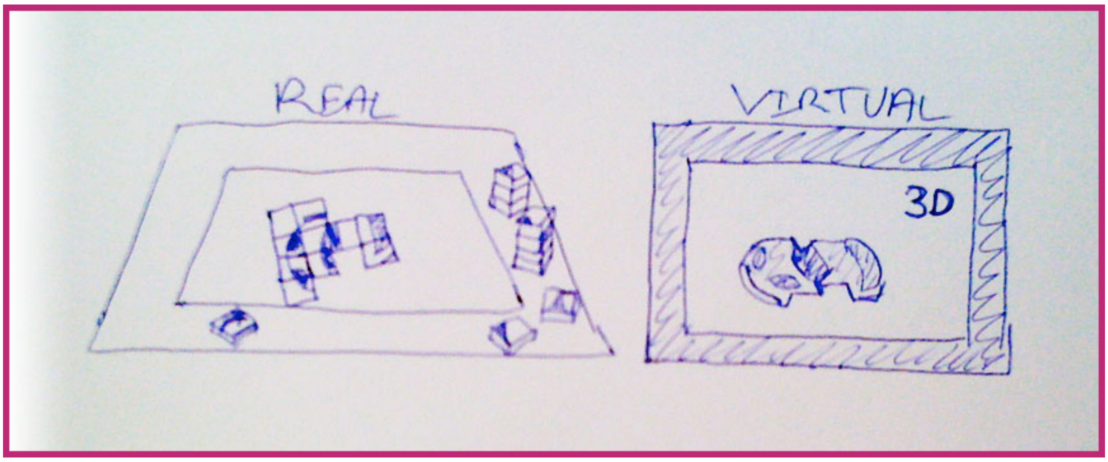

Figure 26 - Concept drawing of the concrete sports car puzzle.

The computer enables hassle free access to 3D content, and if the combination of tangible 2D pieces and virtual 3D representations can be grasped, it provides a simple and tangible interface to exploring 3D content. It can furthermore embellish existing puzzles, display visual information that cannot be seen on the tangible pieces and possibly more. In should in any case present an experience to the target group that can evoke displays of enjoyment and other observable phenomena. The following table (Table 9) denotes the responses to events.

VISUAL/AUDITORY RESPONSES TO EVENTS: SPORTS CAR PUZZLE		
EVENT	VISUAL FEEDBACK	AUDITORY FEEDBACK
A piece placed	3D representational piece	-
10 pieces placed correctly	None besides the individual 3D representations	"Well done. You have placed half of the pieces correctly. Now you are only missing the other half."
Puzzle completed	A full model of the car that is rotating	"Well done. You have solved the puzzle, which depicts one of the fastest cars in the world."

Table 9 – Visual/auditory responses to events in the concrete sports car puzzle.

The rotating 3D model of the car, which is the reward for successful completion of the puzzle, is included to show the 3D model from different perspectives, which is a feature of this virtual representation. The auditory feedback is an additional reward for the successful completion of the puzzle.

15.4 ABSTRACT PUZZLE: SHAPES & COLORS (SCHOOL)

The concept of the abstract puzzle for the older target group is to group similar pieces of the puzzle, which is a task that involves concrete operational knowledge. The puzzle comprises 16 pieces that are divided into 4 groups of different colors, which also depicts 4 different shapes. The colors are red, green, blue and yellow, while the shapes are triangle, square, circle and hexagon. It is thus possible to either match the colors and disregard the depicted shapes or vice versa, and these are the two tasks associated with this puzzle. The concept drawing below (Figure 27) depicts the appearance of the puzzle.

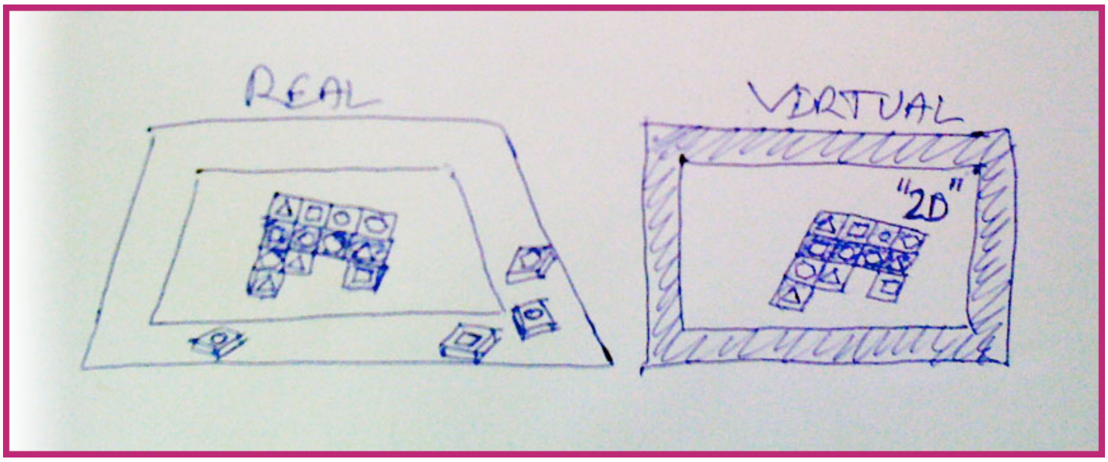

Figure 27 - Concept drawing of the abstract shapes and colors puzzle.

As with the abstract puzzle for the younger target group, the visual representations of the pieces are meant to be replications of the tangible pieces. While the aim in relation to this study is to solve a given task, this type of puzzle could additionally inspire exploration of logical groupings and thus develop concrete operational knowledge. The following table (Table 10) delineates the responses to the events of this puzzle.

VISUAL/AUDITORY RESPONSES TO EVENTS: SHAPES & COLORS PUZZLE		
EVENT	VISUAL FEEDBACK	AUDITORY FEEDBACK
A piece placed	Tangible piece replica	-
Similar colors aligned on a row	None besides the individual representations	"All the [color] pieces are now aligned."
Similar shapes aligned on a row	None besides the individual representations	"All the [shape] pieces are now aligned."
All colors are aligned in 4 matching rows	The final grouping of colors is rotating	"Well done. You have aligned all the pieces in proper rows according to their colors."
All shapes are aligned in 4 matching rows	The final grouping of shapes is rotating	"Well done. You have aligned all the pieces in proper rows according to the depicted shapes."

Table 10 – Visual/auditory responses to events in the abstract shapes and colors puzzle.

The rotating illustration of the grouping is simply included to emphasize that the task is completed successfully, while the auditory feedback rewards the children.

16 DESIGN CONCLUSION

The guidelines presented in this chapter are meant to function as a design manual for the forthcoming implementation phase, and I consider the current state of the descriptions to be sufficient in relation to fulfilling that function.

Bits and pieces of functional dependencies and interconnections are included in the separate chapters and sections, but I find it in order to include a more encompassing model in this conclusion on the design part. It is essentially a compilation of these various bits and pieces, which constitutes a combined model of the interaction with the interface. It is meant to illustrate both the physical and mental interaction, as well as the flow of information through the constituents of the collected interface.

The overarching purpose of depicting these aspects is to have a useful reference to consult with, both during the implementation, but especially during the test scenarios and subsequent evaluation and discussion. The following figure (Figure 28) illustrates the model, and further explanations will be provided successively.

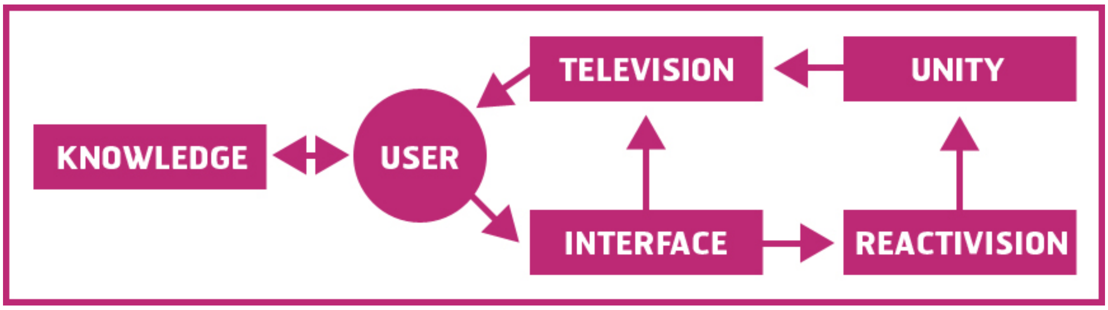

Figure 28 - Interaction model depicting the flow of interaction and information.

The figure above is meant to illustrate how the user interacts with the interface and how this instigates a learning process that affects the user's knowledge. The user interacts on the basis of existing knowledge and previous experiences and this is transformed into actions that function as input to the system. In turn, feedback is provided to the user in relation to these actions. The cycle of interaction there constitutes an iterative process of thought, action and reaction. In other words, the iterative process of action and reaction is affected by thought, but also affect thought itself, which consequently should enable an induction of new knowledge in the mind of the user.

The process of the system is not perceptible by the user, but functions in the background, and is as such therefore a "black box" to the user.

IMPLEMENTATION

The implementation part of the report will describe the process of implementation as concisely as possible, and only provide additional explanations about aspects that did not comply with the guidelines stated in the design part. For those aspects that were not affected by problems during the implementation, I will simply provide descriptions and illustrations of the manifestations of the design guidelines.

