SUPPORTING THE LEARNER'S PLAYFULNESS AND CREATIVITY AS LEARNING MECHANISMS: DESIGN SPECIFICATIONS FOR INTERACTIVE INTERFACES IN ARTS MUSEUMS

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A thesis submitted in partial fulfillment of the requirements of Bournemouth University for the degree of Master of Philosophy

MARCH 2017
Bournemouth University

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ACKNOWLEDGEMENTS

I would like to thank my supervisors, Neal White, Stephen Deutsch and Gerard van Wolferen for their on going support and challenges.

The illustrations in Figures 15, 16, 18, 19, 20, 23, 25, 26 and 31 were drawn by Kasia Burgin

ABSTRACT

The goal of this research is to present design specifications for (digital) interfaces that intend to teach artistic concepts to learners through their playful and creative engagement, and are intended to be situated in arts museums. The aim of such an interface is that learners can develop insights in regard to presented artistic concepts through their playful or creative engagement. The proposed benefit of insight development as a mechanism for learning about the creative arts is that it allows the learner to discover uses of the presented materials that are self-relevant, therefore demonstrating utility in regard to their subjective cognitive style. Artistic concepts are defined as a subjective idea for art creation that an artist has developed through the qualitative and subjective attention to his environment, which he then expresses using his creative process into an artefact. This dissertation presents a *"Cognitive Model for Learning through Creative Engagement with Artefacts"* that delineates how perception and interaction mediates learning during creative activities. This process operates on two principles that describe how a learner's perception of, and, interaction with, man-made objects are processed in the human brain, namely as action representations, or as intentional agents. The way that a learner's playful and creative engagement operates as a mode of learning is explained on the basis of the available literature in the cognitive and neurosciences. Learning is understood in this explanation as a process of formation and consolidation of insights in Long-Term Memory, which in turn informs the changes in the behaviour of the learner. In order to further clarify how play and creativity activities facilitate learning, children's museums that are specialized in the arts have been inquired about their education practices. They produce theme-based play exhibitions, and have developed an expertise in conveying an exhibition's theme through active, experiential and playful means. For the purpose of demonstrating how installations can be designed that teach an artistic concept by means of a learner's creative engagement, two conceptual inferfaces have been designed and discussed. One teaches *"Len Lye's Discovery Process for Novel Figures of Motion"*, and the other teaches the *"Matisse's Composition Process behind his Paper Cut-Outs"*.

CONTENTS

1 INTRODUCTION

This research emerged from my job as a digital media teacher at a now-defunct arts-education institute in Almere, The Netherlands. One of the key tasks of this institute was to provide facilities and teachers for the arts curriculum of the various secondary schools and vocational colleges in the region. This particular setup of arts education at secondary schools allowed me to come into contact with learners with highly different backgrounds, social environments, and educational trajectories. Secondary education in The Netherlands is organised in different trajectories, ranging from pre-university education with a key focus on academic skills, to practical education where there is little focus on academic skills, and learners are being trained for jobs in construction, hospitality, gardening and agriculture. I prepared and taught fairly identical workshops about electronic music composition and photo editing for classes coming from these different learning trajectories. These workshops were given in a classroom consisting of a whiteboard, beamer, sound installation, and 16 computers where learners could create their work on. Learners from the pre-university trajectory were highly comfortable with the classroom-based training I provided and worked confidently on their own ideas. Learners from the practical education trajectory felt much more confident with 1:1 approaches, not only seeking me to provide guidance, but were also keen to inquire each other about their progress. Each of these manners of learning in the classroom were commonplace in their learning trajectories of their secondary schools.

In a later period, I had been given the assignment to provide post production classes to learners attending a theatre production course at a regional vocational college. Most of the learners attending these classes did not come from the usual learning trajectories. For some of them, it was a follow-up from the practical education they attended during secondary school, but others came to these classes after an unsuccessful struggle to find a place in society. I noticed that these learners weren't particularly comfortable with the classroom-based style of tuition and the computer software and interfaces they had to work with. When I discussed the issues that these learners faced with them, I noticed that they were able to articulate their struggles in a very clear manner: "Working with these interfaces is like sifting knowledge from patterns and layers that do not at all come natural to me". The learners viewed that the means to create videos and sounds for their theatre production were put behind interfaces that conveyed a pattern of reasoning which they found ideally suited for the creator of that interface, rather than that it spoke to their intuition of using such interfaces. This gap also put them very far removed from acquainting themselves with all the artistic aspects that are involved in music composition and video editing. Most hours were also spent on learning to operate the software, leaving hardly any time to discuss artistic repetoire that is relevant for their work. After having spent some time observing how the learners who showed the most discomfort with these interfaces interacted with them, I decided to make a simple video editing interface (see figure 1), that allowed their editing process to become much more intuitive. However, this outcome did not yet answer how the views and experiences of relevant, established artists can be communicated through such an interface in order to make their time spent with the interface into an arts education experience.

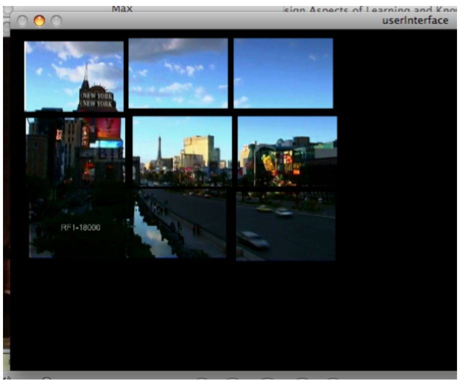


Figure 1: This picture shows the “Visual Reasoning Browser” User-Interface concept. It’s a video-mixer with a videoclip browser. This concept presents the working materials as the interface, rather than providing text-links or textual classifications to these materials. Children can choose a location on a map where they can look for video’s. Their selection will show a panorama which has been divided into nine parts. On the picture you see the result of a selection of a road: a divided panorama of an urbanized environment with all the elements that, both, surround and use a road. If a child would for example look for a car, he could click on a road, see this panorama and drag a car driving on the road into the video-mixer.

I also have worked on educational materials for arts museums and here I found similar disparities between the content being presented to the visitors, and their intent to learn about the artists that created the works being displayed in the museums. One of the materials that I have created was an audiotour for the Leerdam Glassmuseum. When studying their existing booklets and tour guide materials, I noticed that there was a strong tendency to objectify an artist's creative process, often resulting in highly technical explanations of the works that are presented in the museum. Such an explanation tells little about the decisions an artist makes to utilize a certain technique, his motivation to engage in such a creative process and the point of view that he wants to make tangible in the resulting artefact. During the course of creating this audiotour, I also gathered the views of the visitors on the museum's existing materials, who indicated a that the museum's presentation could benefit from including a *'human factor'* in their narratives, which would allow the visitors to make a stronger connection to the museum's presentation. I sought to implement this 'human factor' by placing the biographical information about the artists central in the narrative of this audiotour.

Both the theatre production course and the audiotour for the Leerdam Glassmuseum revealed a similar set of issues that needed to be addressed when creating educational materials. Each of these projects required a reimagining of the roles that each participant takes in an educational system. It could be said that there are three types of roles that a participant can take. One can be the Learner, an individual who spends his time in this system working on his future. An Educator, recounting his views and experiences to his learners. Or a Designer, whose designs enable a particular way of teaching and learning. The role that I took in these educational projects was predominantly that of a designer, also when I was actively teaching in the classroom. Therefore, the resulting outcomes of these projects did not limit itself to a delivered artefact or lecture plan, but also represented a problem specification that attempted to readjust the weight of each role in a educational setting.

I brought this view of this active designer role in education into my thinking about my teaching activities in the classroom, and sought to augment the workshops that I gave for the secondary schools with visits to a nearby modern arts museum called "De Paviljoens". I organised one trial with a secondary school class, where the learners first went to the museum, and then went to the classroom to make collages with pictures found on the internet. Here I observed that their impressions at the museum informed the choices they were making when composing a collage. This outcomes of this trial brought me back to the learners from the theatre production classes who were uncomfortable with this classroom-based style of tuition: wouldn't they benefit if, using their creativity and playfulness, they could create their own pathway to the knowledge I would want to teach them? This question became my key motivation for this research.

During the initial phase of this research, I investigated the literature of the various disciplines that conduct research in educational technologies. From this I concluded that, broadly speaking, the following two underlying assumptions are being made in most of the academic work that I've come across:

1. If you understand the learner, you know how to teach or build a device that can fulfill such a function.
2. It is beneficial to the learner to use digital technologies to adapt educational content to their life-space, style of thinking and their way of engagement with the content.

The first assumption is based on the notion that a certain presumed thinking style or a preference for certain activities of a learner forms an entry point for learning. However, thinking styles are often conceived on the ostensives of observed learning behaviors and the verbalization of learner's experiences. Therefore, they explain very little about the functional mechanisms that underpin a learning activity. The current body of knowledge in cognitive neuroscience does provide some pointers about such mechanisms. Using this knowledge, the theoretical body of this dissertation attempts to provide *functional definitions* for two of the learning mechanisms the human brain has to internalize and find utility in the external world: the engagement of activities in a *playful* or *creative* manner.

The second assumption introduces a problem in the design of (digital) materials for art education. It would require to objectify the practice of an artist or limit the scope to a repertoire of techniques, while it would be ideal to maintain a balance between the techniques, the manner of use by the artist and his reasons to engage in a creative process. The viewpoint that I'll attempt to demonstrate proposes a concept that looks at how HCI mechanisms should function as tuition tool in regard to the creative interactions among children in a space for arts education. Such a viewpoint does not merely attempt to understand the learner, but puts the questions *'what are you going to teach'* and *'how are you going to teach it'* back into the discussion about the design of such materials. One of the commonly mentioned qualities of (classroom) educators are that they have to ability to introduce learners to novel ways of thinking in an inspirational manner and be able to present themselves as a role-model, rather than adapting to their life-space. I find such qualities in the design intentions of games like '*echochrome*', a commercial puzzle-game that is inspired by the artistic work of M.C. Escher, where players are invited to explore the logic that he expresses in his visual works. This game relies solely on game-mechanisms to recount the deep-structure behind some of his expressions and presents these without the intent to adapt to the logic the player takes which for granted in everyday life. Where a game like '*echochrome*' and my interface concept share similar fundamentals in the way that artistic concepts are being presented, the interface concept that I set out in this dissertation are tools for expressive engagement. This means that users are able to express themselves in a creative manner using such an interface, but using mechanisms that represent the deep-structure behind an artistic concept.

On the account of the arguments I've set out in regard to the mentioned assumptions, the outcome of this research project represents a proof of principle of this interface concept. The aim of the resulting conceptual/working models is therefore to make this concept tangible for further discussion about the particular ways of teaching and learning such designs enable.

1.1 RESEARCH AIMS & QUESTIONS

Art museums face a series of challenges in becoming real *learning environments* that offer conceptual, artistic knowledge to learners. They are cultural organizations, that represent cultural beliefs and that offer visitors a rich social, leisure time experience where learning *might* be an outcome (Kuntson & Crowley, 2005). Therefore, the central basis of the Museum's narrative is conceived upon the usage of an exhibition space, where artefacts with a certain historical or technical significance are displayed (Porter & Alexander, 2008). These narratives are designed to embed the museum's discourse into socio-cultural contexts, with the intent of engaging their visitors in a conversation (Leinhardt & Crowley, 2002). However, such a mode of operation is in divergence with the way that these learners are engaged in the current media landscape. They have become active participants in social, conversational online networks like Facebook and Myspace. Central to these conversational activities is the notion of *identity*: how you see yourself and how others perceive you (Greenfield, 2008; Kelly, 2000). Therefore, users of these networks have developed *identity strategies* that motivates them to create and share compositions that are more sophisticated than simple art or stories (Grunwald, 2007). Also, search tools like Google make this media landscape into an 'answer-rich question-poor' environment, enabling learners to find the things that can be of value to them in a fast paced manner. Such an environment lacks an overarching conceptual framework, meaning that facts that are found in a search tool can only be placed and related in the context of their peers (Greenfield, 2008). It is within this divergence that the means can be found to enable 'question-rich answer-poor' type of qualities in the environment of an Art museum. Such qualities can refer to a model that is similar to a '20th century classroom', governed by an authoritative narrator recounting his views to his audience (Greenfield, 2008). For Art museums, it are not the narratives that bridge contemporary society with the museum's discourse, but the artefacts that serve as an entry point to recount the imaginative and creative thoughts of the artist, using his own means of expressivity and his skills and knowledge to use these (Oomkes & Garner, 2003). Eisner (2004) views such artistic expressions as the work from individuals who consciously attend their environment as a qualitative experience in order to pursue a process of creative construction. The results out of such an engagement with the environment communicate the various dispositions of individuals towards empirically observable phenomena (e.g. a painting of a shore is an individual disposition to a natural phenomena, compared to a satellite photograph on Google Maps of the same area). On its turn, the presentation of these results promote the various ways in which people can find meaning and utility in their environment.

Learners up to the age of preadolescence (14 years old) (Stiles, 2008; Huttenlocher & Dabholkar, 1997) have a natural disposition to engage playfully in a *safe environment* with relatively novel stimuli. Such an engagement expresses a flexibility of different views of an individual in a non-serious manner. This flexibility is a product of self-exploration: such stimuli in safe environments provide incentives for individuals to acquaint themselves with their surroundings, in the light of their set of biological, mental (cognitive propensities and prior knowledge) and physiological abilities. These engagements reflect the questions of *"what can I do with the objects in my surroundings?"* and *"how do I relate to others?"* and help to construct a *working knowledge* of the environment. (Pellegrini et al., 2007; Bateson, 2005; Brown & Vaughan, 2009; Gorlitz et al., 1987).

Playful engagement is therefore a mode of learning that is feasible to utilize in the contemporary context of art education, especially when children have reached the cognitive capabilities to engage in creative play activities. In terms of an Art museum being a learning environment that provides a conceptual overarching framework for such activities, the following question needs to be asked:

> *How do you design interfaces that intend to explain artistic concepts by supporting the learner's creativity and playfulness as learning mechanisms?*

In terms of contemporary policies regarding the educational function of cultural institutions, they mention that they seek a change in mode of operation in order keep their practice sustainable in an era where audiences inquire into their collections using digital means. Therefore, these institutions seek to relocate the centre-point of their activities away from being an access provider to their collections. Instead, fulfilling a function that can combine the functions of being a guide and inspirator to their audiences, while they can find self-relevancy in the presented materials though their pro-active engagement (Wolfson, 2008; Bruijnzeels et al., 2010; Frampton, 2011). An answer to the question stated can provide for a method that can make such a function demonstrable, enabling further discussion about the paths can be pursued regarding the curatorial function of cultural institutions. The current Dutch government does not have a programmatic plan for such changes in the institutions' mode of operation. Instead, they motivate them to seek cooperation with the creative industries. The results out of these cooperations aim to inform governmental policy making regarding the communication of culture (Dutch Government, 2012).

1.2 OBJECTIVES

There are several concepts tried in this field: digital technologies for inquiry-based learning in the museum space (Campos et al., 2009), enhancing collaboration among peers using ubiquitous technologies (Hall & Bannon, 2005), and the virtual, online museum (Alwi & McKay, 2009). These are all based on *'minimally guided'* philosophies of learning that share the following assumptions: learners constructing their own solutions lead to the most effective learning experience, and knowledge can be best acquired through experience. However, these philosophies overlook the value of *tuition* (Kirschner et al., 2006). Serious gaming in a museum environment is a concept that is inclusive of this value (Danks et al., 2007). But the use of game mechanisms limit the ability for expressive interaction with the interface.

The objective for this research project is to conceive HCI mechanisms that enable users to experience their individual dispositions towards the way that an artist qualitatively attends his environment, thereby shaping his creative process that lead to artistic expressions that are unique to his views. These mechanisms *do not* recount techniques for inscription and editing of media, but make *artistic concepts* tangible through the user's creative and playful engagement with the digital interface. Such an engagement can be viewed in a similar manner as a creative or playful engagement with a musical instrument. A user can *explore* the palette of representations that are available to his actions, he can *improvise* with different forms of organization, the interface has the aim to be *consistent* in terms of presenting repeatable results, and it allows for *practise* to develop skills to create expressions of a more sophisticated level. The mechanisms required for such an engagement operate on two principles that describe how the human brain construes novel, graspable objects into cultural, action concepts:

1. During creative engagement with ordinary objects (object construction, finding novel, relevant uses for objects) , it is shown that there's a high correlation between the quality of an individual's creative output and the integrity of the synaptic connections between the brain region that plays a key role in disentangling the origin of sensory events[1] and the rest of the brain (Takeuchi et al., 2010; Jardri et al., 2011). This region is responsible for the transaction and acquisition of new knowledge about the actions involved in tool use (*how do I use it?)* (Ishibashi et al., 2011), in recognizing one's own action in others (*imitation and action identity*) (Jackson & Decety, 2004) and making sense of perceptual ambiguity (Vickery & Jiang, 2009). Furthermore, it is argued that concepts of concrete objects and actions are *embodied*. This means that they are mapped to the sensory-motor system of the brain, therefore characterising the semantic content of such concepts in terms of the way we function with our bodies in the world (Gallese & Lakoff, 2005; Mahon & Caramazza, 2008). It also means that such concepts are *self-referential*. Mirror neurons in this brain region (Fogassi et al., 2005) link to the regions that are involved in self-referential processing (Uddin et al., 2007, p. 156). Relevant for an individual's engagement with objects are the 'proto-self' and the 'minimal-self' in this processing system. The 'proto-self' refers to a collection of neural patterns which map the state of the physical body. And the 'minimal-self' refers to basic needs and emotions, therefore dealing with the interaction with objects in the environment (Northoff et al., 2006; Damasio, 2000; Seeley & Sturm, 2007, p. 326). Considering this process of embodiment and self-reference, it means that the brain construes graspable objects as representations of the actions of 'others' (Fogassi et al., 2005; Creem-Regehr & Lee, 2005).

1 This brain region is called the Inferior Parietal Lobule and is discussed in Chapter 1.4.2.4 - '*Sensory-motor and Mentalization aspects* of Creativity' of this dissertation.

2. Individuals have the ability to detect animate and inanimate objects as intentional agents. They register something as an intentional agent when it is understood as acting because of internal states such as beliefs and desires. However, these internal states are attributions to the representations of an object's actions in our inner world: the registration of an intentional agent is a *fully mental phenomena* (Barrett & Johnson, 2003). What is being attributed to an intentional agent is our own 'self experience'. This is observed in its most basic form among infants. They intrinsically construct *action representations* from the perception and production of acts as it is embodied by their imitation of others. These action representations become intentional agents when they ascribe the internal state that regularly goes with that behavior (Meltzoff, 2007). However, the degree that we ascribe our 'self experience' does not end at other humans. We ascribe *mental states* to nonhuman agents, including inanimate, abstract objects when these express goal directedness (e.g. chasing or fighting) (Castelli et al., 2002). In terms of *ascribing intentional agency to HCI mechanisms*, Howard-Jones et al. (2010, p. 795) demonstrated that when individuals engage in a digital gambling game, the virtual actions of an artificial agent (their competitor) is construed in a similar way as the actions of the player. It is also shown that only the *suggestion of action* by the artificial agent is sufficient for this to occur. This might suggest that there are sensitivities to aspects of a task, like its meaning or the relation to the player's task. In terms of user's perception of the HCI mechanism, it means that the visual and audible feedback of the mechanism is experienced as being bound by actions of the user or the artificial agent (McEneaney, 2009).

1.3 MAIN CONCEPTS DISCUSSED IN THIS WORK

The main question of this research, "*How do you design interfaces that intend to explain artistic concepts by supporting the learner's creativity and playfulness as learning mechanisms?*", can be delineated into two problems that deal with the perception, interaction, and learning behaviours of the user of such interfaces. The first problem deals with the perception of, and interaction with, the proposed HCI mechanisms in this work, namely: what are the fundamental requirements for a HCI mechanism that aims for the transmission of concepts in an intuitive manner? And the second problem deals with the context of use of this mechanism: how can such a mechanism facilitate *learning* by means of a learners' playful and creative engagement?

In regard to the basic requirements for the proposed HCI mechanisms, the two points that are mentioned in the research objectives (chapter 1.2), deal with the *perception* (how the involved brain regions disentangle the origin of sensory events during creative engagement) and *interaction* (humans' ability to perceive the objects in their surroundings as intentional agents and action representations) with the proposed mechanism. How these points relate to the development of designs that intend to teach artistic concepts, and how this is being recounted throughout this dissertation, is outlined in Figure 2, which presents a "Basic Framework for the Perception of, and Interaction with, Tuition Mechanisms".

In regard to the way that such a mechanism can facilitate learning, it is best to understand a learners' playful and creative engagement as *natural learning behaviours*. Both play and creative behaviours are underpinned by mechanisms in the brain that allow the learner to acquaint himself with his environment (play), or to develop self-related *insights* by engaging with perceptually ambiguous situations (creativity). These behaviours also modify synaptic connections in the long term. Continued play activities have a positive outcome on the number of synaptic connections that the brain considers relevant to keep in the later stages of development (See Chapter 1.4.1). And insights refer to sudden realizations of a solution to a problem, which is incorporated into Long-Term memory. Therefore, in regard to creative engagement, the other main concept discussed in this work is a description of the cognitive conditions that are favourable for the development of insights, and their consolidation in Long-Term memory (Chapter 1.3.2).

1.3.1 *Basic Framework for the Perception of, and Interaction with, Tuition Mechanisms*

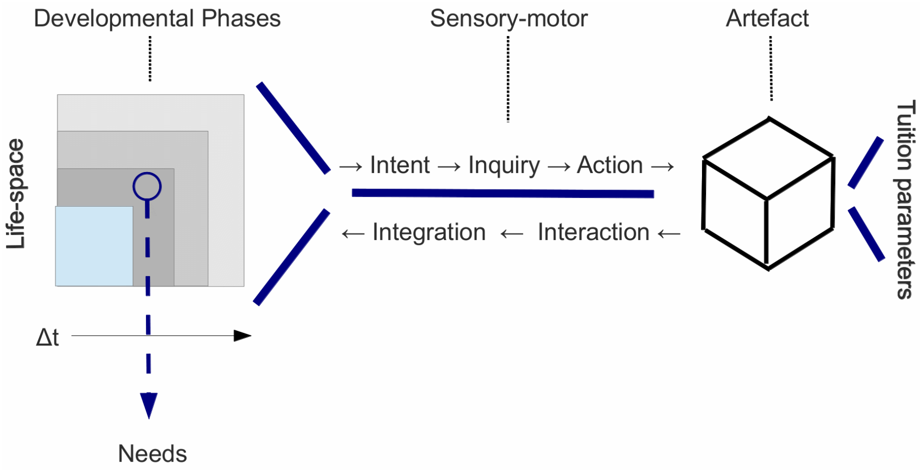


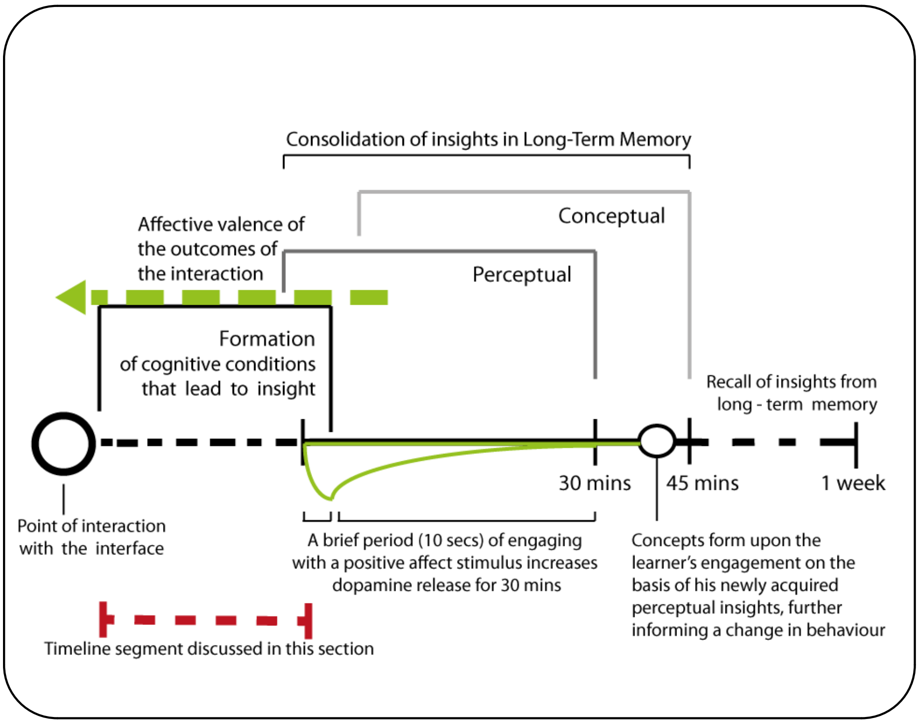
Figure 2: Basic Framework for the Perception of, and Interaction with, Tuition Mechanisms

Developmental Phases Children go through several developmental stages as they grow up, each stage representing an advancement of their cognitive skill level. The basis for the iteration through these stages can be found in the triggering of the structural development of the human brain by genetic cues. How these structures will develop depends on the input that is provided by the environment. (See Chapter 1.4.1 - Play, p. 19)

Sensory-motor Each developmental stage projects a specific set of needs for stimuli and interaction with the environment. If a toddler playfully engages with an artifact, it predominantly serves the purpose of gaining mastery in their sensory-motor development, whereas children in the next developmental stage can build something out of smaller objects, while being guided in their playful engagement by their own imaginative associations. (See Chapter 1.4.1 - Play, p. 21)

Artefact The design of artefacts that intend to teach something about the arts by means of children's playful and creative engagement should therefore should therefore align with the particular bandwidth of developmental stages these designs intend to address. The parameters for teaching a particular artistic topic are best to be found in the understanding of the design as an interrelated set of components, where the manners in which a particular (advanced) expression is created, serves as the main mechanism for tuition. Examples of such tuition mechanisms can be found in Chapter 2.

1.3.2 *Timeframe for the consolidation of Insights in Long-Term Memory*



Learning is understood in this work as a process that leads the consolidation of experiences in Long-Term Memory. In order to understand how this process operates during a learner's creative engagement with the proposed digital interface, I have developed an explanation about the way creativity functions as a learning mechanism on the basis of the available literature in the cognitive and neurosciences. The timeframe that is shown in the above figure reflects the key components of this particular learning process. The central idea is that a creative activity shapes the cognitive and affective conditions that allow for insights to emerge in the learner about tasks in which he is engaged. These follow a process of formation and consolidation, which is followed by a possible emergence of conceptual knowledge that allows the learner to elaborate on his findings by creating a consistent narrative, or a repertoire, that reflects the concept he has in mind.

The durations mentioned in the timeline are there to indicate when certain behaviours can be reasonably expected. These interative steps of formation, consolidation, and the resulting behavioural changes, do not correlate to the time that a learner spends behind a digital interface. They correspond to the learner's initiation of a (subjective) problem-solving task and how his behaviour changes in regard to that particular task: a learner might be working on several tasks during his time spent with the interface.

This timeframe figure is repeatedly shown throughout this work in the relevant chapters and sections with the aim of guiding the reader through the work: what happens when in relation to this frame, and how is this relevant as a Design Specification for the development of the proposed interface. The particular section that is being discussed is indicated with a red dotted line under the timeline. The black frame that encapsulates the timeframe figure indicates that there are some important discussion points in regard to the design of the proposed interface.

1.4 METHODS

The literature review about Play and Creativity in Chapter 1.5 have been spun around the question on how they serve the purpose of learning. During the gestation of the subchapter about Play, I have learned that the play behaviour of children changes over the timespan that they grow up, addressing different purposes in the development of a child towards adulthood. I used this notion to focus the literature review towards what reasonably can be expected in terms of learning and creative expression from a child in different age groups. The subchapter about Creativity is strongly focused towards uncovering the requirements that are necessary for an educational installation design to be successful in supporting creativity as a learning mechanism, and touches on all the aspects that could potentially produce a satisfying learning outcome in arts education. Hence, the article "Musical Creativity and the Brain" from Lopez-Gonzalez & Limb (2012) has been used as the basic framework for this literature review.

The review of educational installation designs in Chapter 2 is centered around field researches in the "Brussels Children's Museum", the educational institution "Art Basics for Children" in Brussels, and the "Aristotle's House" (Huis van Aristoteles) in Amsterdam. These field researches were organised as incidental ethnographies (Pinsky, 2015). This is a research method that accommodates and derives knowledge from observations and interviews taken from the full range of encounters between the researcher and participant. This was also necessary, because with each of the visits that were planned, it wasn't at all sure who I would have a conversation with and what exactly the topic would be. My first series of visits were to the "Brussels Children's Museum". I managed to make an appointment with one of the head designers of the educational installations, who then guided me around in the late evening (when there weren't any visitors in the museum) and discussed the learning aims and design features of their installations. The next morning I was allowed to observe a class of primary school children (average age of 7 years) to learn how they used the installations. In a later time, I went to the "Arts Basics of Children" institution. When I called to make an appointment with them, they asked me to come to their open day. The institution was filled with children and their parents on that day and gave me plenty of opportunity to make observations about how children of very different age groups were interacting with their educational installations. In the midst of this business I did manage to get hold of one of the installation designers, who then discussed the design features and play outcomes of the installations that she conceived. They also told me that they organise workshops for primary schools, and invited me to soundscape workshop that they were going to run in the next couple of days. Here, they allowed me to observe how the children were attending this workshop. The "Aristotle's House" was the last of my field research trips. Just like with the "Arts Basics of Children" institution, I was asked to come to one of their open days. Here, a former colleague of the arts education institution where I used to work, introduced me to their learning philosophies and how these materialized into their installation designs. Unfortunately, they weren't any school workshops being organised in that time period, so I wasn't able to conduct any thorough observation of children actively learning with these installations.

The outcomes of the literature review about Creativity in Chapter 1.5 are graphically depicted as the *"Cognitive Model for Learning through Creative Engagement with Artefacts"* at the start of Chapter 3. - "Implementing the Learning Theories into Designs that Teach". The inputs to this model, "*Manner*", "*Phase*", and "*Tool Identity*" have materialised into the play mechanisms around which the conceptual installation designs have been conceived. As the installation design forms the environment in which the learner uses the play mechanism, the subsequent cognitive processes depicted in this cognitive model gave direction to the type of features that the installation design would have.

1.5 THE LEARNER'S ENGAGEMENT WITH THE PROPOSED HCI TUITION MODEL

> *" A 5 year old boy was building a castle using Lego-bricks, and did so by following the instructions given by the construction manual. During the construction he also imagined himself being in the middle-ages, also addressing questions from his mother in the type of Dutch he envisioned they were talking in that time. A couple of days after he built the castle, his thoughts were fighting between the will to preserve it, or to create something new using the same Lego-bricks. In this tension, his need for creative expression won from his idea to keep it; be it that this was a very doubtful decision. The boy took the castle apart and reconstructed his new idea. He wasn't as happy with the end-result as that he was with the original castle, so he took his construction apart and tried to reinstate the original castle. This failed, and he went to his mother to ask for help. His mother has hidden the construction manual in order to let him seek for creative solutions to solve the problem. As upset as the boy was about this situation, he went to his room with the Lego-bricks, and started working really hard on a solution. Later on, he came back to his mother, looking really happy, presenting her a spherical object which he made from the bricks of the castle. The boy described the spherical object as a bomb, and illustrated this by smashing it with his fist."* - Observation by me of an acquaintance and her son in the summer of 2010

This observation depicts a process of how a child uses tangible objects in order to mediate a broad range of expressions: His aesthetic understanding of the middle-ages, demonstrating an indiscrimination of reality and his imagination as a form of pretend play. And, by using these Lego-bricks as a means to reflect on his emotional state, he finds an unintended use of these: He created an object which he can animate though kinaesthetic action. The actions of his mother seemed to have come from prior knowledge in how to teach creative problem solving to her child. Using little means, she designed an environment where this process of discovery could emerge. Not only did she hide the construction manual physically, but she responded with "I don't know" on any question where the child sought for a practical solution. This observation also shows that play is not just about casual fun, but also a process of discovery where the results of emotive and imaginative reflections are being communicated in a playful fashion. This chapter discusses the operational context in which a child engages with a digital interface that is based on the proposed HCI tuition mechanisms.

Defining and distinguishing between Play and Creativity

Whether a child engages with such HCI mechanisms in a playful or creative manner depends on several developmental factors within the child and the incentives that are given from the environment. The terms Play, Creativity are often used without clear knowledge of their functionality and identified through their ostensives. Play is often associated with the appearance of certain moods and behaviors, like enjoyment, ideaful, imaginative, pro-active, inventiveness and role-play (Rogers et al., 1998). However, the observation I described (beginning of chapter 1.4) shows that the choice to solve a problem through play is not always about enjoyment. Nor does it deal with certain dispositions of a personality that can be identified as playful. It did require guidance for playful behavior to emerge and the activities of the child that I observed also reflect a process of emotional regulation. Furthermore, creativity has often been identified by judging the originality and appropriateness of the resulting product from a creative activity, while being set out against the dispositions in an individual's character. This has led to associations suggesting that the ability to be creative is a certain talent, requiring certain personality traits. (Kasof, 1999). Play and creativity are traits that are also observed in other mammals. Creative activities don't have a big influence in their lives (Heilman, 2005, p. xii), where the quality of the playful activities are often deciding for their well-being (Brown & Vaughan, 2009; Pellis & Pellis, 2009). These observations alone suggest that these traits represent functionalities that have a beneficial evolutionary purpose. From the data that describe Play and Creativity on this functional level, it can be said that they represent two different *modes of learning that a learner* can engage in, depending on the situation he finds himself in:

1.5.1 *Play*

Discussion points in regard to HCI design:

Different age groups engage with materials with learning goals that are motivated by the different developmental stages of the human brain. This chapter discusses how play behaviour is motivated, and looks at three distinct stages of object play (Functional, Constructive and Creative) in order to explain:

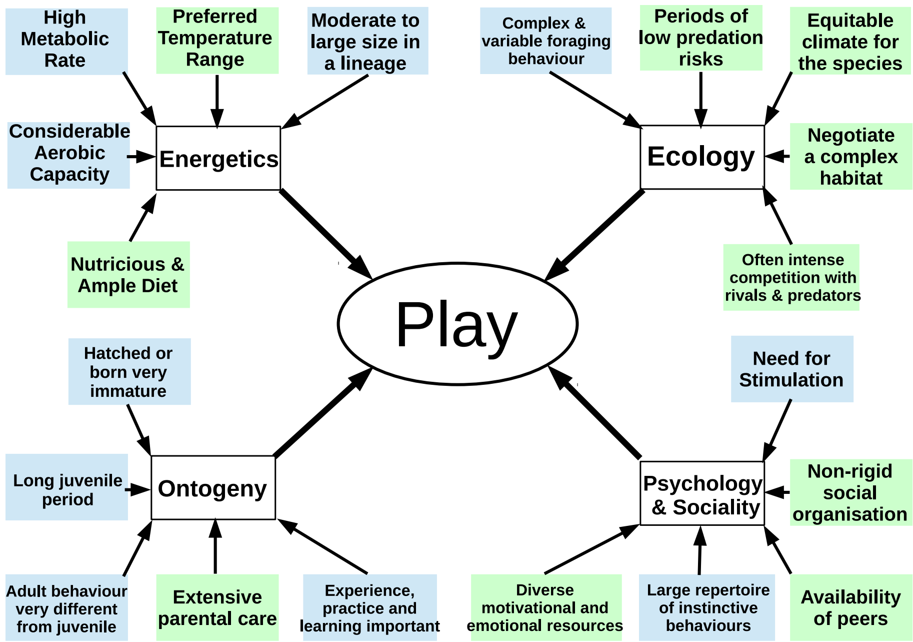
- Play as a learning behaviour that is tied to the various stages of a child's development.
- What kind of playful learning outcomes can be reasonably expected for a certain age group.
- What kind of means and materials can facilitate these learning behaviours.

Play is an activity that is performed by all sorts of human and non-human animals and is defined by its experimental nature. It's an engagement with the environment where a flexibility of different views are being expressed by an individual in a non-serious manner. This flexibility is a product of self-exploration: relatively novel or uncertain stimuli in safe environments provide incentives for individuals to acquaint themselves with their surroundings, in the light of their set of biological, mental (cognitive propensities and prior knowledge) and physiological (Prellwitz & Skar, 2007) abilities. These engagements reflect the questions of "*what can I do with the objects in my surroundings?*" and *"how do I relate to others?"* and help to construct a *working knowledge* of the environment. In nature, this working knowledge is demonstrated in skill sets that are needed for survival and reproduction. This is especially true for animals whose ecology is varied and unstable. In social, human environments, social play aids to the development of emotional stability and well-being of a person and object play aids to the development of problem solving skills in tool use.

From a developmental perspective, play takes the form of a developmental scaffolding: a building framework where adult behavior, and the skills and experiences needed in adulthood are constructed through playful engagements. The metaphor of a scaffolding also describes the nature of this development: playful engagements are much less prevalent when the behaviors and skills are acquired.