The part will commence with a description of the physical construction of the interface, covering both early prototyping and the final product. Then the software implementation will be detailed, encompassing how the various media types were managed and how the scripting was structured. Finally, the implementation of the content for the interface is covered with sequential descriptions of the four different puzzles.

A conclusion on the implementation process is included in the final chapter.

17 INTERFACE CONSTRUCTION

This chapter is meant to make a concise account of the process of constructing the physical interface, from early prototyping experiences to final product. As mentioned in the introduction to this part, the emphasis is on the problematic aspects that occurred during the implementation, rather than on aspects that complied well with the design outlines from the preceding part.

17.1 EARLY PROTOTYPING

An early prototype was developed to ascertain several aspects, such as the best coating for the surface, the reliability of the tracking, and the necessary size of fiducial markers in relation to the given distance to the camera. It was additionally used for the development of the object recognition functionality, but this will be covered in the next chapter concerning the software implementation. The figure below illustrates the prototype setup (Figure 29).

Figure 29 - Early prototype setup: Cardboard objects, surface on chairs & camera mounted on LEGO.

The chairs approximately matched the desired distance from the camera to the surface, and by rising the camera a bit, by means of the LEGO mount, the appropriate distance was ensured. The pieces on top of the surface were cardboard cutouts with fiducial markers attached underneath them.

I could not get a hold of tracing paper for the surface, as recommended by the people behind reacTIVision, but others surface coatings were tested and functioned well. Consequently, no further efforts were made to acquire tracing paper. Baking paper and self-adhesive foil with a “raw glass” coating were tried, and the self-adhesive foil was far easier to apply to the surface with a good result, than was the baking paper. The baking paper gave a more smooth and diffuse coating than the foil, but as they both produced the desired result, the foil was ultimately chosen for its adhesiveness. I believe that tracing paper probably could provide an even better diffused coating, but for prototyping this was a more than sufficiently capable solution.

The reacTIVision software easily recognized the standard sized fiducial markers (5,8cm x 5,8cm with standard print settings) and I therefore proceeded to test smaller sizes, in order to ascertain the approximate threshold. Fiducial markers as small as 60% of the original size (3,5cm x 3,5cm) could be recognized, but the smaller size had severe implications for the stability of the tracking. Fiducial markers that were 70% of the original size (4,1cm x 4,1cm) were recognized with far greater stability, which was deemed to be sufficient for implementation. To be safe, I would though prefer to use as big fiducial markers as the content design allows.

Movements of the fiducial markers were detected reasonably well in good lighting conditions, but very fast movements were not detected at all. At the end of a movement, the fiducial marker would though be detected again and for prototyping purposes this was an acceptable performance compromise.

The fiducial markers used for this early prototype were not coated and this had profound implications for the stability of the tracking over time, as the prints got smudged. A coating was therefore definitely a necessity, and fully transparent self-adhesive foil worked like a charm for this purpose.

17.2 FINAL PRODUCT

The construction of the final product was primarily a simple matter of following the design guidelines, but there were one major exception, namely issues with the lighting. This issue will be covered in a subsection of its own in the following, but first I will provide an image (Figure 30) of the final construction of the tabletop interface, which can be used as a reference in the following.

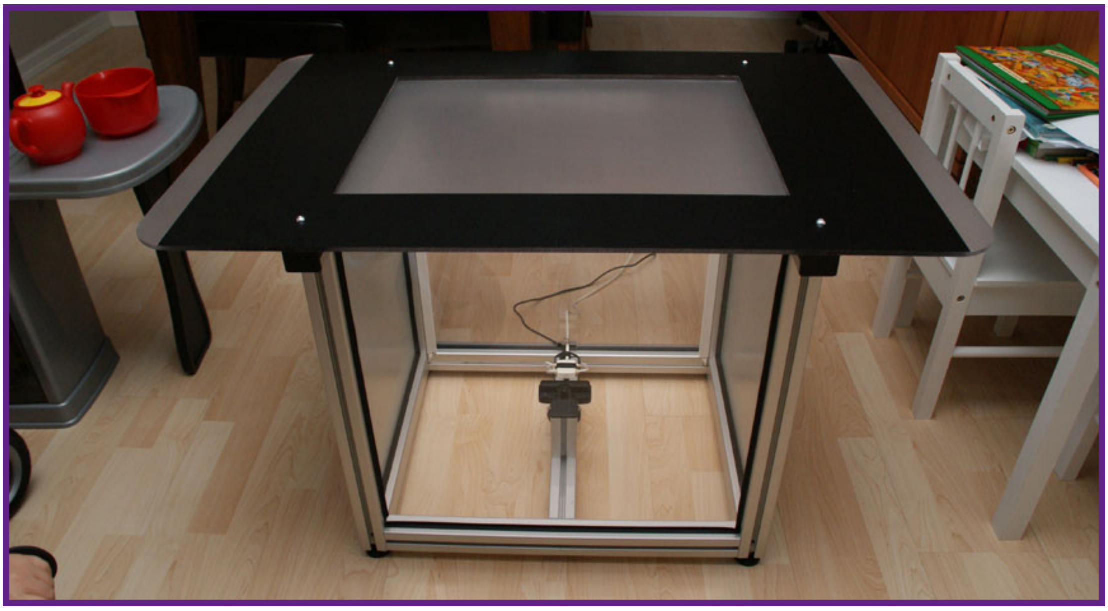

Figure 30 - The final construction of the tabletop interface.

As can be seen in the figure, the table frame is made of aluminum profiles with aluminum plates on the sides and transparent polycarbonate on the front and back. It is thus a closed construction that protects the camera inside the casing.

The tabletop surface is made of transparent polycarbonate as well, but is coated with self-adhesive foil to produce an either semitransparent or black surface.

Lighting Issues

During the implementation, it quickly became apparent that the lighting technique proposed in the design part did not work well enough to be usable. Four LED arrays were placed at the edges of the surface facing into the plate towards the centre. But this approach simply did not light any objects that were positioned on the surface well enough for these to be recognized by the software in poor ambient lighting. There are three possible reasons for this. First, it could be the quality of the LEDs. The LED arrays used were bought in IKEA for convenience, as these were pre-assembled, but the strength of the emitted light could possibly be too poor for this type of use. Second, the length of the LED arrays were 25cm, thus not covering the entire length of the edges. This obviously entails illumination issues in the corners (when centered on the edges), but even in the center of the surface tracking was very unstable. Third, the edges of the polycarbonate were not clear, but rather rough where they had been sawed. This could diffuse and absorb a significant amount of the light before it even enters the internals of the plate, and this is a likely reason for the poor performance.

As a consequence, other lighting solutions were attempted and the best solution appeared to be a placement of the LED arrays underneath the frame supporting the tabletop surface and facing down (see Figure 31). This indirect illumination of the surface, via an illumination of the inside of the box, worked best of the solutions that were tried. Other solutions that illuminated the surface directly resulted in surface reflections that were affecting the recognition of objects negatively.

Figure 31 - The underside of the tabletop surface, illustrating the positioning of the LED arrays.

The solution depicted in the figure worked well in most situations, but had minor problems in certain lighting conditions. Placing a lamp on the floor behind the table could though solve these problems, and I therefore decided not to spend any more time on perfecting the internal illumination.

Features and Additions

This subsection merely serves as a brief account of certain features that were included in the physical design of the tabletop interface. These features address certain aspects of an actual use case scenario of the interface.

As noticeable in the earlier picture of the prototype (Figure 30), the corners of the tabletop surface have been rounded to rid the table of any pointy and sharp edges. Since the table is intended for several target groups, including children, any hazardous aspects must be eliminated.

While the camera was firmly mounted inside the table, the lens was initially still adjustable, which caused a constant need for recalibration. The lens was therefore fixed by making a foam collar that was firmly secured by means of strips. This ensured that the lens would not drift over time.

All internal wires were channeled through cable trays in order to avoid that they accidentally occluded the camera's visibility of the surface. This furthermore ensured that the wires would not get ripped apart during transportation or the like. The wires that went out of the table (USB cable for the camera, and power chord for the LEDs) were additionally secured by means of foam and strips, in order to avoid damages caused by incidental reckless pulling of the wires.

Finally, the active part of the tabletop surface, where objects are visible, has been lowered in relation to the rest of the tabletop (as proposed in the design descriptions). It is therefore not possibly to push objects out of the camera's field of view by accident.

18 SOFTWARE IMPLEMENTATION

This chapter is not meant to be an exhaustive walkthrough of the software implementation related to the functionality of the interface, but rather to be an account of the logic behind this development. In other words, the software implementation is not, in itself, important in relation to the scope of the project. It only becomes relevant because it is a necessary tool for the realization of the functionality that was proposed in the design phase. That said, the software implementation has taken a considerable amount of time, and it is therefore a significant part of the effort exerted during the progress of this study.

The reacTIVision software will not be covered here, as it simply functions as an executable application that has not been altered. Only the development within Unity will be described, and this is divided into *media management* and *script structure* in the following.

All relevant software is included on the appended DVD and further details can be found there, e.g. regarding the libraries and scripts used.

18.1 MEDIA MANAGEMENT

This brief section describes the procedure that I employed to manage the many media components (2D graphics, 3D models and audio clips) within Unity and make them accessible to scripting in a simple manner.