There are several conditions that need to be met in order for individuals to perceive the stimuli in the environment as incentives for play. Burghardt (2005, p. 172) developed the Surplus Resource Theory model (See Figure 5) in which he sets out the conditions of the environment, depending on the behavioral, physiological and mental traits of the individual. These conditions deal with the availability of the following set of resources: aside from the earlier mentioned safe environment that convey a variety of novel stimuli, this environment also requires a social structure that encompasses a non-rigid social organization, availability of peers, diverse motivational and emotional resources and parental care. However, these depend on several factors in the individual: he must be energetic, youthful, must be buffered from stressful situations, is susceptible to boredom and has a lifestyle involving complex tasks in varied conditions (diverse, unpredictable environmental and/or social resources). As the name "Surplus Resource Theory" implies, play occurs when an excess of resources are available to the individual. The incentives to play are significantly reduced when individuals are under conditions of stress, such as the lack of food, extreme temperatures or other unfavourable elements or behaviors in the environment. (Pellegrini et al., 2007; Bateson, 2005; Brown & Vaughan, 2009; Gorlitz et al., 1987)[2]

2 I have developed each statement in this definition of play on the combined views of each of these authors. Each of these views have been weighed on their likelihood and paraphrased to ensure clarity of this definition.



- Blue : factors dealing with the traits of the individual
- Green: resources afforded by the surroundings of the individual

Figure 3: The Surplus Resource Theory Model (Burghardt, 2005)

Object play

There is a model of the human brain which names and maps the functions and the information processing capabilities to the regions of the brain where they occur: the anatomical charts of the brain you can find on the internet or the plastic model you can buy in the stores. However, this model represents the physiology and processes of an *adult* brain. The structural development of the human brain is not completed during pregnancy or right after birth. It takes about 20 years for the brain to reach its full mass, even though after birth an overabundance of neurons and their connections (synapses) is produced reaching a similar total amount compared to the adult brain (Pena-Melian, 2000). There is a production curve of synapses that peaks in overproduction (roughly double the amount of what is found in the adult brain) after which it prunes back into the amount of the adult brain. This peak occurs at a different age of the child *per region of the brain*: during the first year of life in the primary visual cortex and at the age of 5 in the regions of the brain that deal with problem solving (the frontal cortices). Another important aspect of the brain's development is *brain plasticity*. New brain structures and functions build upon the earlier developed ones. The development of each new structure is triggered by genetic cues, but also requires input from the environment (Stiles, 2008; de Graaf-Peters & Hadders-Algra, 2006). These findings correlate with Piaget's (1953b) model of developmental stages, depicting four iterative cognitive skill levels that reflect this triggering by genetic cues. For example, In terms of logical problem solving he concluded that around 7 years of age a major transition in thinking occurs where children can *reliably* structure two pieces of information in a logical manner (Siegal, 2003). In terms of the relationship between the genetic cues and lack of input from the environment, Oliver Sacks (1989)' study into the cognition of pre-lingual deaf children shows that a child is not born with an innate ability for verbal language. Since the sensory modality for hearing is missing from birth on, the brain region that would be the primary auditory cortex in normal children has been recruited by the brain to perform visual tasks. Environmental stimuli play a very important role in the development of the brain structure: an environment that is depleted from a variety of activities, novel stimuli and social interactions shows a significantly lower synapse production curve compared to that of a rich environment (Howard-Jones, 2009, p. 26).

Play is often signified as an activity reflecting "apparent purposelessness" by observers (Brown & Vaughan, 2009), but the act of play can be seen as a *functional learning mechanism that is intrinsically motivated by the developing brain*. Each time a genetic cue is given for a brain region to develop, it can be seen as reflecting the question of "what am I for?" and sequentially, interacts with its sensory modalities, with the rest of the brain by producing an overabundance of connections, and then with the environment by seeking novel stimuli, interactions and activities. Also, the flexibility of different views that is being expressed in the act of engagement with the environment could be seen as a projection of this overabundance of connections.

This functional aspect of play can be enforced by looking at the types of play most commonly observed by researchers (Smith & Pellegrini, 2008; Brown & Vaughan, 2009) in relation to the cognitive traits that are being expressed in these play activities, and comparing these with the behaviors that reflect play-types and traits as they are found in other species (Burghardt, 2005). The brain can be seen as a collection of functions that it has inherited from other species of which humans share common ancestors in the evolutionary timeline. This model of the brain is called the Triune brain (MacLean, 1990; Cory & Gardner Jr, 2002). According to this model, the human brain can be divided into a reptilian brain, mammalian brain, and a neo-cortex (or primate brain) and can be used to compare the play activities of humans with those of other species. Using this integrative framework for the investigation of play functions, I have classified the types of play as having archetypes of which each archetype has its own set of subtypes. These subtypes depict the developmental stages of the various cognitive traits which iterate from the brain regions that develop in time. This chapter discusses the object play archetype, but there is also the social play archetype. This archetype is discussed by Pellis & Pellis (2009) using a similar framework.

The object play archetype consists of *functional, constructive and creative* play subtypes. Each of these subtypes touch on different learning needs in the development of a child. Therefore, it is not always straightforward to understand what part of the activity is the intended play-scheme the child has in mind. Pellegrini & Gustafson (2005) state that play with objects is a conceptually distinct type of interaction when compared to exploration and tool use. Where explorative behavior reflects the question of "what it is", play behavior reflects the question of "What can I do with it?". Furthermore, play is more means oriented when compared to exploration and tool use.

functional play activities are most common among toddlers and holds an ambiguity between explorative and play behavior. It's a mode of learning where children practice, explore, repeat or experiment with previously developed skills in a repetitive manner such as walking, climbing, running, building or turning the pages of a book. This repetition appears to help toddlers begin to differentiate their own actions from that of an object (Seefeldt & Barbour, 1987). During functional play, objects are being addressed in an explorative manner and the play behavior helps the toddles to gain mastery in their sensorimotor development (Pellegrini & Gustafson, 2005).

constructive play is a goal-oriented mode of learning in which children develop a working knowledge about the various uses of play materials by creating or building something. It involves open-ended exploration, gradually becoming more functional in nature, evolving to a signification process using imaginative associations (make-belief transformations). Examples of constructive play are: building a road or castle with wooden blocks, shaping a ball out of clay or constructing a spaceship with recycled materials. There are playful interactions throughout each of these stages. Even when the play objects are used as a tool or to build a tool, it serves the purpose for mediating playful, imaginative associations. However, Pellegrini & Gustafson (2005) state that play behavior in children becomes limited when external goals are set into the play-scheme by educations. (Drew et al., 2008; Dansky, 1980; Pellegrini & Gustafson, 2005).

creative play is often defined as an activity where imagination plays a strong role in the play-scheme the child has in mind (Gorlitz et al., 1987). Imagination allows people to envision simulated realities that are different from the reality an individual perceives *and is a product of the ability to structure internal narratives* (Brown & Vaughan, 2009, p. 86 - 94). Therefore, it can be seen as a mode of learning in which a working knowledge is being developed about the various relations between the internal narratives portraying simulated realities and the stimuli in the environment. But what kind of language (verbal or non-verbal) is involved in these internal narratives and what does verbal language add to the cognitive abilities in regard to envisioning these simulated realities?

This structuring of internal narratives requires *active episodic memory* (Hassabis et al., 2007a; Nelson, 1993), the ability for *temporal and causal sequencing* (Nelson, 1993; Siegal, 2003) and the ability to comprehend that an object in the environment can convey *multiple representations* (or meanings) (Siegal, 2003). For something to be imagined or to be actions from an individual that reflect make-belief transformations, on its most basic level it requires the ability to distinguish the appearance and the reality of an object. For example, milk in a red, transparent bottle may be red in *appearance*, but is white in *reality*. It also requires the ability to understand that there are objects that convey a symbolic meaning that can correspond to other objects in the environment. An object that conveys a symbolic meaning can for example be a maquette of a certain space, showing where various items can be found in that very space. After a child reaches the age of approximately 3 years old, it is understood by him that the maquette is a *model* that can be used to locate items in the space he's in (Siegal, 2003). Also around this age, the cognitive traits start to emerge that are needed to structure two separate pieces of information in a logical, causal or temporal manner (Nelson, 1993; Siegal, 2003, p. 202). Nelson (1993, p. 9) describes activities where toddlers talk to themselves when they are alone. In this self-talk they recall events from their episodic (autobiographical) memory and structure these in temporal and causal sequences. These self-talk activities show a resemblance with the functional play activities mentioned earlier. Recalls from episodic memory are characterized by being memories of novel, past experiences which are relevant to the "self-system" (Nelson, 1993, p. 8). How these recalls from episodic memory look like is best described by patients who suffer from epilepsy in the region of the brain that is involved with the recall and formation of episodic memories (the Medial Temporal Lobe). Their epilepsies cause "experiential hallucinations" which are called "dreamy states". These hallucinations depict scenes which are based on the past memories of these patients: being in the countryside during childhood, reliving a parachute jump, performing on stage with an audience watching you. They are not merely visual, but multimodal in their nature, also consisting of thoughts and feelings. (Vignal et al., 2007). Both recollecting past memories and imagining new fictitious experiences involve the process of constructing scenes from memory. They are not simple holistic recalls, but depend on a sense of subjective time that binds different, distinct elements into a coherent whole. They make use of the same "self-schema" (the ideas and beliefs an individual has about himself) and therefore depend on the same network of regions in the brain [3] that are being recruited for the recollection and imagination of experiences. (Hassabis et al., 2007a,b)

The issue of verbal language in internal narratives is best depicted by Oliver Sacks' (1989, p. 37 - 51) study of the intelligence in prelingual deaf children (children that are born deaf) . He describes the

3 These are the hippocampus that recruits from the, parahippocampal gyrus, retrosplenial cortices, posterior parietial cortices and the ventromedial prefrontal cortex.

cognitive development of several of such children. In each of these cases there was a deprivation from social interaction among peers and with their parents until they went to school, which only happened in their early teenage years. Dautenhahn (2002) argues that narrative capacities develop from pre-verbal, narrative, transactional format that children get engaged in with their parents and peers. Sacks (1989) describes that pre-lingual deaf children in general have a problem with understanding the transactional concept of a question: it's a language form that is hard to convey in a non-verbal manner. The children he described were fully deprived from language. They only had the ability to communicate perceptual phenomena using drawings and pantomime and were unable to form abstract concepts (original mental models?). The example given in the last paragraph (a maquette of a certain space which can be used as a map for that space) depicts a *perceptual understanding* of symbolic representation. But it requires tuition in order for a child to conceive a *conceptual understanding* of a symbolic representation: a model of a tree can not only be a symbolic representation of an actual tree, but can also be an *abstract concept* upon which various sorts of information can be organized. Sacks (1989) proceeds to describe that the tuition of words holds the key to the development of abstract conceptual thinking. Words do not only reflect a sensation or perception of a single object, but also refer to generalizations: to a group or a class of objects (Vygotsky et al., 1962).

In the world of the hearing, children acquire words through observation and a mix of non-verbal cues and verbal transaction. Before children begin to acquire words they have formed concepts of the world. Children search for ways to communicate what they know, therefore their first words are likely to express those early concepts (Kuczaj & Hill, 2003). Their concepts are shaped by *initial mental models* that lends consistency to their beliefs and conceptions and grow to *mature, culturally received mental models* through the child's interaction with peers, parents, educators and other individuals of authority in the culture they live in. Siegal illustrates these initial mental models by providing a comparison between conceptions of the shape of the earth conceived by children from 4 - 6 years old in the U.S.A, and in Australia. Most 4 year olds responded positive on the questions whether the earth was round, but argumented this with the shape of a pancake rather than a sphere. With the 5 and 6 year olds, this became progressively less. The children in Australia are more likely to respond with a sphere, most likely because a lot of Australians have family in the northern hemisphere. (Vosniadou, 1994; Siegal, 2003).

Language in internal narratives doesn't necessarily need to be verbal, but can be other symbol sets like gestures or abstract visual representations that can convey a *word meaning*. The difference between language and internal narratives lies in the transactional component: mental models and narratives can be communicated among peers. According to Joseph, one of the pre-lingual deaf children in Sacks (1989)'s study: "language opens new perspectives, has the ability to transform experiences and enables a child to enter a symbolic world of past and present, far-away places, idealistic or hypothetical events. An individual changes through the acquisition of language: it can do new things or old things in a new way. Language enables to manipulate objects, concepts and causation in our mind."

Figure 4: Children playing with LEGO-bricks in the cantine of the Netherlands Architecture Institute. What is shown are the end results of a constructive play process. The artefacts are externalizations of how these children perceived the exhibition prior to their play-activities in the cantine. They all mimic skyscrapers in a specific manner: most of these artefacts are slightly taller than the children who designed them. Therefore, it might be the case that these artefacts convey an emotive impression based on how they experienced the exhibition.

1.5.2 *Creativity*

A learner's creativity can be used as a learning mechanism if an educational installation design explicitly addresses a learner's drive for creative engagement. Central to the discussion of a learner's creative engagement with educational designs are two cognitive-behavioral processes and their brain mechanisms relevant to the formation of the cognitive conditions that lead to the moments of insight . One is called *'Deliberate Emotional'* creativity. Central to this cognitive-behavioral process lies the moment of *perceptual insight*. This not only refers to a 'Aha' moment: a process where an individual is confronted with an ambiguous problem in their perception after which a sudden realization of the solution may happen, either spontaneously or induced by an external cue, and typically associated with a positive emotion. But it also refers to a mechanism for learning from single events that underpins this experience. In daily life, information that results from moments of insight is, almost by definition, incorporated into long-term memory: the realization of a new way to solve a problem, or to perform a task better and faster, is an insight that is not easily forgotten (Ludmer et al., 2011; Lopez-Gonzalez & Limb, 2012). *'Spontaneous Cognitive'* creativity, refers to a moment of insight that occurs during *cognitive* problem-solving. It is also known as the *'eureka'* moment, occurring after an impasse in the problem-solving process. This impasse is caused by a fixation in a person's thinking where he's guided by his past experiences without looking beyond his repertoire of assumptions with which he's engaged in this process (Bierly et al., 2009). In terms of the formation of the conditions that lead up to a *'eureka'* moment, it is shown that (induced) positive affect (a seemingly mild increase in positive feeling that are being brought about by common place, everyday events), decreases such *'functional fixedness'* in problem solving (Estrada et al., 1997; Ashby et al., 1999). The neurochemical Dopamine plays an important role in the expression of creative behavior in general (Runco, 2007, p. 91), and is of central importance in these cognitive-behavioral processes. It is proposed by Ashby et al. (1999) that Dopamine mediates the cognitive effects of pleasant feelings, and is regulated by the Dopaminergic system, forming a loop between the part of the brain that is involved in motor-emotional acting (forebrain) and the region that is involved in the planning and organization of actions (dorso-lateral prefrontal cortex ; Ballard et al., 2011). This system becomes active in anticipation of a reward (Schultz, 2002), strengthening the neural pathways that result in a flexibility in the planning and organization of actions (Takeuchi et al., 2010). Greenfield (2008, p. 288) views this reward as fulfillment that is informed by self-relevance and self-realization. What makes such an activity a mode of learning is because dopamine enhances synaptic plasticity, and therefore the consolidation of reward relevant experiences, in the region that is involved in encoding long-term memories (the hippocampus) (Howard-Jones et al., 2010; Wittmann et al., 2005). Furthermore, when looking at the *connections* between the brain regions outside of those directly involved in the prior mentioned cognitive-behavioral processes, the aspect of understanding the meaning of presented stimuli or imagined concepts comes to the surface. Takeuchi et al. (2010) measured the overall integrity of the connections in the brain of students using MRI. Prior to scanning, they participated in a test that measured their skill in, e.g. listing unique ways of using typical objects and finding desirable functions for such objects. One of the structures that has been found of importance in creativity is the corpus callosum, a set of connections that plays an important role in thinking about the meaning of events. Patients who lack this connection demonstrate a deficit in the comprehension of narrative humour (birth deficit) or the ability to integrate observations into a narrative (lesion) (Moore et al., 2009).

When looking at these neurological activities, it could be argued that a learner's creative activity could form a template upon which they're able to construct a pathway towards the knowledge being taught using an educational installation design. To use this pathway as an analogy, each step on this pathway then represents a moment where a piece of knowledge has been learned that is inclusive of the manner in which the learner relates to the topic that is being taught.

Creativity is often defined as the ability to produce work that is both novel (i.e. original, unexpected) and appropriate (i.e. useful, adaptive concerning task constraints) (Sternberg, 1999) and can be viewed as a behavioral process that is associated with topics in literature such as intuition, expert knowledge, problem-solving, achievement and case studies of exceptional accomplishment (Lopez-Gonzalez & Limb, 2012). Therefore, creativity encompasses a spectrum of behaviours ranging from cognitive/analytical to emotional/artistic behavioral domains (Jung et al., 2010a). An example of cognitive/analytical creative behavior is for example Hawking's thinking process that led to the conception of the Big Bang theory. In this thinking process, he shaped this result by mentally rearranging a variety of concepts in physics[4]. The other end of the spectrum can be viewed as improvisation. An example of such an activity is are the performances of Jazz artists. Their view of improvisation refers to the moment at which the artist employs immediate, spontaneous decision-making as new ideas are being conceived and integrated into a evolving musical output. As a cognitive process, such improvisation can be defined as the spontaneous generation, selection and execution of novel auditory-motor sequences (Lopez-Gonzalez & Limb, 2012). Creativity is therefore a complex cognitive function that cannot simply be "localized" to a specific region or structure in the brain that governs such behaviors (Jung et al., 2010b). It requires diverse cognitive abilities, such as working memory, sustained attention, cognitive flexibility, and fluency in the generation of ideas and in the judgment of propriety (Takeuchi et al., 2010). Yet, there are generalizations that point to the *functional* aspects of creative behaviours, such as the ability to break conventional or obvious patterns of thinking to adopt new and higher-order rules (Takeuchi et al., 2010) and the drive to generate ideas (Flaherty, 2005). Another generalization is the correlation between specific traits in an individual's personality and their disposition to be creative, such as '*Openness to Experience*' (Jung et al., 2010a), a personality trait that is specified in the NEO Personality Inventory, involving active imagination, aesthetic sensitivity, attentiveness to inner feelings, preference for variety, and intellectual curiosity (Costa & McCrae, 1992). This trait is speculated to correlate with another functional aspect of creativity: brain regions that are involved in internally focused tasks such as autobiographical memory retrieval, envisioning the future and taking the perspective of others, are more active compared to individuals that are less creative (Takeuchi et al., 2011, ; See Chapter 2.1 - Supporting Epistemic actions during Creative engagement).

There are also psychometric approaches to creativity. These methods originated in parallel with the development of intelligence tests and have become as pluriform as the diversity of philosophical and empirical perspectives of the researchers conducting investigations in creativity. Nearing the end of the 20th century psychometric methods have been developed to, for example, measure the creativity of

4 Stephen Hawking's cognitive style is discussed in the BBC Horizon documentary 'The Hawking Paradox', 8:00 - 16.00 mins, first aired in the television season of 2005 - 2006.

products, investigate the environmental characteristics that are associated with creativity, and to refine measures of idea generation and evaluation (see p. 36 ; Plucker & Renzulli, 1999). Some of the studies that are being discussed in this chapter and chapter 2.1 make use of psychometric tests that are similar to the Torrance Creative Thinking Test. These tests are designed to evaluate creativity through divergent thinking and consists of three types of tasks:

(a) Improve a product (list ways to change a certain product so that it will have more desirable characteristics or generate unique ways of using typical objects).

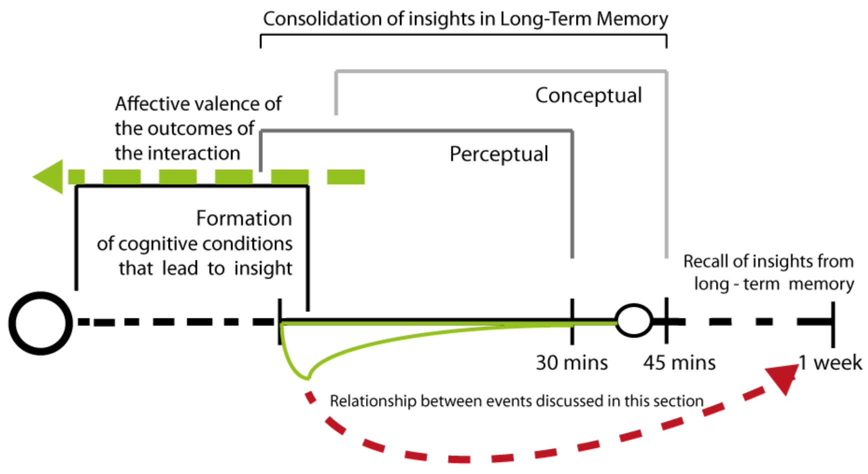
(b) Find interesting, unusual uses or desirable functions for ordinary object

(c) list all the consequences should an improbable situation occur.

These tasks result in a creativity score that encompasses four dimensions using which a creative process is delineated: *fluency* (measured by the number of relevant responses and is related to the ability to produce and consider many alternatives), *originality* (the ability to produce ideas that differ from those of others), *elaboration* (the ability to produce ideas in detail), and *flexibility* (the ability to produce responses from a wide perspective) (Takeuchi et al., 2011). However, in terms of creative activities in a learning environment, it is argued that *appropriateness* (the ability to produce something that has a self-relevant or self-related utility, which relies upon an individuals ability to focus critically upon it and refine it) should be taken into account as a fifth parameter to assess the quality of the learners creative output (Howard-Jones et al., 2002; Sharma & Rastogi, 2009). Because the focus of this study is on the interaction between a learner and the novel materials presented by digital interface, what will be further discussed are: those cognitive-behavioral processes that underpin a learner's creative engagement and elaboration, and their brain mechanisms relevant to the formation of the cognitive conditions that lead to the moments of insight that can be consolidated in long-term memory.

Lopez-Gonzalez & Limb (2012) have delineated four psychological processes that are embodied in creative behavior. These processes are based on the notion that mental images can be generated intentionally or spontaneously during the problem-solving process (Finke, 1996) and that either of these problem-solving modes can occur within a emotional or cognitive context (Dietrich, 2004). On one end of this spectrum there is *'Deliberate Cognitive'* creativity. This process can be viewed as one that is the least related to personality dispositions to be creative, such as 'Openness to Experience' and involves inventiveness that comes from *sustained work in a discipline*. Lopez-Gonzalez & Limb (2012) give an example of the photographer Eadweard Muybridge who experimented for years with multiple cameras and precision timing. Eventually, he created s string of negatives proving that all of a horse's hooves are indeed airborne at a certain point during a trot. And, on the other end of the spectrum there is *'Spontaneous Emotional'* creativity, which is usually referred to as an epiphany. Lopez-Gonzalez & Limb (2012) speculate that this type of creativity occurs when neural activity in the amygdala (a brain region that is involved in the emotional evaluation of a situation ; Kim et al., 2011) "is spontaneously represented in working memory". While no apparent knowledge is necessary, specific skills may be required for these insights to come to fruition. The other two processes are *'Deliberate Emotional'* and *'Spontaneous Cognitive'*. These processes will be elaborately discussed in chapters 1.5.2.1 and 1.5.2.2, because they indicate what the requirements for an installation design would be, in order to support a learner's creativity as a learning mechanism. This could then allow learners to learn about the topic that is embodied in this design and gain knowledge that is inclusive of the manner in which the learner relates to the topic.

1.5.2.1 *Deliberate Emotional*



Discussion points in regard to HCI design:

- How perceptual insight can be induced using an interface
- How a 'discovery game' can be developed that makes use of this mechanism to explain artist's interpretation of objects.

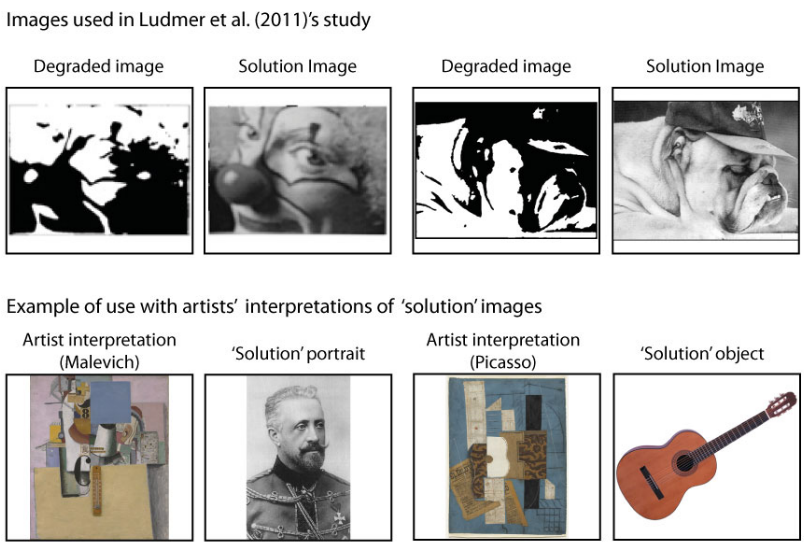
Central to this behavioural process lies the moment of *perceptual insight*. This refers to a process where an individual is confronted with a ambiguous problem in their perception after which a sudden realization of the solution may happen, either spontaneously or induced by an external cue, and is typically associated with a positive emotion. An example of such an activity is the 'Where's Waldo?' game. The purpose of this game is to find a character called 'Waldo' in a book that consists of illustrations depicting dozens or more people doing a variety of amusing activities. The challenge is to find 'Waldo' among the other characters. He can be distinguished by his red-and-white striped shirt, bobble hat, and glasses, but many illustrations make use of red-and-white striped objects in a deceptive or misleading manner (Duckett, 1997). The identification of 'Waldo' in this context is typically referred to as the 'Aha!' moment. Not only does Deliberate Emotional creativity refers to this experience, but also to a mechanism for learning from single events that underpins this experience. In daily life, information that results from moments of insight is, almost by definition, incorporated into long-term memory. This is not only the case for *perceptual* problem solving, but also for *conceptual* problem solving (see 'Spontaneous Cognitive' creativity): the realization of a new way to solve a problem, or to perform a task better and faster, is an insight that is not easily forgotten. Other forms of learning, such as sensory and perceptual learning (e.g. distinguishing musical tones or seeing relations among chess pieces), motor learning (e.g. playing the piano) and rote-learning (learning by repetition) in animals require long training periods and many repeated trials. These timescales correlate with the idea that incorporation of new knowledge into long-term memory involves synaptic modification that require gradual processes, sometimes over weeks or months (e.g. Dudai, 2004). (Ludmer et al., 2011; Lopez-Gonzalez & Limb, 2012)

The neuronal mechanisms that underlie learning of new knowledge from such one-shot experiences was investigated by Ludmer et al. (2011). Their study investigated the moment of *induced* perceptual insight by looking at the encoding of such an insight in long-term memory. Induced insight refers to the availability of external cues, such as the presentation of hints for a brief amount of time, during the activity. The design of the study involved the investigation of participants in two sessions: a fMRI session where the brain activity of the participants is being recorded during their engagement in an activity that can lead to induced perceptual insight, and a recall session (one week later) that tested the memory of the discovered insights. During the fMRI session, participants were presented a succession of images while undergoing an fMRI scan: one degraded image of a real-world scene that was hard to recognise ('camouflage'), followed by brief exposures of a series of original ('solution') images, which led to '*induced insight*' ('aha!'). As a learning *experience*, many participants report that the perceptual transition that occurs because of their moment of insight was rather dramatic: what once was a meaningless collection of ink blots has become a compelling depiction of the underlying scene.

Upon review of the data from the recall session, Ludmer et al. (2011) found that not all insights were recalled. However, they found that the recall of a 'solution' from long-term memory (within the time span of one week) could be reliably correlated to the activation of the amygdala during the moment of induced perceptual insight. This brain region is involved in conjunction with the medial Prefrontal Cortex (mPFC; involved in internally cued self-referential mental activity Gusnard et al., 2001) in the emotional evaluation of an experience (Kim et al., 2011), and therefore the encoding of such experiences of insight in long-term memory on the basis of emotional relevancy.

Implementation of induced insight as an HCI mechanism:

The following set of images aim to demonstrate how the imaginative perceptual views from Malevich and Picasso can be explained using the mechanism used in Ludmer et al. (2011)'s study of showing the degraded image, then switching back and forth to the solution image (this could possibly be left to the decision of the learner).



The lower set of images depict the artists' interpretation of the perception of objects and persons in their environment. These interpretations are collages where they experimented with different compositions of the physical components and the cultural uses that surrounds them, while still being the image they were referring to. The first collage is made by Malevich (1914) and is called "Soldier of the First Division". It contains all sorts of shapes and symbols that were typically associated with a Russian soldier at that time. He masked the area where the head would be with a blue square. The second collage is made by Picasso (1913), and uses the same notion to refer to a classical guitar. Both of these images also depict the sort of aesthetic decisions these artists made throughout their repertoire. This could possibly speak to the preference judgements that are made by the learner during their interaction with these images.

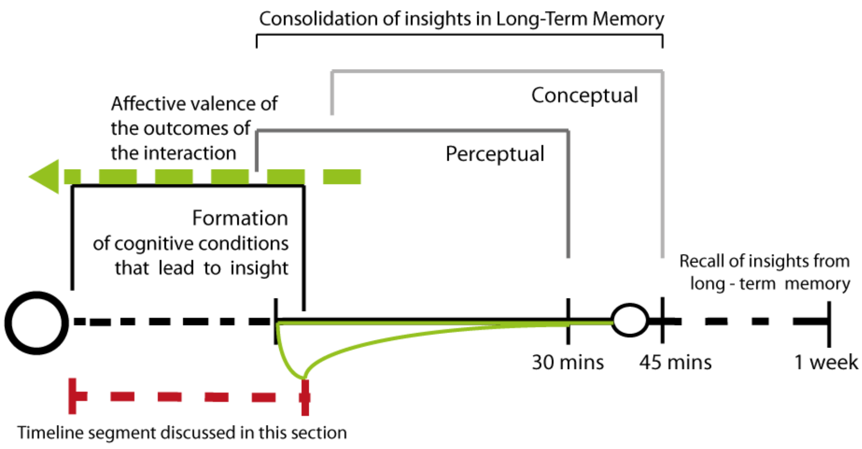
1.5.2.2 *Spontaneous Cognitive*

Similar to 'Deliberate Emotional' creativity, this refers a moment of insight that occurs during *cognitive* problem-solving. It is also known as the '*eureka*' moment, occurring after an impasse in the problem-solving process. This impasse is caused by a fixation in a person's thinking where he's guided by his past experiences without looking beyond his repertoire of assumptions with which he's engaged in this process (Bierly et al., 2009). Ashby et al. (1999) have set out a framework that delineates how *positive affect*, or moderate fluctuations thereof, can systematically influence cognitive processing. What is meant by positive affect in this context, is a seemingly mild increase in positive feeling that are being brought about by common place, everyday events. These can be events like receiving an unanticipated gift, watching a comedic film, reading funny cartoons or experience success on an ambiguous task. In terms of creative problem solving, positive affect both facilitates it, and leads to greater cognitive flexibility: a person's ability to organize ideas in multiple ways and access alternative cognitive perspectives. Also, it has shown that *induced* affect decreases the before mentioned '*functional fixedness*' in problem solving. Estrada et al. (1997) has demonstrated this in a study that recorded the time and the thinking (transcriptions of 'aloud thinking') of physicians, determining how soon the correct domain of the diagnosis was considered for a patient with a liver disease. The design of the study made use of a control group and an 'affect-induction' group, in which the physicians received a small packet of candy prior to the diagnosis. The results showed that this group integrated information earlier and showed less fixedness in determining the diagnosis. However, these kind of results depends on the situation of the problem solving activity: cognitive flexibility usually only increase when the situation is neutral or positive in emotional content, or at least minimally engaging or involving. Also, tasks do not necessarily need to reflect game-like or fun appearance. They can also be of a serious nature, such as coping with negative information. What is key is the relevancy or utility for the individual who is engaged in such a problem solving activity (Estrada et al., 1994).

The moment of insight that emerges in a situation of cognitive problem solving with induced positive affect also has a higher likelihood of being encoded in long-term memory. The Dopaminergic system, and the processing in the brain regions that the projection of dopamine alters, play a very important role in the *formation* and *consolidation* of such insights. First of all, it is proposed by Ashby et al. (1999) that Dopamine mediates the cognitive effects of pleasant feelings. The Amygdala, involved in the emotional evaluation of a situation (Kim et al., 2011), and the Anterior cingulate cortex, involved in the regulation of autonomous functions (e.g. Bush et al., 2000), project into the regions of the Dopaminergic system that produce dopamine[5]. These dopamine cells only fire for a few seconds in the presence of an unanticipated reward (Mirenowicz & Schultz, 1994), whereas the change in affect that is cause by giving an unexpected gift can last for 30 mins or longer. It is shown that dopamine release occurs long after the dopamine producing cells have stopped firing. It is furthermore demonstrated in a study (Floresco et al., 1998) that the stimulation of the basolateral amygdala for 10 seconds increases dopamine release for about 30 minutes. Such cell firing does not only occur in response to stimuli that signal reward, but can also occur to novel and startling stimuli.

5 The (basolateral) amygdala and the anterior cingulate cortex project directly into the nucleus accumbens, a region in the mesolimbic system that is involved in mediating the release of dopamine. On its turn, stimulating the substantia nigra, a region in the midbrain that consist of dopamine producing cells. (Ashby et al., 1999, p. 533-534).

Formation of the cognitive conditions that lead to Insight



Discussion points in regard to HCI design:

The cognitive conditions that lead to insights are:

- An increased associative flexibility in visuospatial working memory and ability to adopt new rules for engagement, which is motivated by the learner's situational interest; he finds something in his environment of personal significance (Krapp, 2002).
- Effortful behaviour, which is coded for in the involved brain regions on the basis of reward anticipation (Holroyd & Yeung, 2012), reflecting feelings of enjoyment, involvement and other positive affective qualities in the learner (Krapp, 2002).

These conditions and behaviours can be facilitated by an interface with the following properies:

- Emanates a purposely chosen balance between Novelty, Typicality and Surprisingness.
- Conveys a certain amount of Uncertainty.
- Provides a balance between Explorability and being Challenging to the user.

(Ciszentmihalyi & Hermanson, 1994; Naumann et al., 2008; Resnick et al., 2005)

How these properties materialize into an educational installation design and support creativity as a learning mechanism can be read in Chapter 3.1.2 "*Teaching Len Lye's Discovery Process for Novel Figures of Motion*", and Chapter 3.1.3 "*Teaching Matisse's Composition Process behind his Paper Cut-Outs*". The explanations and discussions about these interface designs indicate how the above-mentioned cognitive conditions allow learners gain to knowledge using their creative engagement that is inclusive of the manner in which the learner relates to the topic.

In terms of the *formation* of the cognitive conditions that lead to insight, projections of one dopamine producing region (ventral tegmental area) to the Prefrontal Cortex and Anterior Cingulate are the most significant: they provide a direct mechanism through which positive affect can influence cognition. In the Prefrontal Cortex, this projection *facilitates* the operation of spatial working memory. Dopamine alters the efficacy of the neurons in the PFC that are involved in spatial working memory tasks in terms of excitability and information flow. These neurons exhibit an 'inverted U' response to dopamine: too little or too much stimulation impairs cognitive performance (Vijayraghavan et al., 2007). This is compatible with the finding that moderate levels of positive affect may improve working memory, but extreme levels may disrupt it (e.g. Isen, 1999). Furthermore, dopamine enhances cognitive flexibility by strengthening subsets of the pathways (and suppressing the less active ones) between the region that releases dopamine (striatum) and the Prefrontal cortex. This is demonstrated in a study that made use of the Wisconsin Card Sorting Task. This task requires to establish and then shift the rules of engagement with the cards, or task-sets, that entail attending to one specific aspect of the information that is presented on the card. A group of participants whose dopamine was depleted using an administered drink prior to the task and a control group who were given a placebo, performed a computerized version of the task during a fMRI scanning session. Participants were presented with 4 reference cards, displaying one red triangle, two green stars, three yellow crosses and four blue circles. On each trial, a new test card was presented to the participant. They had to match the test card to one of the reference cards based on the color, shape and number of stimuli. After 6 consecutive correct responses, the matching rule changed, resulting in an incorrect match by the participant and therefore negative feedback. This negative feedback signalled a change in the rules of engagement (set shift). In this study, it is shown that the control group was able to establish the new rules of engagement faster compared to the depleted-dopamine group, and with less errors due to fixedness in their mode of engagement (Nagano-Saito et al., 2008).