Unity offers drag-and-drop functionality and supports a wide range of formats, so importing media content into the application is a breeze. When imported, the only thing missing is to make the content available for scripting, i.e. making it controllable. There are many ways to approach this task, but I opted to add all the individual pieces of content to the scene (i.e. the rendering area in Unity) as GameObjects. GameObjects are entities in Unity, which can encompass several components such as graphics, video, audio and scripts.

A great aspect of GameObjects is that any script has access to them simply by means of their given names, and I chose to use this approach rather than scripting the access to all graphical and auditory content. My procedure was to label all the GameObjects that represented puzzle pieces in the following format: "fiducial_[id]". The "[id]" was substituted by the id of the fiducial marker attached to a tangible object, and the graphical appearance of the GameObject was made in accordance with the design guidelines. Let us take a red circular puzzle piece with an id of 11 as an example. Within Unity I then make a GameObject with a red circle as graphic and the name "fiducial_11". This object will now appear when the specific tangible object is placed on the table.

The above is naturally only the case because this functionality has been scripted, but this will be covered in the next section.

Audio clips were handled in a similar way and labeled "audio_[id]". Here the id did not denote a fiducial marker id, but instead an assigned id that could be used during scripting to access an audio clip by means of a simple integer.

18.2 SCRIPT STRUCTURE

The software implementation that underlies the functionality of the interface is in fact a structure that comprises a series of specified scripts. This structure, as well as the functionality of the respective scripts, is the topic of this section, which will aim to provide descriptions in a concise manner. The figure below (Figure 32) illustrates the script structure. It should be noted that an additional script exists (a scene manager), but this is merely used to instantiate the event manager, which is the pivotal script, and it is therefore not included below.

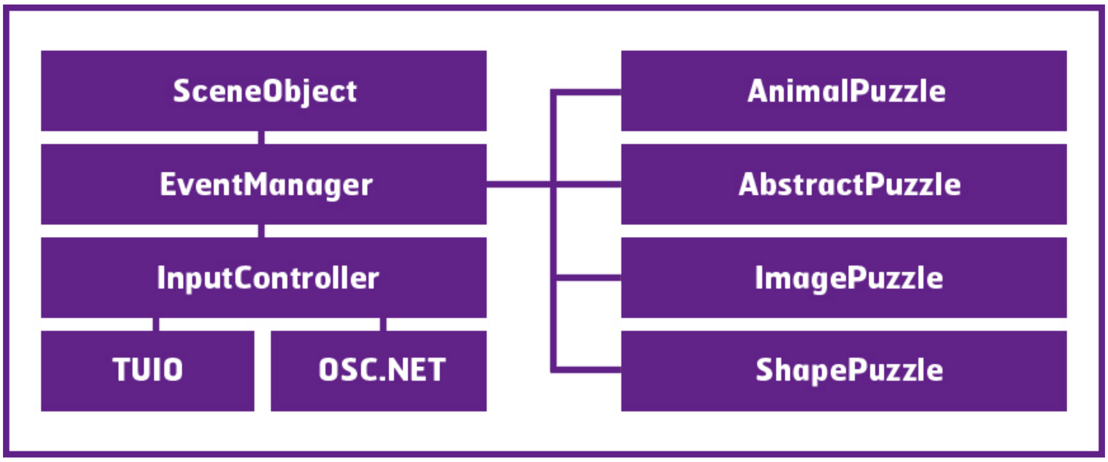

Figure 32 - The script structure used for the development of the software.

To ease the task of describing the scripts properly, and facilitate the intended understanding, the scripts will be described separately in the following subsections. The four scripts in the right side of the figure are all puzzle-specific scripts and therefore combined in the same subsection. The entities *TUIO* and *OSC.NET* are in fact supporting libraries and will also be described collectedly.

TUIO and OSC.NET

These are the founding libraries that make it possible to receive the TUIOs that are transmitted locally by the reacTIVision application. In other words, these libraries enable Unity to receive the necessary information about the objects that are recognized by the tracking software. I have not made any changes to these libraries, but simply included them in the script structure. For that reason I will not cover them in further detail.

InputController

The InputController has a single purpose, namely to listen for transmitted TUIOs and pass these objects on to the EventManager for further processing. The InputController builds on the before mentioned libraries and instantiates a listener that detects the TUIOs. Depending on the nature of the TUIO that is received, one of three callback functions is triggered, namely addTuioObject(), updateTuioObject() or removeTuioObject() (see Table 5 p. 43 for additional details). These callback functions include a TuioObject that contains id, position and angle of rotation, and this object is simply passed on to the EventManager.

The InputController's solitary function is therefore to receive and transmit, and this script does not handle instantiations, transformations or other expressive functions.

EventManager

The EventManager is the core script in the structure. It instantiates, updates or removes objects in relation to the messages that are received from the InputController. When an object is to be added, a SceneObject (described in the following subsection) is instantiated. This SceneObject will be updated when its physical correlate (tangible object) is moved or rotated, and removed if the correlate no longer is positioned on the table. An array containing information about all active objects is continuously updated, thus providing a reference database for this and all other connected scripts.

The EventManager delegates tasks to the puzzle-specific scripts (also described in a later subsection), handles audio feedback and executes the feedback upon successful completion of a puzzle.

An additional feature of the EventManager is that it resets all information when no objects are recognized on the tabletop surface. This eliminates the need for menus, and a change of puzzles is simply a matter of removing one and adding another.

SceneObject

The SceneObject class is a structure that can contain all the relevant information about the objects that are instantiated (id, position, rotation and more). It is instantiated, maintained and deleted by the EventManager, and functions solely as a structure.

Puzzle-Specific Scripts

These puzzle-specific scripts are called by the EventManager and they are each tailored to the puzzle they represent. They are as such responsible for checking if the puzzle pieces are positioned in a way that should trigger an event. If this is the case, the given script triggers the appropriate event by executing the corresponding function in the EventManager script. These scripts are, in other words, specific algorithms that evaluate a certain range of puzzle pieces in order to determine if the puzzle's goal, or part goals, has been successfully reached.

19 CONTENT IMPLEMENTATION

The implementation of the content for the interface comprises the construction of tangible objects to be used as input, and the development of visual and auditory feedback. This chapter serves to describe and illustrate the outcome of this implementation, encompassing the necessary crafting of objects, the graphical development and the audio recording. All 2D graphics have been edited using Photoshop CS4 (Adobe, 2008), all 3D models have been altered using Maya 2011 (Autodesk, 2010), and all sounds have been recorded using Audacity 1.3.12 (Audacity, 2010).

19.1 CONCRETE PUZZLE: ANIMALS (DAYCARE)

The implementation of the animal puzzle generally followed the proposed design guideline, and there is therefore little to add here, besides the fact that the puzzle board and the pieces were difficult to carve out with a piercing saw. The 3D models used for the graphical representations are free-to-use models, downloaded from this source (3Dcool.net, 2010). The graphics used for the tangible objects are paid stock photos. The following figure (Figure 33) depicts the final implementation of the tangible pieces and visual representations.

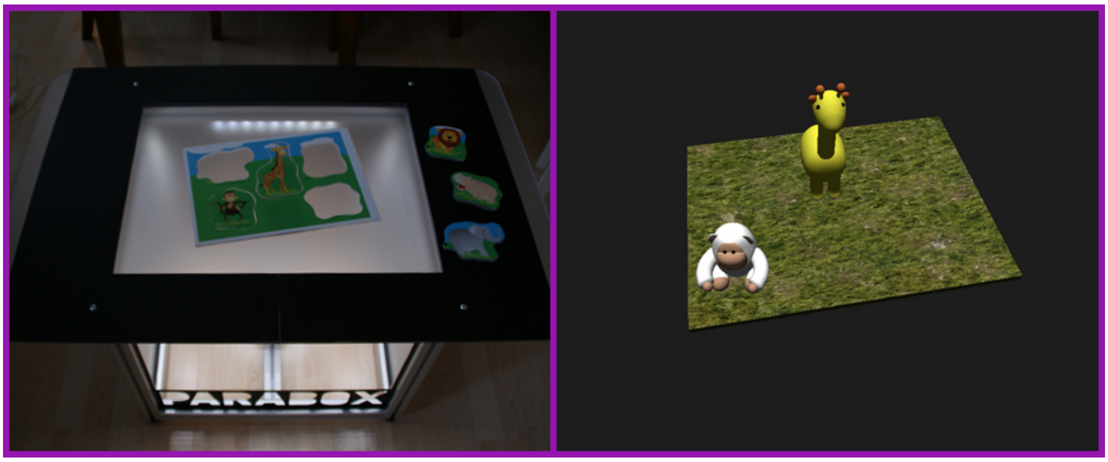

Figure 33 – Animals: The tangible pieces (left) and the virtual representations (right).

As can be seen in the figure, the tangible objects create visual representations when placed on the table. In this example, a monkey and a giraffe have been placed in the corresponding holes in the puzzle board. Accordingly, the 3D animals are placed on the grassy field in the virtual representation.

19.2 ABSTRACT PUZZLE: SHAPES & COLORS (DAYCARE)

As with its concrete counterpart, this puzzle also followed the design guidelines well. The graphics for both the tangible objects and the visual representations were simple and therefore easily applied. The craft of carving out the pieces with a piercing saw were though especially demanding for this puzzle, resulting in certain pieces that were slightly more crooked than initially desired. The star shape was the biggest challenge, but ended up being acceptable in relation to its intended use. Again, an exemplifying illustration (Figure 34) is provided, depicting both tangible and virtual objects.