It is said that the projection of dopamine to the Anterior Cingulate Cortex (ACC) is responsible for motivating the pursuit of hedonic (pleasurable) rewards by coding for promoting effortful behavior by coding for the average reward rate. Holroyd & Yeung (2012) further propose that the ACC supports the selection and maintenance of 'options' - extended context-specific sequences of behavior directed toward particular goals, of which its executive attention is influenced by affective states (Kanske & Kotz, 2011), and that are learned through a hierarchical process of 'reinforcement learning'[6]. Such options are defined by their associated *goal* states (for example, the supermarket or a restaurant) and the set of *initiation* states that trigger the option (hunger, access to a vehicle, etc ..). The transition between the initiation state and the goal state conveys a declarative layer that consist of simple, primitive actions: the individual steps that are needed to bring the hungry individual to a supermarket or restaurant. Such effortful behavior can therefore be seen as a result of other, affective functions that are mediated by the ACC. It is shown that the anterior parts (rostral) of the ACC[7] play a direct role in in mediating a number of affective processes, including the regulation of autonomic (e.g. heart rate, respiration, pain processing; Rainville et al. (1997)) and endocrine function (regulation of the hormone system), conditioned emotional learning, assessment of motivational content and the assignment of emotional valence to internal and external stimuli, and social interactions. Furthermore, electrical stimulation of this region of the ACC elicits emotional responses such as fear, sadness, anguish and euphoria (Ashby et al., 1999, p. 537). The ACC also has a cognitive subdivision[8] to which various functions have been ascribed, including the modulation of attention, motivation and anticipation of cognitively demanding tasks. It is further shown that positive affect has a lasting effect on later decision making (Bush et al., 2000) In this regard, the ACC is involved in the selection of cognitive perspective (Ashby et al., 1999). As a part of the distributed attentional network that includes the dorsolateral-prefrontal cortex (involved in working memory), in terms of cognitive control, the ACC has been linked to the regulation of emotional responses. It is shown that there is less activity in this region in individuals who have a difficulty in excerting cognitive control over emotional information (they are rated high in certain types of anxiety, such a anxious arousal and anxious apprehension) (Banich et al., 2009, p. 6). In relation to positive affect and the projection of

6 A process by which rewards and punishments adaptively modify behavior

7 This affective subdivision of the ACC is connected to the amygdala, periquaductal gyrus, nucleus accumbens, hypothalamus, anterior insula, hippocampus and orbitofrontal cortex, and has outflow in autonomic, visceromotor and endocrine systems (Bush et al., 2000).

8 The cognitive subdivision of the ACC is part of a distributed attentional network. It maintains strong reciprocal interconnections with areas in the lateral prefrontal cortex, parietal cortex, premotor and supplementary motor areas (Bush et al., 2000).

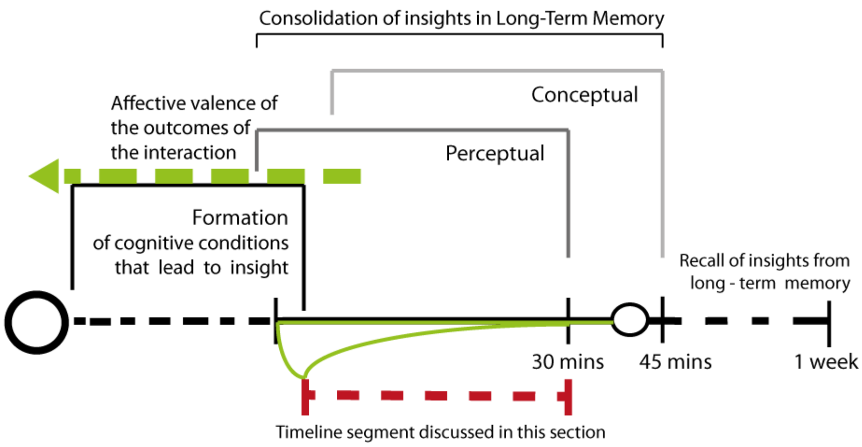
dopamine, it is proposed that dopamine supports the maintenance of a selected option by keeping information about its sub-goals in working memory (Holroyd & Yeung, 2012). Furthermore, in terms of flexibility among the maintenance of such options, it is shown in an experiment using rats[9] that the dorsal anterior cingulate cortex may enhance cognitive flexibility by decreasing interference of irrelevant stimuli when conditions require a shift in choice patterns (Ragozzino & Rozman, 2007).

In regard to the formation of the conditions that lead up to a '*eureka*' moment, new perspectives cannot be gained until the problem-solving task is temporarily removed from conscious awareness: searching in vain for novel solutions forces one in a mental gridlock. Seemingly unrelated activity for short periods of time that can promote positive affect, enable the Prefrontal cortex to connect information in novel ways via unconscious mental processing that is induced by the dopaminergic system (Lopez-Gonzalez & Limb, 2012).

Once a insight is formed, the knowledge that it represents in the learner is not the discovered solution, but also includes how the learner's physical and cognitive dispositions, abilities, and manner of engagemment with the activity has contributed to this solution. The development of insights could therefore be viewed as a learning element that is key to the discovery of their talents.

9 This experiment investigated the effect of muscimol injections, a psychoactive drug, into the rat's dorsal anterior cingulate on a 4-choice stimulus discrimination task with the aim of rendering this region inactive. This task consisted of reversal learning in a setting consisting of four cups that contain distinct odours. Reversal learning is a method to measure adaptations in the executive behaviors of animals according to changes in stimulus–*reward* contingencies (Albert & Moss, 1999, p. 9). In case of this experiment, one odor cup containing cereal was reinforced during acquisition, whereas a different cup with cereal was used during reversal learning. The other 2 cups were never associated with reinforcement. During reversal learning, dorsal anterior cingulate inactivation did not lead to perseveration but selectively increased errors to the odor cups that were never reinforced (Ragozzino & Rozman, 2007).

Requirements for the Consolidation of Insights in Long-Term Memory



Discussion points in regard to HCI design:

The process of consolidation of Insights in Long-Term Memory is governed by several of the following requirements:

- The learner's state of positive affect
- The richness of associated elements in which an insight emerged
- The self-relatedness of some of these elements in regard to the individual

A plausible outcome of the process of consolidation could be the further development of the learner's *working interest* in the presented materials, which could reflect in a further developed ability to envision meaningful goals in regard to the learning materials. In its turn, relating to his actual goals, and longer-lasting motives and values (Krapp, 2002).

As a Design Specification, it means that the design of the learning experience should be conceived as multimodal as possible in terms of the modes of engagement that the learner can address. For example, a typical computer interface only facilitates one mode of behaviour, regardless of whether the device makes use of keyboard or touch input, namely that of pressing buttons to achieve a certain goal. It is therefore feasible to inquiry how other types of behaviour can facilitate a learning process. An example of the use of whole-body interaction for the tuition of artistic concepts is shown in Figure 15. Furthermore, other modes of engagement are discussed throughout Chapter 2 of this dissertation.

In terms of the *consolidation* of such insights, dopamine also plays a very important role in the acquisition of novel information in long-term memory. Novelty detection involves the comparison of an existing memory with new sensory information. It is therefore proposed that the VTA (ventral tegmental area) and the hippocampus form a functional loop that detects novelty. This novelty signal would then gate behaviourally relevant information into long-term memory. Such memories are formed through the strengthening and weakening of synaptic connections in the hippocampus. Lemon & Manahan-Vaughan (2006) studied this acquisition of novel information by looking a specific subregion (CA1) of the Rat's hippocampus. It is shown that in this subregion, Long-term Potentiation (synaptic strengthening) [10] is facilitated through the exploration of novel spaces, whereas Long-term Depresssion (synaptic weakening) [11] is facilitated through the exploration of novel objects or familiar object in novel spatial configurations. The hippocampus serves a critical role in *declarative memory* (referring to all forms of conscious or explicit memory, including episodic, semantic and familiarity-based recognition), specifically in spatial and episodic memories (Burgess et al., 2002), and it is argued that this is supported by the processing of disparate elements of an experience. It is suggested that the hippocampus consolidates these memories by encoding associations among stimuli, actions and places that compose discrete events. It is known that in one region of the hippocampus (referred to as CA3) that the potentiation of synaptic connections is triggered by multiple projections to this region (afferents) coming from the cortical association areas (parts of the cerebral cortex that don't receive direct sensory input ; Brodal, 2010), of which this region of the hippocampus is connected to virtually all of them (Eichenbaum, 2004). These association areas are involved in higher level perceptual information about attended stimuli by receiving and integrating various types of information. Some regions integrate two or more sensory modalities, others integrate highly processed sensory information with information about intentions and goals. These areas also include the higher order cognition that occurs in the prefrontal cortex (Eichenbaum, 2004; Brodal, 2010, p. 500). Furthermore, the hippocampus is interconnected with other brain regions such as the amygdala. In terms of Episodic memory, i.e. memory for personally

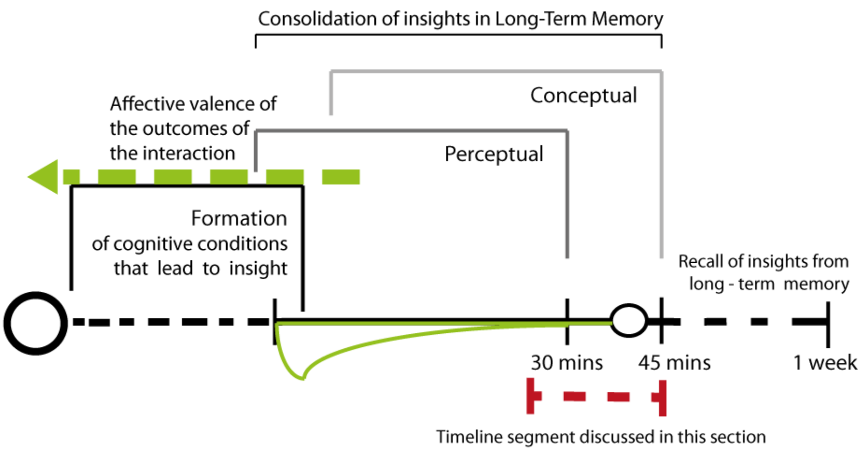
10 Long-term Potentiation (LTP) refers to a long-lasting enhancement in signal transmission between two neurons by stimulating them synchronously (Cooke & Bliss, 2006)

11 Long-term Depression (LTD) refers to the lasting decrease in synaptic effectiveness (Bear & Abraham, 1996). However, this is not the same as depotentiation, which is speculated to be induced by exposure to stress of the individual (Massey & Bashir, 2007; Diamond et al., 2005).

experienced events set in a spatio-temporal context (Tulving, 1984), it means that the hippocampus is more activated during encoding or retrieval of associations of many elements of a memory (a characteristic of content-rich episodic memories). For example, Davachi & Wagner (2002) compared the hippocampal activation in two learning tasks. Participants were given a triplet of words during a fMRI scanning session. They were asked to either learn this set of words using verbal rote rehearsal or to reorder the words in the triplet along the subjective dimension of "desirability", going from least to most desirable. The instructions that were given to the participants further emphasized that they should settle on their order only after considering the desirability of each item *in relation* to the other items in the triplet. Compared to the rote rehearsal of individual words, the activity of linking words to one other by systematic comparison of words showed more activity in the hippocampus. Furthermore, the magnitude of hippocampal activation during such relational processing predicted later success in recognition. Activation of the hippocampus during autobiographical memory retrieval also has been reported (Maguire, 2001). Addis et al. (2004) also found that the level of detail, personal significance and emotionality each contributed to the hippocampal activation of autobiographical memories. (Eichenbaum, 2004) As discussed in the chapter about 'Deliberate Emotional' creativity, the amygdala plays a key role in the relationship between memory and affect, which also receives a dopamine projection from the VTA (ventral tegmental area) and is reciprocally connected to the hippocampus. As Ludmer et al. (2011)'s study in perceptual insight demonstrated, plays the amygdala an important role in associating an affective state with a memory trace. Such tagging or marking could affect memory in two ways. First, traces with extreme affect states might be easier to recall, and second, the person's current affective state might serve as a cue that facilitates the recall of materials tagged with that state (Ashby et al., 1999).

Dopamine projection into the hippocampus also has shown to increase the release of the chemical 'acetylcholine' in the hippocampus, of which its normal functioning depends critically on this chemical (Imperato et al., 1993), and has shown to increase the magnitude of early Long-Term Potentiation of hippocampal synapses (in the CA1 subregion; Otmakhova & Lisman, 1996). When looking at the consolidation of insight, it can therefore be argued that this process is governed by an individual's state of positive affect, the richness of associated elements in which an insight emerged and the self-relatedness of some of these elements in regard to the individual.

1.5.2.3 *The emergence of Conceptual Knowledge*



Discussion points in regard to HCI design:

Conceptual knowledge is acquired gradually during learning, and is being formed by the decisions a learner makes on the basis of his newly acquired perceptual experiences. This is a notion that becomes particularly useful when trying to understand how certain types of interaction behaviours emerge during the time frame of the learner's engagement with the interface. The use of an installation for the production of stop motion animations (described in Chapter 2.2, Figure 7) illustrates what possibly could be expected:

- The Designers of this interface created flat, jointed figurines, which were being held together with elastic rubberbands.
- By means of play, the learners discovered that there figurines could demonstrate different modes of very agile motor coordination.
- On the basis of this perceptual insight, some of these learners decided to create narratives depicting concrete sports and dance activities: they have found a *concept* that allowed them to develop a consistent narrative using these figurines.

As a Design Specification, it means that an interface should be able to allow the learner to further elaborate the particular concept that he has in mind. This can take the form of supporting the learner's design of a narrative in connection to his discovered uses of the materials. From the perspective of learning through creative engagement, the acquisition of conceptual knowledge is key in setting the shape that the learner's pathway will follow in relating his physical and cognitive disposition, abilities and manner of engaging with the interface to the topic that has been embodied in an educational installation design.

The ability for humans to use concepts conveys the capacity to bring prior knowledge to bear in novel situations. Such concepts are formed through abstractions, and capture the shared meaning of similar entities through an organising principle that explains their relatedness. What this requires is a neural system that abstracts the commonalities across multiple related experiences, thereby creating a network of conceptual knowledge that captures the higher-order structure of the environment. Therefore, the hippocampus has been proposed (e.g. Eichenbaum, 2004) as a key player in the emergence of conceptual knowledge. Kumaran et al. (2009) have conducted a study that highlights the profound effect that (newly acquired) conceptual knowledge has on goal-directed behavior. They also demonstrated that a functionally coupled circuit involving the hippocampus, which supports conceptual learning through the networking of discrete memories, and the ventromedial prefrontal cortex (vmPFC), supporting valuation of concepts for decision-making purposes (e.g. Fellows & Farah, 2007), underpins the emergence of conceptual knowledge and its effect on choice behavior. In this study, three different stages can be identified regarding the learning of novel concepts and it's use in the participants' choice behavior. The first stage involves the identification of brain areas involved in memory for individual associative pairings (a learned correct response to a given pattern) in the given exercise, the second one involves the identification of regions involved in conceptual representations, and the third one involves the application of a learned schema (abstract conceptual representation of the task structure) in a new setting by the participant.

The design of this study consisted of two sessions, "Initial" and "New", where participants were given the task to learn to predict the weather (whether it's sunny or rainy) on the basis of a given "pattern" on the screen during fMRI scanning. These patterns were made up from pictures of fractals. This was chosen instead of real-life objects for the aim of the participant's process of learning of new concepts to be uncontaminated by previous experiences. Each of these sessions consisted of a series of tasks that entail the actual learning of the weather prediction activity, referred to as *'learning trials'*, and tasks that entail the measurement of the emergence of conceptual knowledge by the investigators, which are referred to as *'probe trials'* and *'debriefing protocol'*. In the learning and probe trials of both sessions, the participants were told to imagine themselves as a weather forecaster who has to predict if it will be sunny or rainy on the basis of a given pattern, which was said to represent constellations of stars in the night sky. Their task was to learn how each of eight given patterns predicted the weather. These patterns were created from two fractals out of a palette of four fractals, where four patterns were intended to be read on the placement (left or right) of one fractal in regard to the other, and another four on the combination of two fractals. Participants were not explicitly told about these spatial and non-spatial structures and had to acquire them through learning: successful performance required them to conceive associations between these symbols on the basis of shape-shape and shape-location conjunctions. During the learning trials, participants viewed a given pattern on the screen, entered a prediction (sun or rain), received feedback regarding correctness (correct/incorrect) and reward (win/lose money). The probe trials occurred after each learning block and assessed whether spatial or non-spatial conceptual knowledge was acquired. These trials did not involve feedback, but they were rewarded for correct predictions at the end of the experiment. Furthermore, after they entered their prediction, they were asked to provide a confidence rating (sure/not sure) about their answer. The patterns that were presented during the probe trials were partial patterns ("as if the sky was partially obscured by clouds"), requiring participants to generalize. The difference between the 'Initial" and "New" scanning sessions is the time duration, the "Initial" session lasting 45 minutes and the "New" session 15 minutes, and the only difference between the tasks in the sessions was that a new set of fractals was used. The purpose of this session was to inquire whether the participants were able to use the conceptual knowledge they have gained from the previous session in an environment that was perceptually novel, but has a similar underlying conceptual structure. After each scanning session there was a 'debriefing protocol' where participants were removed from the scanner and interviewed in order to evaluate the presence and nature of conceptual knowledge concerning the task structure. These interviews consisted of general questions, such as: '*How did you find that?*' and '*Can you say briefly what the task was about, and what you were using to predict the weather?*', but also specific questions, such as: '*What percentage of time were the following* (fractals) *associated with a sunny outcome?*'.

Kumaran et al. (2009) found that the following brain areas show a significant positive correlation with proficient performance during the *learning trials*: parahippocampal cortex[12], ventromedial prefrontal cortex (vmPFC)[13], posterior cingulate cortex (PCC)[14], ventral striatum[15], amygdala. Here, proficient performance is understood as the probability of success that is measured in time, and refers to the probability (chance) that a participant has entered either a right or wrong result for each consecutive block in the learning trial. Indices has been made per participant that reflect this data. An example index has been given of one participant's progress during the initial learning trial (Figure

12 The parahippocampal cortex (PHC) is a region in the medial temporal lobe that surrounds the hippocampus. The results of Kumaran et al. (2009)'s study depict that this region is involved in memory for individual associative parings. This region consists of the posterior part of the parahippocampal gyrus and the medial portion of the fusiform gyrus and has been implicated in the processing of place-related information and episodic memories, even if they're not related to unique places. Aminoff et al. (2007) therefore proposed that the PHC plays a more general role of processing contextual associations. Here, "context" does necessarily refer to background information, but to the relatedness of the individual stimuli that are being presented (they "co-occur" in a given situation, e.g. champagne and confetti) .

13 The vmPFC is a region that is involved in decision-making and plays a crucial role in value-based decision making under both certain and ambiguous conditions. This has been investigated by testing the ability for making consistent preference judgements in participants with vmPFC damage. Within the vmPFC lies the orbitofrontal cortex, which is said to be a region that is involved in encoding the value of stimuli in a flexible manner. Such values are not fixed features of stimuli, but are relative and context dependent. These can depict the attractiveness of a piece of pie, relative to a chocolate cake and a piece of fruit. But can also lie along different sorts of dimensions, for example the choice between eating chocolate cake or a stroll in the park. Another route for preference judgement relies on the autobiographical knowledge of a person's 'preference history'. However, it is argued that this route is not predominantly underpinned by activity in the vmPFC (Fellows & Farah, 2007).

14 The Posterior Cingulate Cortex (PCC) is a region that is part of the brain's Default Mode Network. This network is involved in internally focused tasks including autobiographical memory retrieval, envisioning the future and taking the perspective of others (Buckner et al., 2008, ; see Chapter 2.1 of this dissertation). Neuronal activity in the PCC is known to vary with learning, memory, reward and task engagement. Yet, the function of the PCC is not well understood. Pearson et al. (2011) propose that these modulations in the PCC reflect the underlying process of change detection, motivating subsequent shifts in behavior. Unexpected changes in the environment necessitate a shift in behavioral policy, forcing individuals to engage learning systems, switch mental states and shift attention, among other adjustments. Such a mechanism facilitates sudden changes in the possibility to obtain a reward. Examples can be a traffic jam that alters the time it takes to reach a destination, or a new road that has opened, offering the possibility of a shortcut. As a mechanism for learning, it doesn't necessarily contrast the standard model for Reinforcement Learning, which reflects a gradual change in behavior using punishment and reward. But, reinforcement learning can be viewed as a sub-process within such a change detection system.

15 The Ventral Striatum is a key region in the processing of reward value. In studies that made use of reward predicting stimuli, neuronal activity in this region reflected the coding of quantity and probability of reward. It is shown that this activity is relative to to the time that the actual reward is received, therefore reflecting a subjective, rather than a objective value of the reward (Gregorius-Pippas et al., 2009). The ventral striatum consists of the nucleus accumbens, olfactory tubercle, and the ventromedial parts of the caudate nucleus and the putamen (Martin, 2003, p. 393).

2A, p. 892, Kumaran et al., 2009). This index depicts the performance of the participant per block (correct/incorrect) and this data is also depicted as a probability chart of correct responses (between 0.0 and 1.0). This example suggests a seemingly random interaction by the participant in the first 8 blocks of the learning trial. It could be speculated that the learner shaped a conceptual picture that he got consistently wrong for 4 blocks , after which the participant demonstrated a consistently correct outcome for most of the blocks. The analysis of fMRI data on the ground of these learning trials, resulting in the positive correlation of the aforementioned brain areas, does not yet dissociate between the brain regions that are involved in memory for individual associative pairings (a learned correct response to a given pattern) and those supporting conceptual representations. In order to identify the circuitry specifically underpinning the emergence of conceptual knowledge and it's influence on choice behavior, Kumaran et al. (2009) further inquired the performance data on the probe trials. A similar plot has been made using this data, using which they sought to identify where neural activity on a given trial selectively tracked the emergence of conceptual knowledge. Here they found that neural activity within the left hippocampus[16], ventromedial prefrontal cortex, posterior cingulate cortex showed a robust positive correlation with performance in the probe trials. Furthermore, no significant activation was observed in the other areas identified in the learning trials, including the parahippocampal cortex, which is consistent with the notion that this region plays a greater role in memory for individual associative parings. Upon further investigation, on the basis that conceptual knowledge is acquired gradually during learning, that have found that the hippocampus and vmPFC (which are reciprocally connected

This essentially means that concepts are being formed upon acting on your experiences.

16 It appears that the left hippocampus is more involved in context-dependent episodic or autobiographical memory, whereas the right hippocampus appears particularly involved in memory for locations within an environment (Burgess et al., 2002). Kumaran & Maguire (2007) investigated the role that the hippocampus plays in novelty detection through its ability to act as a comparator between past and present experience. They designed a study where participants were asked to compare two series (1-back task) of a group of four consecutive images during an fMRI scanning for 140 trials long. Each image in such a group consisted of a photograph that was placed on an invisible 3x2 grid and were shown for one second each, followed by a fixation cross for 3 seconds. The participants were asked to press a button if a photograph repeated at the same sequence position in time or its location on the grid, when comparing the current series they were viewing with the prior one. In this study, they observed increased activity in the left hippocampus under conditions where one temporal or spatial contextual component was repeated and the other novel, and not when both components were novel. This demonstrates the role of the left hippocampus as a match-mismatch detector during the processing of associative novelty. On the other hand, activity in the right hippocampus reflect the presence of objects in familiar locations.

regions), act as a circuit during the acquisition and application of conceptual knowledge during decision-making.

Next, Kumaran et al. (2009) turned to the data acquired from the New session. Here they have found that the hippocampus underpins the use of conceptual knowledge as a guiding schema in perceptually novel situations. The task setting required the participants to transfer previously acquired knowledge into the new situation by representing prior knowledge in an abstract form. When looking at the behaviors of the participants, they demonstrated that their performance on this task was superior compared to their performance on the Initial session. However, there was no difference in motor-activity: the participants did not act faster compared to their response times in the Initial session. Furthermore, analysis of the fMRI data also depicted a difference between the anterior and posterior parts of the left hippocampus. When looking at the data from both sessions, they demonstrated that neural activity in the anterior region of the left hippocampus in the Initial session reflects schema formation, whereas activity in its posterior region reflects schema retrieval.

1.5.2.4 *Sensory-motor and Mentalization aspects*

The chapters about 'Deliberate Emotional' and 'Spontaneous Cognitive' creativity delineated several mental processes that specifically reside in the frontal and temporal regions of the brain. From the perspective that creativity involves the production of relevant responses from a wide perspective and to envision previously unresolved problems "in a new light", Takeuchi et al. (2010) set out to investigate the structural integrity of the white matter of brain in relation to the quality of the creative output of the participants in this study (see chapter 2.1 for the methodology). White matter refers to the white, fatty tissue within the brain that holds the neural pathways that connect the different brain regions, and 'structural integrity' refers to the quality of these connections . What the result of this study shows is that the neural pathways that show a significant correlation with creativity point to brain regions that play a role in:

- Mediating the thinking about the meaning of events
- Making sense of perceptual ambiguity in connection to the actions of others
- Understanding manmade objects in relation to the actions involved in their use
- Shifting attention to unexpected stimuli

An example of an interaction design that makes use of these notions is the 'Drift Table' from Gaver et al. (2004). It is an electronic coffee table that displays slowly moving aerial photography (through a small hole in the surface) controlled by the distribution of weight (by placing objects) on its surface. This table is specifically designed to de-emphasize the pursuit of external, utilitarian goals, and speak to the curiousity of its users. The designers used the common usage of a coffee table, namely to place items on it during a moment of conversation, as a mediator to introduce the users to its novel use of scrolling through aerial photographs with their own neighbourhood as a starting point. This creates an ambiguity in the action representation. However, the mechanism is simple enough to maintain openness in regard to the meanings that the users ascribe to the experience. The brain regions that underpin such perceptual, sensory-motor aspects of creative behaviour are as follows:

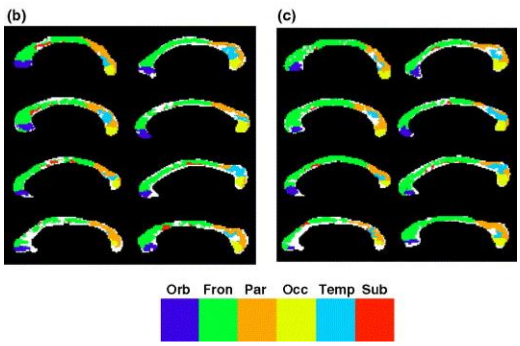
The Inferior Parietal Lobule (IPL) in both hemispheres Interaction with objects can reflect the following questions: *what is it?*, *how do I use it?* and *what is it for?* . On the question of *what is it?* ,both Inferior Parietal Lobules play a key role in disentangling the origin of sensory events(Jardri et al., 2011). The right IPL is involved in self-other discrimination: in terms of facial recognition (discriminating between one's own face and those of others) (Uddin et al., 2006) and recognizing one's own action in others (imitation and action identity) (Jackson & Decety, 2004). But the right IPL is also involved in making sense of *perceptual ambiguity* in the actions of others. An example of such ambiguity can be seen in a computer simulated penalty-kick soccer game. In this game, the perceiver (player) is the goalie and the computer is the kicker, being able to shoot the ball left or right into the goal at full random. This creates a situation where the uncertainty of the actions of another actor is fully optimized in regard to the perceiver(Vickery & Jiang, 2009).

The left IPL is involved in the question of *how do I use it?* of man-made objects and is considered as an interface between between perceptual and motor information. It is responsible for the transaction and aquisition of new knowledge about the actions involved in tool use (Ishibashi et al., 2011). Lesion studies show that people are unable to repeat observed actions (Buxbaum et al., 2007).

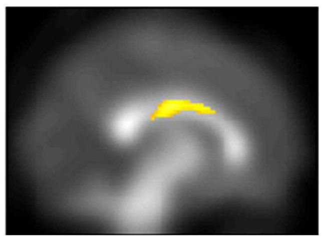
The *Temporo-Parietal Junction in the right hemisphere (rTPJ)* This cortical region is involved in social cognition and shifting attention to unexpected stimuli in the environment. It has shown to become active when is involved in perceiving the stimuli that represent other's beliefs and thoughts. These stimuli can be mediated by linguistic structures through reading, hearing and sign language (e.g. "Bob knows his flight is delayed" or "Grace thinks the white powder is sugar"). But these stimuli can also be a non-verbal cartoon that depicts a mental state, or a mental state that is *attributed* to that cartoon. The unexpected stimuli in the environment don't need to reflect any social beliefs or states for the right Temporo-Parietal Junction to be active, but can be anything that lies outside of an individual's intended goal to give attention to (Saxe, 2010, p. 13).

Bi-hemispheric intergration of information and the Corpus Callosum

The left and right hemispheres of the cerebral cortex process similar types of information in a different manner. The left hemisphere appears to process information in a linear manner, from parts to whole. It also appears to have a focused attentional perspective. These processing mechanisms are reflected in the specializations that are dominant in the left hemisphere: categorical processing, language and motor control of skilled movement. The right hemisphere appears to process information holistically, from whole to parts and appears to have a global attentional perspective. It's processing mechanisms are reflected in its specializations: spatial cognition, coordinate coding, face recognition and emotional communication.(Heilman et al., 2003) The *corpus callosum* (see Figure 8) is the white matter structure that interconnects the cortical regions in both hemispheres that process similar types of information (homologous regions). There is a strong correlation between its structural integrity and the quality of an individual's creative output (Takeuchi et al., 2010). In studies of patients where the function of the corpus callosum is absent, it is shown that the *corpus callosum plays an important role in thinking about the meaning of events*. A strong deficit is observed in the ability for the intergration of observations into a narrative in patients whose corpus callosum was cut. These narratives were also short and lacked elaboration. Patients who were born without a corpus callosum (birth defect) also demonstrated a deficit in the comprehension of narrative humour. (Moore et al., 2009)



(a) Parcellation maps of the corpus callosum. The vertical-sideways (sagittal) view of 8 healthy individuals is shown in sub-figures (b) from the left-side, and (c) from the right side. These figures show that the callosal structures are highly variable among individuals. The callosal fibres of the *orbital lobe* are painted blue, the *frontal lobe* green, the *parietal lobe* orange, the *occipital lobe* yellow, the *temporal lobe* cyan and the *subcortical nuclei* red (Huang et al., 2005).



(b) This visualization depicts the structural integrity of regions in the corpus callosum that correlate with the quality of an individual's creative output (Takeuchi et al., 2010). However, Subfigure (a) shows that the structure of the corpus callosum is highly variable among each individual. This may imply that the structural integrity is only measurable in those regions where the structures are the least variable.

Figure 6: The corpus callosum: review of its structural anatomy and the correlation of its structural integrity to the quality of an individual's creative output.

2 REVIEW OF CREATIVE INTERACTION MECHANISMS FOR THE TUITION OF THE ARTS

To conceive and develop an educational concept from the perspective of teaching, while keeping the expressive freedom of the learner in mind is not entirely new. Even though it is a very rare subject in academia, such a perspective describes the daily practice of various children's museums that focus on the creative arts. Central to the discussion of the prior art that aims for such a concept of teaching is their relevance to the development of the proposed HCI tuition mechanisms into a working model for a given operational context. Such prior art involves interaction on the level of the interface: what should be considered to support the flexibility of thinking in a given age group, how can a digital interface aid in offloading a cognitive process during creative activities, and in what way do the shapes of objects and their underlying interaction mechanisms communicate their rules of use. But they also involve aspects like nurturing the representational understanding of stimuli, symbols and objects and the interpretation of their subjective meaning to others in a collaborative environment. These aspects are being set out as a discussion of the results from my field research. These results originate from my conversations with installation designers, educators and observations of conducted activities in the following children's museums: Art Basics for Children and 'The Children's museum' in Brussels, and the 'Huis van Artistoteles' (Aristotle's House) in Amsterdam. Each of these institutions have their own specific set of philosophies where they base their designs of educational materials and engagement with their audience on. The findings from these inquires are being compared and augmented with some of the outcomes in academia and contextualized with the developmental and educational models as they are found in psychology and neuroscience.

'

2.1 SUPPORTING EPISTEMIC ACTIONS DURING CREATIVE ENGAGEMENT

Epistemic actions have shown to play a crucial role in the ways that an individual can discover views, uses of objects or other sorts of information that is relevant to the goal he has in mind. They are physical actions that are meant to offload a cognitive process from working memory into the environment. This chapter discusses the relationship between working memory and creativity, and sets out the role of epistemic actions as a means for the development of skillful use of the proposed digital interface during creative engagement with novel, artistic concepts by the learner.

WORKING MEMORY facilitates a wide range of higher order cognitive activities such as reasoning, learning and comprehension and is involved in the maintenance and manipulation of information over short periods of time (Takeuchi et al., 2011), thus supporting human thought processes by providing an interface between perception, long-term memory and action (Baddeley, 2003). When processing novel information, working memory is known to be very limited in duration and capacity. This capacity is also varying depending on the nature of the processing required in a given task (Kirschner et al., 2006). There are two clearly understood concepts of working memory that can be localized in different regions of the brain. One is called the '*visuospatial sketchpad*' and provides the capacity to hold and manipulate visuospatial representations, including imagery and mental synthesis. An example study into such an activity might involve the presentation of verbally described shapes to a subject, for example 'J' and 'D', with the assignment to combine them into an object. A suitable outcome from this activity might be an umbrella. The other concept is called the '*phonological loop*' and facilitates the acquisition of language, linking speech and non-speech inputs in a sub-vocal (involving the actions to produce speech, like lip movement or other speech organs) rehearsal loop and operates in the temporal domain. Studies into this concept of working memory involve the use of immediate serial recall (*n*-back task), typically using a small set of digits, letters or unrelated words (Baddeley, 2003).

The capacity of working memory is being expressed in a measurement called 'chunks' during recall tasks in psychological trials. The capacity of number of 'chunks' that can be process in working memory is argued to be about 4, but also can be as low as 2 or 3, depending on the nature of processing required (Kirschner et al., 2006). Such chunks can best be defined by the semantics of the stimuli an individual has to work with. For example, in a study about visuospatial working memory in chess experts, chunks were identified upon the behavior of the expert. They were engaged in the task of reconstructing the arrangement of chess pieces from one board on to the other (both boards were placed in view) (Gobet, 2001) Their glances between the two boards and either the placement or re-placement of pieces on a board was used to discern between individual chunks and their contents. Gobet (2001) identified that *re*-placement of a piece within two seconds belong to the same chunk and that these chunks could be defined upon the following semantic relationships: attack, defense, proximity, color and type of piece (Cowan, 2005). In another study by Zhang & Simon (1985), the recall of language symbols in chinese speakers was used to provide insights on the semantics of such 'chunks'. The Chinese language consists of *radicals*, visual configurations with no pronunciation, *characters* that are elaborations of radicals that do have pronunciation and *words* consisting of a multiple of characters. They concluded their study with a model to measure the chunks recalled for materials that were in phonological form. The model involved the rehearsal time of a given list of symbols, the time to bring each new chunk into the articulatory mechanism and the time to articulate each syllable beyond the first. One of the outcomes of this study was that a basic chunk could be seen as a character with a single syllable pronunciation that serves as a pointer to a concept, whereas an unprouncable radical or a word can be encoded as multiple chunks, depending on the concepts they point to (Cowan, 2005).

During creative activities, it is speculated that individuals having a disposition to be more creative have a better ability in associating two ideas represented in different networks of the brain (Takeuchi et al., 2011). Damasio (2001) argues that a working memory buffer is critical for creative thinking because it allows for the retention of relevant knowledge while problem-solving: aside from the generation of a strong representational diversity that can be brought to the conscious mind, working memory allows us to hold concepts such as images actively 'online', work on them, rearranging them in space, and recombine them into new forms. However, Takeuchi et al. (2011) argue that it's rather a relationship between a individual's disposition to be more creative and the way the brain's resources (in terms of energy spent) is being allocated among the networks that deal with *internally* (self-related) and *externally* (goal-directed) focused tasks, than a relationship with the capacity of their working memory. Their study consisted of a Creativity assessment and a n-back Working Memory task (during a fMRI scanning session) that was performed on 63 individual subjects. The 'S-A Creativity test' (see Takeuchi et al., 2011, p. 682), a divergent thinking test, was used to assess creativity and involved three types of tasks that needs to be executed by each subject: generating unique ways of using typical objects, imagining desirable functions in ordinary objects, imagining the consequences of unimaginable things happening. This provided a total creativity score on the ground of the four dimensions in the creative process (fluency, originality, elaboration and flexibility). The n-back task made use of Japanese letters and consisted of two conditions: 0-back and 2-back. In the 0-back task, a target stimulus was given before the execution of the task. The subject was asked to press a button when this target stimulus was presented during the execution of the task and another button when other stimuli were presented. During the 2-back task, subjects were asked to push a button when the currently presented stimuli and the stimuli presented two letters previously were the same, and to push another button when the currently presented stimuli and the stimuli presented two letters previously were different (see Takeuchi et al., 2011, p. 683 for further elaboration of the task).