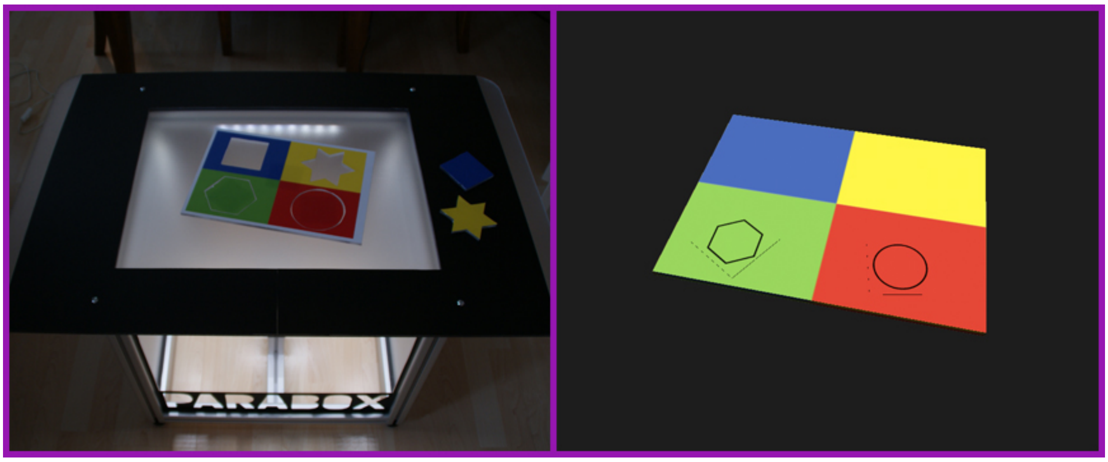

Figure 34 - Shapes & colors: The tangible pieces (left) and the virtual representations (right).

The figure shows how the green hexagon and the red circle, which are placed on the table, also are represented in the visual feedback, along with the puzzle board itself.

19.3 CONCRETE PUZZLE: SPORTS CAR (SCHOOL)

The pieces for this puzzle were cut using a circular saw with a distance guide, in order to ensure equally sized pieces (5,8cm x 5,8cm). The result was premium and made it easy to attach both fiducial markers and graphics to the pieces. The separate graphics for the pieces were manufactured by rendering out a top view of the chosen 3D model of a car and dividing this render in 20 equally sized squares (5 x 4 pieces). The 3D model was free-to-use and downloaded from the following source (Free 3D Models, 2010).

The division of the same 3D model into 20 equally sized 3D fragments was an otherwise difficult task, especially for a 3D novice like myself. But with assistance from a colleague it was made possible, though with a substantial amount of menial labor involved (grouping, ungrouping, using face selection tools, cut face tools and much more).

Apart from this, the process followed the design guideline well. The following figure (Figure 35) depicts the final result of the tangible pieces as well as their virtual counterparts.

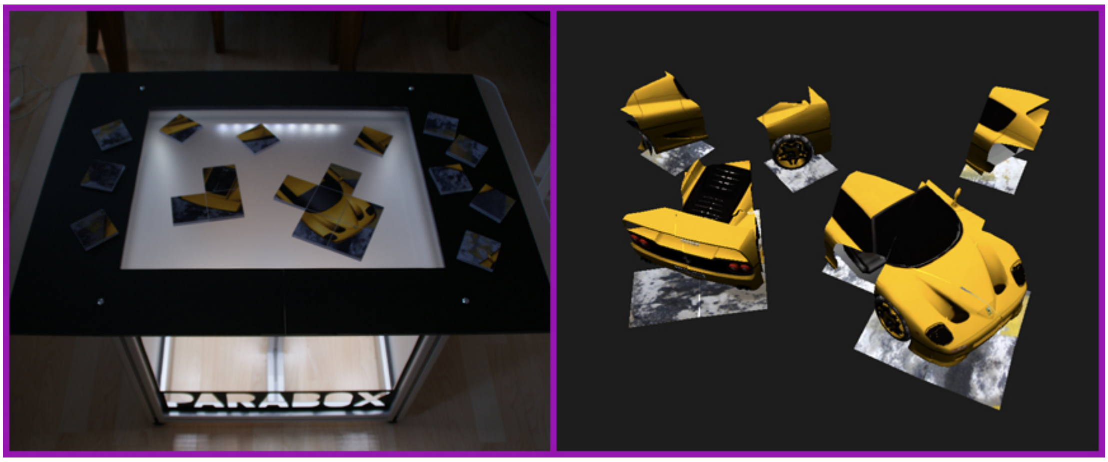

Figure 35 - Sports car: The tangible pieces (left) and the virtual representations (right).

Here the virtual 3D fragments represent the 2D images on the puzzle pieces, which allow the user to explore two different views.

19.4 ABSTRACT PUZZLE: SHAPES & COLORS (SCHOOL)

This puzzle uses pieces of a size that is similar to those in the previously described sports car puzzle. The implementation of this puzzle was, fairly simple except for one aspect. The algorithm that was meant to check if any logical groups were made (shapes or colors) posed substantial problems. The approach used for the development of the algorithm for the sports car puzzle was similar, but that was implemented after this one and did therefore not pose a problem. The solution was in fact simple. Angle calculations were done with degrees and not radians. A simple Deg2Rad conversion solved the issue immediately.

I decided not to implement the auditory feedback that was supposed to be provided whenever a row of similar pieces was made. This solution simply caused a cacophony of verbal feedback. The following illustration (Figure 36) shows the visual appearance of the implementation of this puzzle.

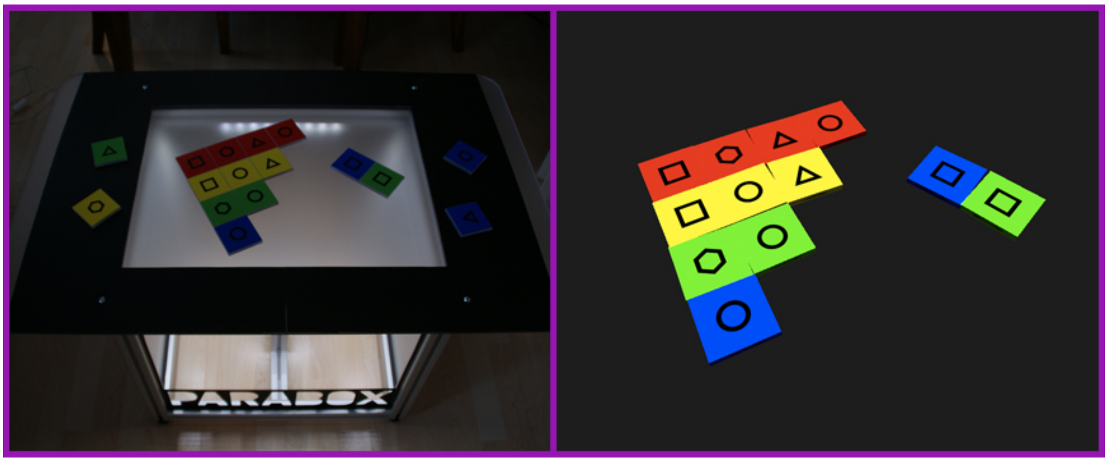

Figure 36 - Shapes & colors: The tangible pieces (left) and the virtual representations (right).

In this puzzle the user can explore shapes and colors, and try to group them in relation to one another's characteristics.

20 IMPLEMENTATION CONCLUSION

Although several people, including myself, simply consider programming and other aspects of software development as a means to a goal, the several hours spent programming has swayed this view a bit. While it most certainly is a means, or maybe even a tool, to achieve something it is also an indisputable craft alongside other crafts. Figuratively, the road to glory was winding, but the end result made it all worthwhile. In general, I feel that the accomplished implementation has brought the visions from the design phase to life with only minor alterations needed.

I felt compelled to turn down the nitpicking during the audio implementation in order to ensure that there would be sufficient time for all the aspects that should be addressed. Consequently, the auditory feedback is less developed than I initially desired, but given the multidisciplinary approach needed for this study I feel that this compromise was prudent.

Especially the sports car puzzle has turned out particularly well, and I very much look forward to seeing the reactions to this type of tangible interface application. The mixture of a 2D puzzle and a 3D representation seemingly has many applications, but it naturally requires that the target group understands the connection, and more importantly, find it interesting and enjoyable.

TESTING

The testing part of the report serves to detail the entire process related to the acquisition of proper test results that enables an evaluation of the validity of the final hypothesis of the study.

First, the test methodology will be described, encompassing preparations, setup, conduction, evaluation and bias. These aspects are all deemed to be crucial components of a successful testing process. Secondly, the actual test conduction will be covered, explaining the important and relevant aspects of the respective test executions. Third, the test results will be presented and evaluated, and this last chapter will found the subsequent discussion and conclusion of the study's outcome.

Finally, a conclusion will be provided on the entire process of testing as such.

21 TEST METHODOLOGY

Despite the fact that the interface must be tested on two separate target groups, a similar methodology can be applied to the two test scenarios. I will therefore explain a collected methodology in this chapter, and if any apparent differences surface, these will be noted separately as to avoid confusion.

A proper methodology is quintessential if the validity of the hypothesis is to be assessed beyond uncertainty, and I will therefore seek to delineate the following aspects in an irrefutable fashion to rid the methodology of any precariousness.

21.1 PREPARATIONS

Being orderly prepared is essential for any test scenario. First of all, the subject matter of the test scenario must be defined, both in the sense of a proper hypothesis and in the sense of a fully functional test vehicle. In this particular case, the hypothesis is clearly stated and the product in question is developed to a sufficiently functional state. These aspects are therefore not the preparations I am considering in this relation.

My concern is rather the formal preparations that underlie the subsequent test conduction, and this study's aim of testing on children that obviously are below the age of legal responsibility necessitates such formal preparations. Written permissions must be gathered from the parents to allow the children to participate in the tests, and to allow video recordings of the test scenarios. The first aspect is naturally a necessity, since there can be no test without children. The second aspect is deemed essential as well, since I am alone in this investigation and therefore must introduce, instruct and observe collectedly and at the same time. Having video recordings of the test sessions will greatly enhance the potential for making a plurality of justifiable observations.

A permission formula must therefore be made, which can be distributed to the parents of the children in the target group prior to the actual test conduction. Only children with returned and signed permission slips at the day of the test conduction can therefore participate. In order to assure the parents of my good intentions and of the situation as such, certain criteria of confidentiality must be included in the permission formula. I choose to offer full anonymity in the sense that no names, pictures or video recordings will be published in any way, by reassuring the parents that such information solely will be used internally.

In continuation of the preceding consideration, another important preparation is to contact potential test locations (e.g. daycare and after-school institutions) a good while in advance. If no permissions are returned, or the parents decline, there must be sufficient time to set up new arrangements. It is therefore of utmost importance not to put the test conductions in the eleventh hour of the project period.

21.2 SETUP

To ensure that the test setup is similar across test conductions and that all equipment is brought to these, I choose to delineate the test setup in this section. The following items are considered requirements for the setup and general conduction of the tests.

- Tabletop interface
- Computer
- All the puzzles
- External monitor
- Additional light source
- Extension cord and plug box
- Video camera with formatted memory and fresh battery
- DSLR camera with free memory and fresh battery
- Pen and paper

The last three entries are used for documentation, while the preceding items are necessities for the functionality of the prototype. The video camera is for the recordings of interactions with the prototype, the DSLR camera is for the documentation of the test setup and the pen and paper is for the notation of each test subject's age and gender.

The equipment must be set up so that the tabletop interface is accessible from three sides, while the fourth (long) side is positioned in the proximity of a piece of furniture that can support the placement of the external monitor. The vertical location of the monitor must be appropriate in relation to the test subjects.

The computer must be positioned close to the monitor, both due to the lengths of the supplied cables and due to the use of the computer's built-in speakers for the auditory feedback. This last aspect was tested and deemed sufficient.

The puzzles should be placed behind the monitor, or in some other location where currently unused puzzles will not steal the test subject's immediate attention.

21.3 CONDUCTION

The test must be conducted in an acceptably remote location rid of disturbing noises and people. It should at the same time not be too remote, since the children should feel comfortable and "at home" in the given location.

It is generally the intention to induce trust and a feeling of being comfortable, since the participation in a test of something unknown, conducted by an unknown person (me), may be intimidating. Emphasis must therefore be put on a proper and comforting introduction of the product and myself, in order to reassure the children. It is meant to be a rewarding and interesting experience for the children as well as for me.

To inspire mutual communication, which is observable, the children should be tested in pairs. Testing one child after another introduces the apparent risk of not getting any responses and/or intimidating the child. Participating in pairs should also make the whole situation for comfortable for the children.

The introductions and instructions must be provided calmly and with the natural vocabulary of the children. No sudden voice raisings or fancy words should be part of the dialogue with the children.

All test sessions must be introduced initially, explaining the children the reason for conducting the test and why they are specifically needed. After the test session, the children must be properly thanked for their participation so they leave the room with a good feeling. Concerning the instruction of tasks in between, these are dependant on the given target group and will therefore be described separately in the following subsections. For all tasks, instruction and guidance will be provided during the task solving if deemed relevant.

The Daycare Group

The animal puzzle and its functionality must be explained to the children in a concise manner before swiftly progressing to a more hands-on description. Children this age are not adept at following long verbal instructions, and the introduction of the puzzles should be short. If any guidance is needed during the task solving, this can naturally just be provided.

Given that the two puzzles for this target group are very similar in physical appearance and functionality, the same approach can be used for the puzzle with shapes and colors.

The School Group

The sports car puzzle must be introduced by explaining the relation between the tangible puzzle pieces with a top view of the car, and the virtual pieces that represent 3D fragments of the car. This information should be sufficient and there should also be space for some exploration.

The puzzle with shapes and colors contains two tasks, which are given sequentially. First the children are asked to group the pieces in rows, such that all the pieces in a row are the same color. Upon completion the children are given a similar task, but this time they must group the pieces in rows according to the depicted shapes.

21.4 EVALUATION

Given the ages of the test subjects I choose to perform an observational assessment of the final hypothesis, i.e. to obtain data from the conducted tests through observation. I do not regard quantitative assessment methods as applicable in relation to this study for two reasons. First, children this age are likely to be unfamiliar with the format of questionnaires and scales, and there is therefore an apparent risk of obtaining uncertain data that essentially will be of little use regarding a validation of the hypothesis. Secondly, the pleasing mentality of children towards adults is likely to be influential on the results, e.g. if the children were asked to rate their experience on a scale from 1 to 10.

As previously mentioned, I will therefore perform on-the-spot observations as well as subsequent evaluations of video recordings from the test sessions. For this type of assessment several considerations must be made prior to the actual observation, and this is the topic of the remaining part of this section.

A significant preparation for such an observational study is to define the criteria for the evaluation, i.e. the aspects to look for in the experiences of the test subjects. Before defining these criteria, another aspect is prudent to consider, namely whether the qualitative nature of the observations should be quantified by means of codification. That is, whether specific occurrences should be counted according to the specified criteria. As the aim is to assess the test subjects' levels of interest I find such quantification rather irrelevant, since the amount of displays of interest is less important than the assessment of whether such interest is kept throughout the experience. Thus, the evaluation of the tests will be purely qualitative.

In relation to the study's hypothesis the essential factor is the test subject's level of interest in relation to the presented experience, which in turn is a matter the interface's, as well as the content's, ability to maintain a high level of interest. On that foundation, three criteria can be defined that must be attended to during the observation. These are presented in the following.

- Displays of interest, both explicit and implicit.
- Understandings of the relation between input and feedback.
- Intentional interactions with the content in relation to the given task.

The first entry denotes the test subject's interest in the experience with the product as such, and implies observation of both explicit displays, such as public utterances, and implicit displays, such as a focus of attention to the experience. The second entry concerns the functional purpose of the interface and an example observation could be a test subject moving a tangible object while paying attention to the visual (virtual) feedback. This criterion serves to ascertain the usability of the interface, which in turn implies whether the interest of the test subject is firmly rooted in the interaction. The third and final entry regards the use of the interface's functionality in relation to solving the given task. This aspect is meant to reveal if the content is properly designed for the target group, and if the interface inspires new ways of interacting with the content. Conclusively, the evaluation will be based on these three criteria.

21.5 BIAS

An effort must be made to preempt biasing of the test results, and I therefore choose to consider potential sources that can cause an erroneous interpretation of the obtained results.

The fascination of that which is new poses a significant risk for the interpretation of the observational data, since any interest in the test experience could be ascribed to the news value of the interface. This source of bias can be difficult to overcome without a longitudinal investigation, but this is not an option in this case. I therefore suggest that displays of interest that include phrases in line with "cool" are cautiously interpreted, as these may refer to the interface itself and not the experience.

An even more significant risk of bias lies in the task of instruction, and thus with me as I will be carrying out that task. Any intentional or unintentional instruction that directly founds a corresponding response from the test subject must be considered a profound bias on the results. To exemplify this, an utterance concerning the coherence of two puzzle pieces is irrelevant if I have just guided the test subject to combine or regard these specific pieces.

Besides the above statements, it is also important to be continuously aware of potential sources of bias during the test conduction, since such sources may appear on the fly. Besides the preemption of bias, it is thus additionally important to detect errors that have already occurred and act accordingly during the interpretation of the results.

22 TEST CONDUCTION

In this chapter, the specifics concerning the two test conductions will be described. It is meant to provide an insight into the actual test scenarios.

22.1 THE DAYCARE GROUP (2-3 YEARS)

This test was conducted May 11th 2010 in the daycare institution Børnehuset Ringen in Roskilde, Denmark. The arrangement of the date and the physical location of the test conduction were decided cooperatively with the manager of the daycare institution two weeks in advance.

Prior to the test conduction, a descriptive document concerning the test had been handed out to the parents of children within the target group. This document included a written permission slip that should be signed and returned in the event that the child would be allowed to participate in the test.

Figure 37 - The test setup for the session in the daycare institution.

The equipment for the test was set up in accordance with the descriptions in the previous chapter (Chapter 21 – Test Methodology). The test setup is illustrated in the figure above (Figure 37).