The results out of these tests[1] demonstrate that there is indeed a correlation between the allocation of the brain's resources and an individual's disposition to be creative. This correlation is referred to as '*reduced Task Induced Deactivation*'. Specific cognitive tasks are governed by a specific network of activity in the brain. When a subject engages in the before mentioned Working Memory task, the network that is being activated[2] is commonly being recruited by *externally focused*

1 Even though the 'S-A Creativity test' and the n-back task address two different forms of working memory. The first addresses the '*visuospatial sketchpad*', while the latter addresses the '*phonological loop*'.

2 This network consists of activity in the lateral frontal and parietal cortices (Takeuchi et al., 2011)

attention-demanding tasks. Another network, the Default Mode Network is involved in *internally focused tasks* including autobiographical memory retrieval, envisioning the future and taking the perspective of others (Buckner et al., 2008). These networks usually anticorrelate: when one network is activated, the other one is deactivated (Fox et al., 2005). However, what has been found is that the *deactivation of the precuneus* (a key node in the Default Mode Network) is *reduced* in creative individuals. The precuneus[3] is part of a network that represents the *'proto-self'* (Damasio, 2000), helping to subserve the primitive representation of the self in relation to the outside world. Therefore, the precuneus is shown to be engaged self-related mental processing, like judgments on one's own versus another's personality traits, in first and third person perspective taking in the visuospatial and story domain, empathic reasoning and episodic memory retrieval during rest (Cavanna & Trimble, 2006). It is argued that reduced Task Induced Deactivation during externally focused attention-demanding tasks reflect the qualitative attention that is being spent on such a task. In a study where subjects performed an auditory detection task during fMRI, involving the discrimination of two sounds (of which one was defined as the target stimuli), it is shown that the processing resources are increasingly diverted from ongoing, internal processes that occur at 'rest' to the areas that are involved in the task, relative to the difficulty of the task (Mckiernan et al., 2003). This idea is consistent with the reported positive correlation between task performance and Task Induced Deactivation in the Default Mode Network (Sambataro et al., 2010). Thus, observed reduced Task Induced Deactivation in the precuneus might indicate that creative individuals are not able to suppress or inhibit cognitive activity that is irrelevant to the task that is being performed (Task Unrelated Thought; McKiernan et al., 2006). This leads up to the conclusion that the inability to suppress an irrelevant network when one network is recruited may lead to the intrusion of thoughts from the irrelevant network and may allow two isolated ideas to combine. (Takeuchi et al., 2011)

3 The precuneus is part of the Cortical Midline Structure which is involved in self-referential processing (Uddin et al., 2007; Northoff et al., 2006). In the different fMRI studies that are being discussed by Cavanna & Trimble (2006), this region shows consistent activation in tasks that require visuo-spatial imagery, spatial attention and attention shifting, reflective self-awareness, and episodic memory. It is suggested that the precuneus plays a key role in the processing of self-consciousness.

EPISTEMIC ACTIONS is a term that is proposed by Kirsh & Maglio (1994) to describe the actions of an individual that specifically intend to *offload a cognitive process* by means of changing the environment in order to simplify a problem solving task. They are physical, external actions that an individual performs to change his or her own computational state. An example of such behavior can be that of a novice chess player who finds it helpful to physically move a chess piece when thinking about the possible consequences. By physically altering the chess board, novices find it easier to detect replies, counter-replies and positions, compared to merely imagining moving a piece. Likewise, a more advanced player often finds it helpful to change his or her spatial position to view the game from a new vantage point to see if otherwise unnoticed positions leap into focus, or to help break any mindset that comes from a particular way of viewing the board. Epistemic actions can be seen as a way to use ordinary actions to *unearth valuable information that is currently unavailable, hard to detect or hard to compute*. From a biological perspective it could be argued that such actions are at influence of the costs involved in terms of the energy required for getting to a certain goal: they simplify computational tasks that cost more time and effort when solved by mental activity alone. It is shown in a study about mental arithmetic (Hitch, 1978) that various intermediate results, which in principle could be stored in working memory, are recorded externally to reduce cognitive load. Also, in expert activities such as musical composition (Lerdahl et al., 1983), it is shown that the performace is demonstrably worse of those who rely on their mental computational ability without the help of external supports. An epistemic action is therefore a physical action whose primary function is to improve cognition by:

1. Reducing the memory involved in mental computation; space complexity
2. Reducing the number of steps involved in mental computation; time complexity
3. Reducing the probability of error in mental computation; unreliability

In terms of an individual's internalization of novel concepts during a creative engagement with a digital interface, the following question come to mind: *in what way do epistemic actions support the process of chunk discovery in a creative activity?*

Kirsh & Maglio (1994) have formulated study that makes use of the game '*Tetris*' to demonstrate the existence of epistemic actions. Tetris is a fast-paced, repetitive (puzzle) action game requiring split-second decisions of the perceptual and cognitive sort. Every action in this game has the effect of bringing a piece either closer or further away of the intended goal of the game. It is therefore easy to distinguish between moves that are epistemic and those that are consciously planned. For this study, they have formulated a hypothesis that makes use of a process-model called '*RoboTetris*'. This process-model is based on a classical imformation-processing model for skill acquisition that is based on the supposition that cognition in Tetris proceeds in 4 major phases:

1. *Create an early, visual (bitmap) representation of selected features of the current situation.* In early visual processing there's a brief sensory memory called 'iconic memory' (or buffer; mention evidence for the existence of the iconic buffer). The contents of iconic memory are similar to maps, in which important visual features, such as contours, corners, colors, and so forth are present, but not encoded symbolically.

2. *Encode these stimuli in a more compact, chunked, symbolic representation.* Task-relevant features are extracted and explicitly encoded in working memory. (use a different explanation involving prior knowledge and experience; rather than what is mentioned in the paper: Anderson (1996))

3. *Conceive the best place to put the puzzle-element (zoid).* Once the puzzle element and the contour of the structure where this element should fit in are encoded in symbolic features and chunk, they can be compared in working memory to identify the best region of the contour to place the puzzle element.

4. *Conceive a motor-plan to achieve the goal placement.* (see Chapter 3; Cognitive Model for Learning through Creative Engagement with Artefacts). In terms of cognition in Tetris, it means that an individual conceives a series of purposeful actions for the goal that he has in mind.

I find this model to be clear and fundamental enough to be used as a guideline that involves the process of chunking in the context of creative engagement with the interfaces that are being discussed in the following chapters. One of the important points of such an engagement is to provide the possibility for the learner to, initially, shape generalizations through this process of chunking that include self-relevant and self-related views towards the novel concepts that are being presented. In this regard, epistemic actions serve the purpose of discovering both, subjectively meaningful patterns among the presented materials, and enhancing the flexibility of views over those that can be solely imagined by the learner. Therefore, supporting the aim of elaborating these findings into works that demonstrate originality and appropriateness.

2.2 SUPPORTING FLEXIBILITY IN DEVELOPMENTAL STAGES

Figure 7: An installation for the production of stop motion animations. It was part of the 'Nature and Aesthetics' exhibition in the Art Basics for Children institute in Brussels in 2009. Only the part of the installation is shown that allows children to express themselves creatively. The stand has two boards and a camera mounted to it. Paintings, drawings or photos can be placed on the lower, black board and serve as a background. The board in the middle of the stand is a transparent plate with a sandbox on top. This is the working area of the installation. Children can either draw in the sand, make shapes by moving the sand to various areas of the box and use their own artwork or materials that are provided by the teachers as subjects for their stop motion animation. The other part of the installation (not shown in this picture) is a computer with a big, red button mounted next to it. Each time the children created something in the sandbox, they can press this button. This will capture one frame and add it to a quicktime video.

Resnick et al. (2005) developed a set of '*design principles*' to guide the development of tools to that enable people to express themselves creatively. The installation shown in figure 4 can be seen as an example of their '*Low threshold, high ceiling, wide walls*' principle. 'Low threshold' means that the interface should give novices confidence and not intimidating in its complexity. 'High ceiling' means that expert user can create sophisticated expressions. And 'wide walls' refers to the support of individual dispositions and styles in the interface.

The designers of this installation created flat, jointed figurines that can be used for the production of a stop motion animation. The limbs of the figurines were held together with small elastic rubberbands. This design was conceived for practical reasons: it was easy to replace when broken. Against the expectations of the designers, the animations that the children produced showed some very agile motor coordination of the figurines. Some animations even had dance and sports activities central to their narrative. The production process of a stop motion animation consist of procedures that require advanced planning. It might be argued that the children drew their inspiration from the jumpiness of the figurines.

It is often noticed by educators that children can find original uses of an object much faster than adults. As discussed in Chapter 1.1.1.1 about Play, the origin of this behavior lies in the difference between the structural composition of an adult and a developing brain. The children using this installation had an average age of 8 years. This means that they roughly have double the amount of synapses in the frontal cortices compared to adults who created the installation (Stiles, 2008, p. 269). The exact region that has been measured is the Middle Frontal Gyrus of the Prefrontal Cortex, which has a peak in synaptic exuberance at about 5 years old, pruning back to the number of synapses found in adults when late adolescence is reached (Huttenlocher & Dabholkar, 1997). The Middle Frontal Gyrus participates with the primary motor cortex in the control and initiation of voluntary movements. It supports higher cognitive functions related to personality, insight and foresight (Orrison, 2008).

In order to develop a stop motion animation with a *narrative consistency*, children have to be able to conceive class inclusions (part-whole relations) and be able to take different perspectives (the ability to assign mental states to intentional agents). These cognitive traits become reliable at an average age of 7 years (Siegal, 2003; Wellman et al., 2001).

The ability for narrative consistency and the synaptic exuberance in the middle frontal gyrus are reflected in the observations from the designers of this installation.

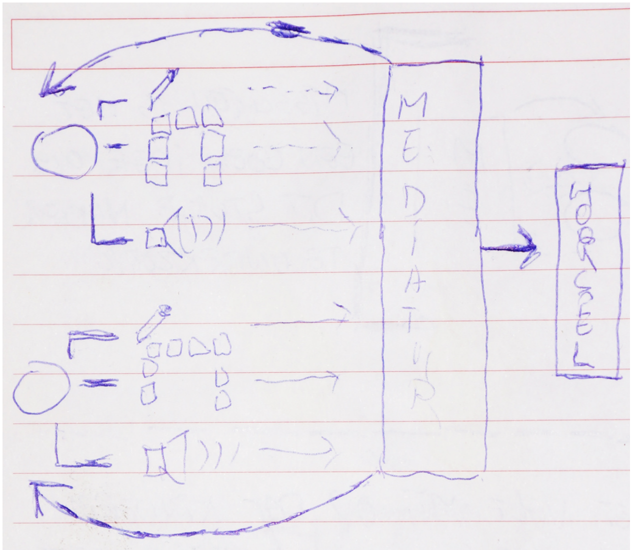
2.3 NURTURING REPRESENTATIONAL UNDERSTANDING

'*Bricolage*' refers to a way of producing sounds with commonly known, household items, which makes them into a means that a child can use to explore his imagination. Figure 8 shows several of such items that are given to learners with an instruction of use. By following these instructions, these objects produce sounds that are unrelated to the common use these objects. A dessert glass becomes a ringing phone, bottles become a honking ship, or the sound of ice rocks. A plastic box with chickpeas become the sound of a seashore, etc .. These sounds aim to be reference points for the role of these events in the prior experiences of a child. Therefore, these objects become tools that allow children to act out the memories of these events and to explore their imagination regarding alternative occurrences of these events. During the act of playful exploration of the use of these sounds, they can be considered proto-linguistic elements. Abstract play objects like a plastic sphere can be proto-linguistic elements. They can represent natural forms like the sun, moon, bubbles, shells and flowers in the mind of a learner (Wilson, 1967, - See Chapter 2.4 - Manipulatives). Likewise, the sound of a seashore can refer to different contexts or situations. It can refer to walking along the Belgian coastline for one child, but a holiday in Southern Europe for the other, making these elements self-referential, and not yet carrying the dialogical properties that would make them linguistic. Levinson (1997) argues that there are thoughts that cannot be clearly expressed in language. Examples of such thoughts are a visual image of one's bedroom, appreciation of a smell, memories of the tactile properties of a shark-skin, and memories of vague, less than propositional thoughts (e.g. hard to make explicit to others). He postulates that such thoughts convey a conceptual representation of our experiences with our environment, whereas linguistic meaning embodies a semantic form that is shared among a community using linguistic symbols. This form entails *referential* facets; meaning that they depends on references in the environment, *inferential* facets; which concerns the gap between what is stated using this symbol and what is implicated by the actor, and *differential* facets; involving the way that a community maintains the use of this symbol (Anolli, 2005, - See Chapter 3.2.1, p. 66 of this disseration). Henceforth, linguistic symbols aren't very capable to provide specific, precise accounts of the conceptual representations that we think with: a picture cannot be non-specific about metric properties and shapes, while a linguistic description can hardly avoid being so (Levinson, 1997).

Yet, 'Bricolage' provides a means that enable children to exemplify their imagination to their peers, providing the ground to develop narratives using non-linguistic symbols. Figure 9 depicts an activity where children collaboratively work on a soundscape. They utilise various means of expression for the ideation and conversation about the topic and the narrative of the soundscape. Aside from the 'Bricolage' activities, there are also drawing and construction activities. These activities are guided by an educator, who essentially plays the role of curator among the emergent ideas, but also reflects with the children about the collaborative meaning of each of their individual expressions. This activities demonstrates how the combination of linguistic meaning and non-linguistic thought can aid in a deeper understanding of each individuals' frame of mind in relation to the topic that is being discussed.

Figure 8: '*Bricolage*', Art Basics for Children. A set of tools that are designed for playful exploration of the representational aspect of objects. These objects have been chosen to represent a certain auditive phenomena when used in a certain way. The cardboard boxes shown in this figure can be identified by the auditive phenomena their contents represent. And each contain a set of objects that are accompanied by an instruction card explaining such a use. Two examples of such boxes are shown in the bottom-right image. The box on the left is called '*phone*' (verb) and consists of drinking glass and a spoon. The instruction describes the activity to make the sound of a (mid/late 20th century) phone. The box on the right is called '*ship honking*' and contains the bottles and an instruction to make such a sound. The image on the top-right shows a similar set of bottles, but then with the description '*cruncing of the ice*'. The term '*bricolage*' is borrowed from the french verb '*bricoler*', of which the core meaning is "to fiddle, tinker". And, by extension means "to make creative and resourceful use of whatever materials are at hand (regardless of their original purpose)" (White, 2008). It is also a concept in Harel & Papert (1991)'s educational theory called '*constructionism*'. They refer to it as a mode of learning-by-making where the learner is guided by his work rather than staying with a pre-established plan.

(a) An architectural structure that the children who built it referred to as a 'house'. They built this structure after they played with the bricolage objects and made drawings (CD covers) depicting the narrative of the soundscape that they had in mind. The children were experimenting with the spatial properties of their narrative using this structure. The findings of this activity could clearly be heard as an element in the resulting soundscape.



(b) The resulting plot from my observations. It describes the relationship between the educator, peers and the resulting output as a co-creation model. The peers (circles) are shown on the left and express themselves with drawing, visuospatial and sound production activities, but also with conversations with the educator. The results out of these activities inform the educator about her strategies for guidance, maintaining a collective view through the guidance of individuals and curating the emerging concept towards the development of the actual soundscape that is the conclusion of this process. The educator uses her own *pedagogical* (keeping the children in line with the project) and *imaginative* skills as an instrument for guidance throughout this process.

Figure 9: Case of use: Soundscape workshop at Art Basics for Children, Spring 2009. The goal of this workshop was that 3 groups of children (divided in 3 age groups: 6 - 8, 8 - 10, 10 - 12) each collaboratively produced a soundscape using the means available at the ABC House. These were not only the play-objects, but also a Protools-setup (Digital Audio Workstation) that was operated by the educators at the end of the workshop. I attended the last day out of the three days that the workshop lasted. This day was divided into three segments. Starting off with an 'inspiration session' where the children listened to a rather long radio play, they went on with their activities, after which they collectively worked on their ideas in a Protools-session. Central to my inquiry was the following question: *'How are the children going to organize their findings on a timeline that it reflects their ideas and imagination?'*. What I found here was that the educator takes the role of a director in this process. She operates on a preconceived plan which hasn't been made explicit, maintaining the organization of the soundscape she has in mind by interacting with the ideas and views of her peers.

2.4 MICROWORLDS: RULE-BASED SYSTEMS FOR PLAYFUL ENGAGEMENT WITH CULTURAL CONCEPTS

There are different types of play systems that children can use to experiment, discover or express their ideas by assembling individual components of such a system. These systems are rule-based and communicate their rules with the shape of the individual components and the mechanisms that allows the user to assemble them in a certain way. There are two categories of (physical) play systems mentioned in literature:

TANGIBLES Tangible play systems emphasize touch and physicality as the user's interface (O'Malley & Fraser, 2004, p. 7). They bear an obvious and concrete relationship to the visual or tactile properties of entities like inanimate objects or social actors (Rowland et al., 1990). Van Leeuwen (2008) provides an example with the Playmobil toy system which is specifically designed to represent the social word in play. This system consists of plastic dolls and utilities that can be used by them. The designer of this system drew his inspiration for the visual appearance of the toys from children's drawings. In the trials that the designer conducted, he investigated whether the dolls would fit in the children's frame of reference in such a way that they could naturally engage in role play in a narrative scenario (Walker, 1997).

MANIPULATIVES are abstract, physical play-objects. They allow learners to explore an idea in an active, hands-on approach , but also enabling them to design real world objects and physical structures (Zuckerman et al., 2005). This concept for expression by the learner finds its origin in the work of Froebel and Montessori. Froebel originated the term 'kindergarten' to describe a concept for preschool education that is based on natural play. By respecting the freedom of infants and by viewing play as a creative activity, he conceived a set of '*gifts*' that enabled infants to project their 'inner states' upon. Therefore, they depend on the make-believe transformations as they occur in the child's mind. These 'gifts' were basic geometric shapes that emerged from a framework he conceived to value their usability as a protolinguistic element. This means that an object could connote a range of symbolic meanings. For example, a sphere could represent natural forms like the sun, moon, bubbles, shells and flowers (Wilson, 1967).

Learners can also deepen their understanding of abstract concepts using manipulatives. Montessori found that building and representing using manipulatives help the learner in understanding abstract mathematical concepts. This is also supported in different studies (Piaget, 1953a; Bruner, 1966; Martin & Schwartz, 2005; Rieser et al., 1994) that demonstrate that there's a notable difference between a child's ability to solve problems using physical action compared to solving the same problem symbolically (O'Malley & Fraser, 2004, p. 18). It can be said that such internalisation of abstract concepts make use of the brain's mechanism to construe graspable objects as action representations (explained in the research objectives).