Test Participants

At the date of the test conduction, 7 permissions signed by the parents had been returned, allowing a total of 7 test participants. However, only 5 of these participated in the test, since two potential test subjects were deemed unfit to participate at the time. One child fell asleep at the table during lunch, and another was grumpy at the time and did not wish to participate.

Thus, a total of 5 test participants were observed. These were divided into two groups, one with the three oldest children and one with the two youngest. The age span of the children comprised two 2 year-olds, two 3 year-olds and a single 4 year-old, and the children were all boys. Although the last participant exceeded the age span of the proposed target group (he had recently turned 4 years) he was included as a test participant, given the already approximate nature of the division of target groups.

Test Location

A dedicated room within the institution was provided, with a door that could be closed in order to prevent other children from barging in during the conduction of the test. The room was rid of any objects that could steal the attention of the children away from the interaction with the interface.

Test Conduction

The actual conduction of the test generally went as planned and followed the procedure proposed in the test methodology. The children were less hesitative than initially expected when asked to join me for the test session, and they appeared to be exited about the experience they were facing. I had been worried that the children would be shy at first and need a long warm-up session, but this was definitely not the case.

Both of the groups that were participating in the test were very good at either taking turns to try the puzzles or collaborate without any conflicts. I had the presumption that conflicts could become an issue, since children this young often fight over toys, but luckily this was not the case here.

During both test sessions it became evident that the children solved the puzzles faster than expected, and therefore were candidates for a more challenging task. As I had all the developed puzzles with me, I readily decided to try the shapes and colors puzzle that was meant for the older target group. This was done after the children's experiences with the two intended puzzles and did therefore not interfere with the initial aim of the test. The outcome of this on-the-fly experiment will be discussed in chapter 23 - Test Results and Evaluation.

The only diversion from the intended progression of the test was that the otherwise very good location was not as isolated as I could have wished for. During the session with the second group, several of the other children in the daycare knocked on the door, which made the test subjects loose their focus of attention momentarily. This was of course not preferable, as the level of interest in the interaction with the interface, among other aspects, were to be assessed in relation to the attention of the test subjects. Children do though digress easily and such behavior can be expected, even without disturbances. Furthermore, the test variable at stake in this study is the level of interest and not immersion. The minor sidetracking was therefore considered acceptable.

22.2 THE SCHOOL GROUP (6-8 YEARS)

This test was conducted May 10th 2010 in the after-school institution Vor Frue SFO in Vor Frue, Roskilde, Denmark. The arrangement of the date and the physical location of the test conduction were decided cooperatively with the manager of the after-school institution two weeks in advance.

Prior to the test conduction, a descriptive document concerning the test had been handed out to the parents of children within the target group. This document included a written permission slip that should be signed and returned in the event that the child would be allowed to participate in the test.

Figure 38 - The test setup for the session in the after-school institution.

The equipment for the test was set up in accordance with the descriptions in the previous chapter (Chapter 21 - Test Methodology). The test setup is illustrated in the figure above (Figure 38).

Test Participants

At the date of the test conduction, 17 permissions signed by the parents had been returned, allowing a total of 17 test participants. Contrary to the case with the younger target group, all of these participated in the test.

The children were divided into groups of two, with a single child trying the interface on his own. The age span of the children comprised two 6 year-olds, five 7 year-olds, seven 8 year-olds and three 9 year-olds. 10 of the children were boys and 7 were girls. The 9 year-olds had all recently turned 9 years, and although they exceeded the age span of the target group, they were included on the grounds that the target group age span already was an approximation.

Test Location

A dedicated room within the institution was provided, with a door that could be closed in order to prevent other children from barging in during the conduction of the test. No immediately disturbing elements were present in the room, which therefore accommodated the desired focus on the interaction with the interface.

Test Conduction

The conduction of the test generally went well, though with a few exceptions. The children were outspoken and energetic, and seemed to have high expectations for experience with the interface. Several children that did not bring permission slips from their parents displayed a significant interest when seeing the interface, and I therefore agreed with the manager of the institution to let them try it casually after the actual test sessions.

One of the mentioned exceptions that influenced the test negatively was, similarly to the other target group, a disturbance from people barging into the room. In this case, the people did in fact come all the way into the room, which obviously disturbed the children a bit. These disturbances were only caused by adult employees and not by any children, and I did not feel empowered to forbid them entrance to the room. I kindly asked them to wait until the end of a session, which was well accepted. There were thus many undisturbed test sessions and as with the younger target group, the influence on the test results was minimal.

Another exception, and possibly the reason the initial disturbances, was that the manager of the institution wished to be present in the room during the tests. Although this affected the intended test methodology quite a bit, it was a request I could not turn down at such short notice. I therefore decided to try to get the best out of the situation and asked him to partake as an instructor during the tests. The logic behind this choice was to not have him standing mysteriously in the corner, possibly affecting the children negatively, but instead explicitly incorporating him into the flow of the test. This worked beyond expectation, and the positive relationship between the manager and the children resulted in a lot of explicitly displayed information about the children's experience. It was clear that the children felt comfortable with the manager and the influence on the test was more positive than negative, when evaluated retrospectively.

In relation to the above, there is though an important consideration that must be added to the intended evaluation method. The abovementioned explicit emotional displays must be considered critically, since the intention is to obtain information about the children's interest in the interface and not their social relations to the manager.

23 TEST RESULTS AND EVALUATION

In this chapter, the observations from the conducted tests will be described and evaluated. The observations mentioned in the following are those that comply with the criteria mentioned in the test methodology chapter.

23.1 THE DAYCARE GROUP (2-3 YEARS)

The two test groups exhibited different skills and behaviors while interacting with the interface and I will therefore refer specifically to the respective groups, rather than make a general account. In the following, the groups will be labeled group A (3-4 years) and group B (2 years).

An apparent difference between the groups, and the children as such, was that the proficiency at solving the puzzles and the ability to shift focus between the tangible pieces and the virtual representations was dependant on age. The oldest participant from group A (4 years) shifted focus swiftly and constantly, and appeared to have a good understanding of the relationship between input and output. All the children did though pay attention to both types of representations and the difference was largely the degree to which this attention was exhibited.

As previously mentioned, both groups solved the puzzles that were designed specifically for this target group very fast, suggesting that the difficulty of the designs were too low. All children uttered that they would like to try the puzzles a second time, which suggested a substantial degree of interest in the interaction with the interface, and the puzzles were solved faster in the second tries. While the children were a little hesitant at first they seemed to gain confidence over time.

The children were initially instructed to remove the pieces from the table when they had solved a puzzle, which would cause the system to reset and be prepared for the next. After the solving of the third puzzle, the children from group A automatically removed the pieces without any instruction, indicating a full understanding of this resetting process. The other group did not autonomously do this without instruction. An amusing occurrence with a member from group B was when I asked him how the mouse (used as completion reward) could be removed from the screen. I tried to hint a removal of the pieces, but he instead replied “You shoot it!” and aimed at the screen.

All the members of both groups responded to the auditory feedback several times, and replicated the spoken sentences, e.g. when the red circle was placed in the correct position, the children would say “A red circle” after the feedback from the system. This was a general tendency and occurred without instruction.

Group B displayed enthusiasm a lot more explicitly throughout the test session than group B that was calmer, but I believe that these expressions were more related to personality than to interest. As an example, members of group A would respond verbally to the positioning and feedback of the piece with the lion in a calm manner, while group B simultaneously would yell "GRRRRRR!!! A dangerous lion!". The response to the lion piece was general for group B and seemed to constitute one of the microevents mentioned in the section about interaction narratives. A member of group B also responded to the monkey piece by making the sound of a monkey although this was not included in the auditory feedback. Thus, there was a link to existing knowledge about the artifact at hand.

All of the children pointed at the virtual feedback several times and definitely paid attention to that part of the interface. There seemed to be a bigger interest in the virtual representations than in the tangible objects when solving the animal puzzle, which also created more significant responses than the shapes and colors puzzle. The latter puzzle seemed to be less appealing and engaging to the children, plausibly due to its abstract appearance.

The additionally given task of solving the abstract puzzle developed for the older target group revealed a significant difference between the two groups. Group A was able to solve it fairly quickly with little instruction and displayed a good understanding of the similarity between certain pieces. Especially the 4 year-old showed proficiency and grasped the concept immediately. Group A was capable of solving the puzzle in relation to both shapes and colors respectively, but solving for color matching seemed to be easier for the children.

This suggests an age dependency, which correlates well with Piaget's account of developmental stages where the development of concrete operational knowledge takes place between the age of 2 and 7 years, approximately. Group B was not able to solve the task, even with substantial instruction, and given the members' lower age it complies well with the theory. When the children from group B placed a puzzle piece incorrectly in relation to another piece, I asked them if it was the same type as the other, e.g. "are these the same color?". This revealed that they knew both shapes and colors well, but they still were not capable of grouping them logically. They did though place the pieces in rows that despite their unmatched nature still could be considered a logical structure. This indicates that the interface, with a proper design of content, could be used to practice such logical/mathematical skills. One could of course argue that this would be possible with the pieces alone, but considering the additional dimension of instructional potential, the interface should have an advantage. In other words, the interface would be able to guide the interaction and provide feedback on logical groups of pieces and the like.

23.2 THE SCHOOL GROUP (6-8 YEARS)

To my surprise all the tested groups showed a similar proficiency in solving both the presented puzzles, albeit with different degrees of explicit enthusiasm. The following will therefore be a general account that is applicable to all of the groups, though with specific examples where appropriate.

To cover the mention of explicit enthusiasm first, the majority of groups communicated a lot internally and discussed solutions to the puzzles. A single group distinguished itself by not communicating at all, which clearly was contrary to the case with the other groups. During the approximately 15 minutes long test session only a few words were uttered, and this was generally in relation to a question asked during instruction. The only self-initiated utterance was a member of the group that noted the similarity between the sports car puzzle and the character Bumblebee from the movie Transformers.

The lack of communication in the above example should though not be confused with lack of interest in the experience, since both of the members in that particular group paid full attention to their interaction with the interface during the complete 15 minutes of testing. Independent of the level of explicit displays of interest in the experience, it was a general tendency that the children kept focus during the entire period of testing. Considering the rather long test sessions, I believe that this indicates a fair amount of interest in the interaction with the interface and its contents. Even when disturbed by people barging in, as mentioned previously, the children kept paying attention to the interface after a brief glance at the "intruder".

The temporal length of the test sessions was primarily influenced by the time it took the groups to solve the sports car puzzle. It was a lot more difficult for the children to solve than initially expected, and on average it took 10 minutes for that puzzle alone. While the children luckily still found the task interesting, it revealed a flaw in the design of the graphics for the puzzle pieces. The symmetry of the car's placement resulted in several similarly looking pieces, which made it difficult for the children to distinguish them. The asphalt background was furthermore very generic and the four pieces not including any part of the car were difficult for the children to position correctly.

But despite the difficulty of the sports car puzzle, the children were not demotivated and a lot of interesting observations were made. All of the children used the virtual representations of the car in conjunction with the tangible pieces, and they shifted focus between the table and the screen continuously. A very interesting observation was that the majority of the children rotated the tangible pieces while looking at the virtual representations, in order to identify the specific part of the car. Especially the taillights of the car, which were not visible on the tangible pieces, were identified several times. I found this use of the 2D and 3D representations very interesting, and it established the children's understanding of the functionality of the interface as well as the puzzle.

The abstract shapes and colors puzzle was solved very fast by all groups, which again complies well with the assumed capabilities of children at the concrete operational developmental stage. None of the subtasks (rows of shapes or colors) posed problems for the children. Many groups asked about the shapes on the pieces when asked to solve in relation to colors, and a single group actually managed to solve both tasks simultaneously as they positioned the pieces to form rows of similar colors and columns of similar shapes.

For both puzzles there were no real response to the auditory feedback provided by the system, and the children tended to glance at me when the feedback was provided. One of the children even asked if it was my voice and stated that it would be funnier if the voice had been that of Donald Duck. This of course suggests an inadequacy of the sound design, which surely could have been developed more, but it did not seem to affect the children's interest in the experience as such. Furthermore, the auditory feedback for the younger target group was recorded in the same way as for this one, but they responded to the provided sounds several times. This indicates that the older audience is more critical of the provided feedback, and less developed visual feedback would probably have been criticized as well.

One of the essential observations was the general tendency of collaborating and communicating more when solving the difficult sports car puzzle, than when solving the easier shapes and colors puzzle. There are of course several variables to consider across the puzzles, but I am confident that the difficulty itself plays a major role. When being faced with a task that is not immediately solvable, it seems prudent to discuss solutions with the partner, and seemingly this was what happened during the majority of the test sessions. In fact, it was only the previously mentioned non-communicating group that did not fit into this pattern.

24 TEST CONCLUSION

The actual conductions of the tests, and the subsequent evaluation of the observations, revealed a few flaws in the design of the puzzles as well as in the test procedure as such. The degree of difficulty in the puzzles did though not affect the test results negatively, and the disturbances during a few of the test sessions did likewise not have any long-term effect on the children's attention to the interface.

As such, the test design, conduction and evaluation were a success, though with the minor exceptions mentioned above. The observations made during the testing revealed several interesting aspects that founded an interesting evaluation of these.

For future test scenarios an elimination of disturbances may be preferable, and pilot tests should be conducted to assess if the difficulty of the content is appropriate. An appropriate difficulty would in this relation be one that provides a sufficiently challenging task without being beyond the capabilities of the target group.

DISCUSSION & CONCLUSION

This final part of the report is intended to provide a thorough discussion, and subsequently a conclusion, of the outcome of the project.

The discussion is meant to cover several fundamental aspects of the project, both ones that are directly related to the assessment of the hypothesis, and ones that are significantly influential in relation to the interface itself.

The conclusion will provide a definite evaluation of whether the stated hypothesis can be accepted or should be rejected, primarily based on the aspects included in the discussion.

Finally, a description of future perspectives will outline some interesting and appropriate directions for this project, in the case of further development.

25 DISCUSSION

In the following chapter I will discuss three main aspects, namely *theoretical foundation*, *test results* and *product applicability*. In further detail, I wish do discuss the appropriateness and adequacy of the included theoretical foundation, contemplate the outcome of the testing in relation to the hypothesis, and reflect on the potential of the developed product.

25.1 THEORETICAL FOUNDATION

A significant part of a proper design and implementation of any product is a proper theoretical foundation for the choices made during these phases of development. In the case of this study, an appropriate theoretical foundation would require a multidisciplinary effort, as also mentioned in the delimitation. In our field of study (Medialogy) we pride ourselves on being multidisciplinary problem solvers and developers, but the amount of scientific areas involved here was beyond the capabilities of a single developer, even a Medialogist.

Several compromises therefore had to be made, which effectively excluded certain areas that otherwise could have been influential. Furthermore, the included areas may not have been covered in the depth that it preferably should have been. The time allotted to the development of all aspects in this study simply did not allow for in-depth reviews of all areas.

A profound figure throughout the report is Jean Piaget, whose theories have founded many aspects of the project. The choice of using Piaget as a main source of information and inspiration was a deliberate one, given his stature within the field of cognitive development. I acknowledge that many other significant authors have influenced this scientific field, and others, but a line had to be drawn to allow the necessary insights into several relevant fields. Piaget is a renowned figure within his specific field of expertise, and I opted to allot my limited time to his generally accepted theories, rather than basing my work on less established contemporary theories. In other words, Piaget appeared to be the safe and stable choice.

I likewise only scratched the surface of the full potential of narrativity, and it is indisputably a resource of methods and inspiration that should be further investigated. But in relation to the developed interface, I consider the theoretical coverage of narrativity to be acceptable, given that the interface supports the creation of many different applications, which can be infused with narrative content. I therefore do not regard the lack of an extensive review of narrativity as a negative influence on the final product, or on the process of the project as such.

The above view applies to the descriptions of cognitive theories for learning as well, which I regard as valuable methods for creating effective learning applications. These methods or strategies should appropriately be used in the development of content, and is therefore fully supported by the very concept of the interface.

25.2 TEST RESULTS

The observations of the test subjects' interactions with the interface revealed a substantial interest in solving the given tasks. The attention of the test subjects was focused on the developed content for the majority of the time spent, and contrary to what I initially would have presumed, this was a general tendency of the tests conducted on both target groups. At a glance, the hypothesis of this study therefore appeared to be ascertainable.

But the observed tendencies are only one side of the whole story, and as mentioned in the description of potential biases, other aspects must be considered in conjunction with the observational data. I consider two aspects to be potentially influential in this relation, namely the news value of the interface and my presence in the location where the test sessions were conducted.

The whole process of introducing the interface in the letter to the parents, and subsequently bringing the actual product at the date of the test conduction, may very well have created a considerable amount of anticipation. The children may therefore already have been excited about the experience they were going to partake in, prior to the actual interaction with the product itself. This anticipatory excitement applies to the older target group.

The actual session of interacting with the interface was additionally a new experience for all the children, including those in the younger target. And that which is new is by default interesting, which obviously can have a profound effect on the immediate interest in the experience.

The other influential aspect is the fact that I was present in the room during the test sessions, and the children could as a result have felt obligated to pay attention to the given tasks. I intentionally made an effort to take on the role of a helper or guide, rather than the role of a supervisor, with this specific issue in mind. But there is still a risk that the children could have been intimidated or affected by my presence, albeit I would consider this a marginal risk.

Upon re-evaluation of the recorded videos from the tests, I did not notice any situations that would indicate the occurrence of the second aspect. The children appeared to be genuinely attentive, and manipulated the content in a consistent manner that indicated a sincere attempt to solve the puzzles. I likewise do not consider the manager's presence in the test with the school children as a negative influence. He instructed and guided in a calm manner, and it generally appeared as if the relationship between him and the children was a friendly one.

In relation to the first aspect, I must acknowledge the possibility that the children's levels of interest may have been affected by the mere fact that the experience was new to the children. But considering that the concept of the interface is to support several types of content, and new content therefore should be available with reasonable intervals, I do not consider this as a crucial factor in terms of assessing if the interface can maintain high levels of interest.

25.3 PRODUCT APPLICABILITY

This last section of the discussion serves to provide reflections on the potential of the interface in relation to both consumers and businesses. The inclusion of such a discussion is inspired by the notion that even a superb product is worthless if it is inaccessible to the target group.

In relation to products such as the one developed during this project, accessibility is largely a matter of affordability. If the target group cannot afford to acquire the product, its purpose is essentially irrelevant. This was also the primary reason for not including visual and auditory feedback as an inherent part of the developed interface. By exploiting appliances that already are part of the average household, the costs can be diminished and plausibly put the product within an affordable range.

As such, the aim must be to provide the necessary functionality in the interface to support the creation of diverse types of content. The interface thus becomes the foundation for a voluntary customization of its purpose and functionality. In other words, the interface can be acquired without paying for potentially needless appended content, and be customized with whatever content that is found interesting or in other ways useful.

This not only allows customers to tailor the product to their needs, it also provides an opportunity for businesses to reach a broad market of users, and produce and sell an abundance of additional content packages. In a very real sense, it is relatable to the App Store for the iPhone or the many peripheral controller casings for the Nintendo Wii. It is a matter of changing the affordances of a single system by modifying it with additional content.

26 CONCLUSION

In relation to its founding hypothesis, this study set out to develop a flexible interface capable of accommodating edutainment across several target groups, by supporting customizability of its content. In other words, the content should define the purpose and functionality of the interface.

To properly inform the design of such an interface concept, a broad array of scientific areas was surveyed, ranging from cognitive development, through cognitive strategies for learning, to interactive narratives. Such an encompassing approach was required, given the necessity for a multidisciplinary coverage of all related scientific areas.

The design and implementation amounted to the creation of the interface, as well as four distinct puzzles, two for each of the study's two target groups, and the subsequent tests supported the evaluation of the test subjects' levels of interest.

In the discussion, several relevant topics were considered with a primary emphasis on the validity of the hypothesis. The provision of an ultimate conclusion on this validity is the singular purpose of this chapter, which either accepts or rejects the hypothesis.

The observations from the conducted tests formed the basis for a thorough evaluation of the experiences of the test subjects in relation to the three criteria that were defined in accordance with the hypothesis. In turn, this enabled the discussion of the immediate findings through a critical view on potential biases. No significant sources of bias were found to affect the integrity of the observational data.

On that foundation of reasoning, I deem the hypothesis acceptable. I find the potential of the interface concept to be irrefutable, based on the high degree of certainty induced by the data from the observations.

27 FUTURE PERSPECTIVES

For any future development of this interface concept, I see two major aspects that must be attended to, namely *tracking performance* and *content development*.

Improving the performance of the camera tracking of objects will significantly enhance the potential of the interface, opening up for possibilities beyond those of the interface at its current stage of development. This has two sub aspects, namely *resolution* and *framerate*. A higher resolution enables the possibility of smaller fiducial markers, and a higher framerate should enhance the perceived relation between tangible objects and virtual representations during fast movement. The latter should also enable the development of games, which usually relies on a stable means of input.

This leads to the aspect of content development, which essentially concerns the creation of several different types of content. Not only will a broader variety of content render the interface more appealing, it will also enable further evaluations of its ability to support specific content types.

Other interesting improvements encompass adjustable height of the table, in order to match the height of a wider range of users, and a better internal lighting system. Especially the latter is important in relation to the performance of the object tracking.

IMAGE REFERENCES

The following represents the references to any source locations, from where images have been borrowed for illustrative purposes. Unless specifically noted, the references are either links to the appropriate websites or references to literature in line with the citations in the rest of this report.

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APPENDIX

This part contains the appendix of the report, which encompasses the aspects that have been considered unfit for inclusion in the report writings.

A: THINKING/INTELLIGENCE STYLES

The following appendices are examples of how certain professions can be classified by means of thinking style tendencies and the theory of multiple intelligences. For each type of intelligence there is a division into four distinct types of thinking, and examples of professions that adhere to each category is given. The appendices are taken from the article *"Schools, Thinking Style Models and At Risk Learners"* (Unknown Author, 2009).

Appendix A: Gardner's Intelligence as Dimensions of the Four Jungian Thinking Styles

Linguistic

The ability to use language to describe events and sequence activities

Journalist *Technical Writer*
Administrator *Contractor*

The ability to build trust and rapport

Sales person *Counselor*
Clergyperson *Therapist*

The ability to develop logical arguments and use rhetoric

Lawyer *Professor*
Orator *Philosopher*

The ability to use metaphoric and expressive language

Playwright *Poet*
Storyteller *Novelist*

Logical/Mathematical

The ability to use numbers to describe and document

Accountant *Bookkeeper*
Statician

The ability to value specific number systems having personal relevance

Tradespeople *Homemakers*

The ability to manipulate symbolic systems and reason well with mathematics

Logician *Computer Programmer*
Scientist *Quantitative Problem Solvers*

The ability to be sensitive to mathematical patterns, symmetry and the logic, beauty and aesthetics of mathematics

Composers *Engineer* *Inventors*
Designers *Qualitative Problem Solvers*

Spatial Relations

The ability to perceive the visual spatial world accurately

Illustrator *Artist*
Guide *Photographer*

The ability to arrange color, line, shape, form and space

Interior Decorator *Clothing Designer*
Painter *Weaver* *Builder*

The ability to graphically represent and interpret visual or spatial ideas.

Architect *Iconographer*
Computer graphics *Sculptor*

The ability to transform visual or spatial ideas into creative products.

Artist *Inventor*
Model Builder *Cinematographer*

Bodily/Kinesthetic

The ability to use tools to construct or take apart

Mechanic *Contractor*
Craftsperson *Tool and Die Maker*

The ability to express one's ideas and feelings through the whole body

Actor *Mime* *Puppeteer*

The ability to express oneself symbolically through physical movement

Choreographer *Dancer*
Professional Athlete

The ability to use one's body and hands to form ideas and things into new forms of expression

Sculptor *Dancer*

Musical

The ability to demonstrate musical skills

Technician *Music Teacher*
Instrument Maker

The ability to express one's feelings musically and/or be clear about the music one likes

Performer *Listener*
Collector

The ability to discriminate musically

Music Critic
Aficionado
Music Collector

The ability to create musically

Composer *Conductor*
Instrumentalist

Extroversion

Interpersonal

The ability to organize people and to communicate clearly what needs to be done

Administrator *Manager*

The ability to work cooperatively and respond appropriately to the facial expressions, voice and gesture of others

Team Member

The ability to discriminate and interpret among different kinds of interpersonal cues

Sociologist *Psychologist* *Psychotherapist*

The ability to influence and inspire others to work towards a common goal

Consultant
Politician
Charismatic Leader
Evangelist

Introversion

Intrapersonal

The ability to demonstrate self discipline and affective maturity

The ability to be in touch with one's affective state and that of others

The ability to reflect upon one's assets and liabilities objectively

The ability to reflect upon ones inner moods, intuitions and temperament

B: CONTENT SPECIFICATION (PUZZLES)

The following table outlines the attributes that are ascribed to each of the puzzles developed for the assessment of this project's final hypothesis. It has been developed as a guideline for the design and implementation phase, and has been used solely for this purpose.

Target group	2-3 year-olds		6-8 year-olds	
Category	Animals	Shapes/Colors	Regular image	Grouping
Size	5 pieces	6 pieces (3 x 2)	20 pieces (5 x 4)	16 pieces (4 x 4)
Type	Concrete	Abstract	Concrete	Abstract
Board	Yes	Yes	No	No
Pieces description (and board if applicable)	Each piece depicts a specific animal, while the puzzle board depicts a natural context.	Each piece depicts a certain shape of a certain color, and the puzzle board depicts the matching holes and colors.	Each piece depicts a part of one big collected image.	The pieces are divided into four groups of colors and 4 groups of shapes (e.g. four red pieces that depicts four different shapes and so forth).
Task description	The animals must be positioned in the relevant places in the environment by inserting the pieces into the correspondingly shaped holes in the puzzle board.	The colored shapes must be inserted into the correspondingly shaped holes in the puzzle board.	The pieces must be assembled to make up a collected image. The task is similar to that of regular jigsaw puzzles.	The colored pieces (also depicting a certain shape) must be grouped in relevant ways according to either color or shape. There are multiple solutions to this.
Milestone reward	When a piece is correctly inserted, the animal appears on the screen and its characteristics are provided by means of audio (e.g. name, color and sound).	When a piece is correctly inserted, the shape appears on the screen and its characteristics are provided by means of audio (e.g. shape and color).	When a certain amount of pieces are correctly placed in relation to one another, a motivating remark will be given (e.g. you're on the right track).	When a certain category of pieces is correctly grouped, a motivating remark will be given (e.g. all the red pieces are gathered on a line).
Completion reward	The child is applauded by a virtual character and the coherence of the task is explained (e.g. you helped all the animals find their homes).	The child is applauded by a virtual character and the coherence of the task is explained (e.g. you put all the shapes in the right holes).	The child is applauded by a virtual character and the coherence of the task is explained with details about the image (e.g. you solved the puzzle which depicts a Ferrari Enzo, one of the fastest cars in the world).	The child is applauded by a virtual character and the coherence of the task is explained (e.g. you grouped all the pieces in four rows of the same color).
Learning goals	The child can learn the names, sounds and colors of the different animals and see them in their natural context (e.g. the savannah).	The child can learn the names of the shapes and colors of the different pieces, and the physical relation between the shapes and holes.	The child can learn specific details about the depicted image that would not be accessible from a merely physical 2D puzzle, both by means of audio and visual 3D representation.	The child can develop operational knowledge about the relationship between similar types of pieces, which is involved in grouping tasks.