Figure 10: '*Japanese Gardens*'. An installation in the Art Basic for Children Institute in Brussels, 2009. One of the differences between Japanese and Western culture is the relationship that is envisioned between people and nature. They see it as their wisdom of life to live in harmony with nature, rather than being for the benefit of people. Maintaining a miniature garden in a domestic space is therefore seen as means to reflect on this relationship (Watanabe, 1974). Because of its scale, it can make the microworld that a miniature garden represents intelligible to the mind of the user. Such a microworld is a system with its own rules and internal behaviors (Gingold, 2003). The designers of this installation used this concept to conceive a play context and play objects that can be used for constructive play by children. The play context is communicated by the demarcated spaces on the table. These intent to motivate individual engagement with the play objects, as opposed to collaborative play strategies that might come to mind in the user. The theme of the installation is communicated by the sand that fill these spaces and the play objects themselves. These consist of diced and whole tree branches, small stones and pine cones.

The installation shown in figure 10 is designed with preschool children in mind. It makes use of the idea of manipulatives to acquaint children of this age-group with the 'nature and aesthetics' concept that is presented in this exhibition. The upper-right picture in figure 10 shows the result of a child's interaction with the installation. This result speaks more strongly of mechanisms, relations (and possibly behaviors) between objects that are projected from the imaginary world of the child, rather than a subjective understanding of the rules and internal behaviors of a Japanese garden. The dissonance between the tuition intent and the outcome of use can be explained as follows. An installation that makes use of manipulatives as a free-form exercise can only function in the larger context of an exhibition with different presentations using different forms of media about the concept. In this case, the symbolism that the manipulatives convey communicate a connection between the exhibition, rather than explorable rules of a constrained system. Aside from this installation, visitors could also visit a puppet theatre, look through books and engage in guided drawing activities. In this age-group, stories and dramatisations in the physical environment feeds their imagination, motivating them to create meaning in object play activities. Their imagination is not captured by an object itself, but by the story which gives the object and the actions their meaning (Lindqvist, 2001). Piaget (1953b) observed that children from 4 years of age cannot tell the difference between their imagination and reality. For example children in this age might claim that dreams are real and take place outside of themselves as "pictures on the window", "a circus in the room" or "something from the sky"[4] (Bernstein, 2010). When taking such a view into account, manipulatives that communicate the exhibition context in their symbolism, might introduce preschool children to novel rules and behaviors, providing challenges to their imagination.

Digital designs that allow learners to acquaint themselves with rules, allow for direct feedback on their curious, playful engagement with the learning materials. Kim (2010) designed an installation (see Figure 11) that introduces its user to a cultural concept that exists in South-Korea, namely that the way someone engages a plant tells something about

4 I recall from my own early childhood that I could literally 'project' the story that my mom was reading from a book on the wall or on the wardrobe door. These 'projections' were more abstract than pictorial and looked more or less like an animated luminance map.

the person's personality. This can be viewed as a general truth, but it is meant with the same aim in mind as the 'Japanese Garden' installation described in Figure 10: that it is a good custom to live in harmony with nature, rather than viewing it as being for the benefit of people. This view is represented in the way that the learner engages with the plant (a Cymbidium) in Kim (2010)'s installation. By touching the plant in a certain way (like 'brushing off dust from a Cymbidium leaf'), the system creates a painting in a traditional 'ink-and-wash' style that is informed by these touches. The aim of this installation is to 'enhance the sense of order, independence, and concentration through the sense of sight and touch' in the learner. Kim & Choi (2010) further explored such a design for playful engagement by using a bamboo-flute with a breathe sensor installed, instead of the Cybidium plant with bend sensors. In this setup, the 'ink-and-wash' style painting is created on the basis of the breathing velocities it receives from the flute. The strength and length of the user's breath determine the shading of the ink and the length of the leaf that is presented in the painting.

Figure 11: Kim (2010)'s installation as I have found it at the ICMC 2010 conference in Barcelona, Spain. The installation consists of a Cymbidium plant with bend-sensors attached to its leaves. These sensors are connected to a computer running the Processing development environment (www.processing.org). The software developed in this environment represents the users touches as leaf shapes on the monitor.

2.5 prior knowledge and experience as an entry-point for collaborative learning activities

There are children's museum that make use of play activities to come to a collaborative conclusion with their visitors. Means like artefacts and interactive interfaces that support such activities are used as mediators to communicate the subjective points of view of the individuals among a peer group. The mission that the Children's museum in Brussels sets for itself is the notion of affective development through the children's playful engagement with each other. The activities are guided by educators and make use of materials that are designed to fit within a given theme. Their aim for this type of education is to teach how their peers think differently about subjective experiences, with the goal of producing more "open" individuals that are tolerant and welcoming to others. Central in the play activities are the discussions about the findings of the children during play. Figures 6 and 7 show two different installations that mediate such activities.

top-left "Which whisle *sounds* louder?"
top-right "Which doll *is* the softest?"
bottom-left "Which scarf *feels* the softest?"

Figure 12: "Touchable paintings", an installation in the Children's museum in Brussels in 2009. The purpose of this installation is to promote discussion about the experience of color among the children during group visits. Each of the frames contain identical objects that are painted in a different color. The texts below the frame serve as an instruction to guides the discussions. Only the paintings on the bottom are within the reach of the children. The frame on the top-right serves a purpose for verbal reasoning about their experiences.

Figure 13: The 'Red room', an installation in the 'Children's museum' in Brussels, 2009. This installation supports the activity of finding hidden objects. Each of the interfaces in this room are designed with different modes of searching in mind. These modes can either be a passive or a proactive form of engagement and are inspired on the play activities that children commonly find themselves in at home or outdoor. Such home activities are reflected in the bookshelf (top-left), picture frames on the wall (bottom-left) and the bed (bottom-middle). The display that is composed from a sink, holographic image of a water tap and a light projection mimicking a ghost (top-middle) supports the passive activity of different ways of seeing. The interface on the top-right and bottom-right supports explorative activities. The one on the top-right is composed from 3 doors, each with their own set of locks hiding a display with a rotating ballerina. The one on the bottom-right mimics the idea of a submarine. Using the wheel a child can scroll through a set of pictures.

Anderson et al. (2002) report about the learning nature through museum experiences of 4 - 7 year olds. They define museums spaces as being both physical and social, and investigate the effectiveness of play and story concepts in exhibition spaces. Their study focuses on the children's recall of the presented discourse in the exhibition space and discusses the following dimensions of learning:

SOCIO-CULTURAL the ways in which children interact and use the museum in the light of their own knowledge

COGNITIVE the construction of knowledge through interaction with objects and people

AESTHETIC sensory, perceptual, affective and emotional experiences and activities of learners

MOTIVATIONAL interest to seek learning opportunities

COLLABORATIVE co-construction of knowledge through peer-to-peer interaction

What the children recall from their visits to the museums show that impressions which are "larger-than-life" in terms of exhibition space, or installation size, are effective, especially when they embodied *kinaesthetic* and *tactile* experiences: Many of the children's responses convey associations with these experiences and viewed their actions as being similar to how they perform in *outdoor play*. Stories have also been identified as as good mediators for learning, they can be seen as familiar and indentifiable frameworks for children, in which the narratives of a museum can be placed. When the story narrations are mixed with hands-on experiences with the artefacts presented in a museum, it shows that it improves the quality of recollection.

When comparing the practices of the 'Children's museum' in Brussels with those of the 'Huis van Aristoteles' (see figure 7) in terms of the above mentioned dimensions of learning, the latter demonstrates a more generalized approach that can encompass both affective development and cultural learning. The element of collaborative story creation can essentially be viewed as discussions that are mediated through activities that demonstrate the subjective views of the peers, while the 'Children's museum' focuses on reflective discussions about the visitors' activities. Due to the embodied nature of the transactional elements in the play activities that are conducted in the 'Huis van Aristoteles', they are more likely to fully address the mentioned dimensions of learning per play activity.

(a) The exhibition space of the 'Huis van Aristoteles'. The theme of the exhibition is inspired on the Dutch children's book 'Pluk van de Petteflet' by Annie M.G. Schimdt. The design of the space intends to mimic the illustrations in the book. Using the balcony in the space, an apartment block has been built into the space. Each of these 'apartments' houses different activities relating to the book and are guided by educators, sometimes dressed as the figures in the book. The area in front of the apartment block is a free playing space where children can engage in whatever playful activity they please.

(b) The intention for this installation is to support 'intermodal' activities among children. On top of the bed are several dolls and some books. It has the aim to be used by two children (communicated by the size of the room) who can use the dolls to enact one of the stories, either by one reading to the other enacting or discuss the scenarios for enacting.

Figure 14: Huis van Aristoteles, A Children's museum in Amsterdam (2008 - 2011). Nurturing the reading skills of children stood central to their mission. The play activities have the overarching theme of a book and are conceived on the basis that a story can be made experiential and interactive through different modes of presentation. This includes a differentiation between autonomous and guided activities. Some of the activities are guided and usually involve some form of storytelling by the guide. But there are also collaborative story creation activities like constructing a puppet theatre play. They base this educational design on a concept for education that Aristotle proposed in 334 BC. He observed that "each child possessed specific talents and skills" and stated that a strong emphasis should be put on "all round and balanced development", where play, physical training, music, debate, and the study of science and philosophy were all to have their place (Smith, 2001)

3 IMPLEMENTING THE LEARNING THEORIES INTO DESIGNS THAT TEACH

This chapter will provide two conceptual interfaces that serve the explanation of artistic concepts by means of the learners' creative engagement, namely an installation that aims to teach *"Len Lye's Discovery Process for Novel Figures of Motion"* (Chapter 3.1.2) and a touchscreen interface that aims to teach the *"Composition Process behind Matisse's Paper Cut-Outs"* (Chapter 3.1.3). These conceptual interfaces aim to demonstrate how a more accurate understanding of the neural processes that underpin the consolidation of experiences during the learners' creative engagement in long-term memory can lead to designs that are more empathetic to this particular learning process. In the prior chapters, I have discussed how play, when viewed as a learning behaviour, is tied to the various stages of a child's development and what kind of learning outcomes can be reasonably expected for a certain age group (See Chapter 1.4.1), and how creativity, when also viewed as a learning behaviour, shapes the cognitive conditions that are favourable to the development of self-referential insights (See Chapter 1.4.2). Furthermore, the installation designs that are discussed in Chapter 2 provide insights about the various interaction modes that are available when designing tangible, interactive play spaces. Figure 15, the *"Cognitive Model for Learning through Creative Engagement with Artefacts"*, aims to integrate these two viewpoints by providing an anwser the following question: *where exactly lies the interface between the cognitive processing in learners and the (interactive) artefacts that aim to support creativity and playfulness as learning mechanisms?*

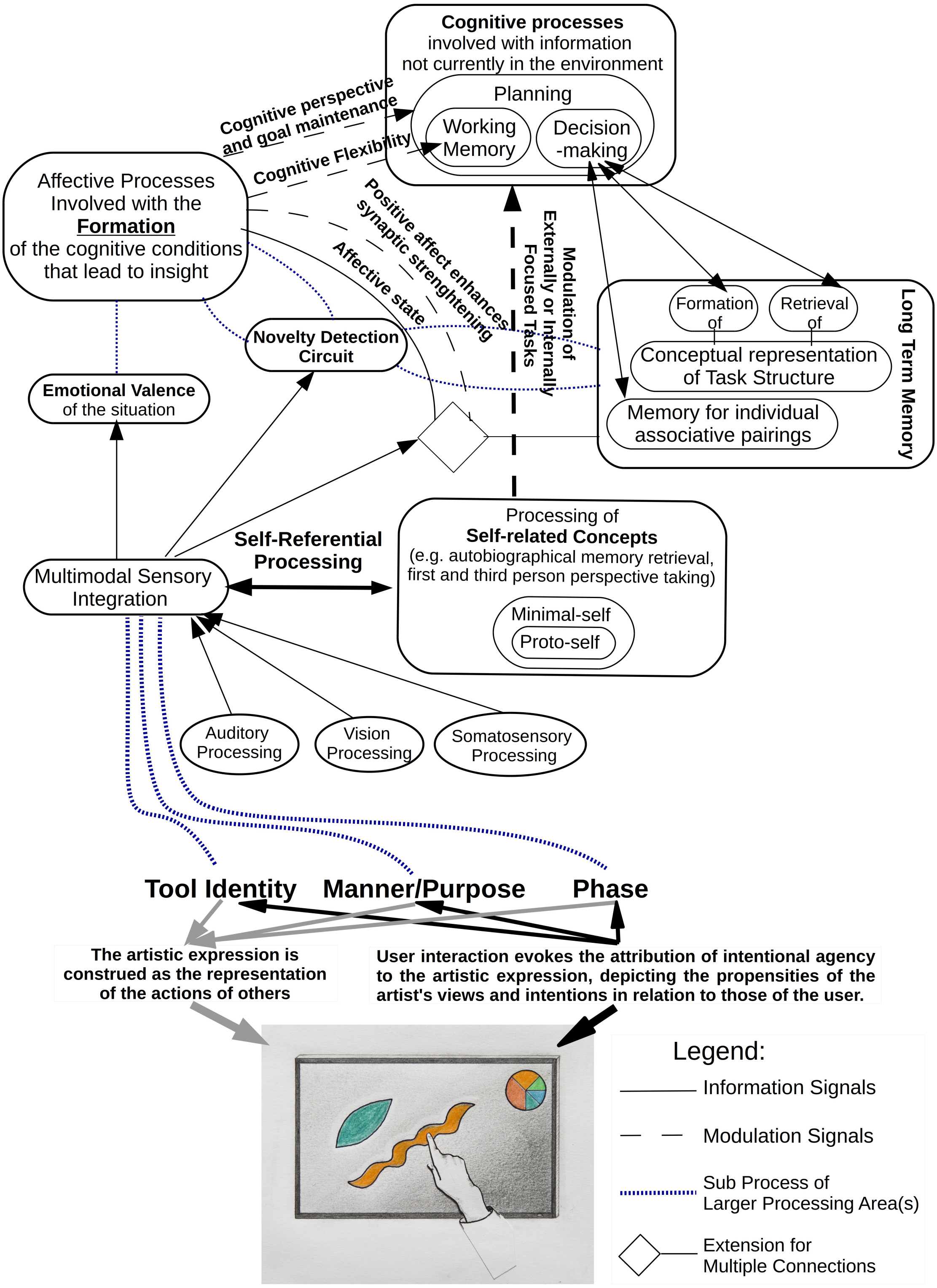


Figure 15: Cognitive Model for Learning through Creative Engagement with Artefacts.

The concepts in this diagram are described in the following chapters: *Self-Referential Processing*, Chapter 1.2; *Multimodal Sensory Integration*, Chapter 1.5.2.4; *Emotional Valence*, Chapter 1.5.2.1; Formation of the Cognitive Conditions that lead to Insight, Chapter 1.5.2.2, *Cognitive processes involved with information not currenty in the environment* (Goldman-Rakic et al., 1996) and *Modulation of externaly or internally focused tasks*, Chapter 2.1; *Conceptual representation of task structure* , Chapter 1.5.2.3.

The outcome of the delineation that the *"Cognitive Model for Learning through Creative Engagement with Artefacts"* represents is that the cognitive and affective processing that is *relevant* to the *formation of the cognitive conditions that lead to insight* and, in turn, *the consolidation of insights in long-term memory*, is driven by the neural processing that is involved in integrating the information that comes from the different sensory systems. This integration process seeks to disentangle the origin of the sensory events in the environment and therefore construes the objects and events respectively as *action representations* (see page 10) or as *intentional agents* (see page 11) using the following *action representation modes*:

MANNER The various ways in which a particular action can be executed, including its meaning, complexity and its relationship to the observer (Gallese & Lakoff, 2005; Shmuelof & Zohary, 2006).

PHASE A purposeful action can be divided into segmented temporal phases (Gallese & Lakoff, 2005). In terms of an artistic expression these can be viewed as temporal phases of inscription and editing of media.

TOOL-IDENTITY the functional identity of a tool is construed as a *motor experience* in regard to the purpose of a particular action (Creem-Regehr & Lee, 2005)

These action representation modes will form the basis for the design of interfaces that aim to teach artistic concepts by means of the learners' creative engagement.

3.1 INTERFACE DESIGNS

The topics of the conceptual interfaces that are presented in Chapters 3.1.2 and 3.1.3, respectively *"Len Lye's Discovery Process for Novel Figures of Motion"* and *"The Composition Process behind Matisse's Paper Cut-Outs"*, have been chosen because they fit very well with the prior mentioned action representation modes. They have a clear and well-documented *manner* of ideating a concept that they wanted to express, which was also mediated though the use of their *tools*, and they had a clearly laid out creation process. Their concepts also had some very clear connections to the manner in which they experienced the zeitgeist they lived in. In the case of Len Lye, he perceived it as an era of discovery and invention, and in the case of Matisse, he sought the musicality of Jazz music to inspire his expressivity in his use of lines and colours in his visual work.

When it comes to defining and choosing the tangible, interactive elements that make a particular artistic concept explorable as a play space, it needs to be kept in mind that the learner requires a low threshold to interact with a certain degree of confidence with the interface (See Chapter 2.2). These tangible elements should therefore form a bridge between the materials and its uses that they already know, and the possibility to discover how to create more sophisticated expressions (Anderson et al., 2002). For instance, the slinky, a popular toy that is made from spring steel, has been chosen as the main interaction element in the installation that represents Len Lye's artistic concept, and the context of use, a conveyor belt with triangular steps, has been designed to support the discovery of novel and expressions that are of a higher sophistication. The following list therefore describes a basic set of properties that can be used for the selection and further design of the interactive elements of an interface:

- Emanates a purposely chosen balance between Novelty, Typicality and Surprisingness.
- Conveys a certain amount of Uncertainty.
- Provides a balance between Explorability and being Challenging to the learner.

(Ciszentmihalyi & Hermanson, 1994; Naumann et al., 2008; Resnick et al., 2005)

Furthermore, on the assumption that a strong artistic concept is unique to the personality and subjective experience of the artist, defining the properties of *Uncertainty* and *being Challenging to the learner* for a particular installation can be viewed as the most faithful application of an artist's views and mannerisms in his ideation and creation process to the design of an installation that aims to teach these views and mannerisms.

3.1.1 *Further Guidelines for Interface Design*

In order to allow the learner to further develop his interest into the subject, not only does the entry for engagement need to be specified, but also how a sophisticated use of the installation can possibly be achieved. The conceptual interfaces in Chapters 3.1.2 and 3.1.3 aim to cover this by being designed as having similar features to that of an musical instrument: its palette of representations to the learner's actions is fully *explorable*, the learner can *improvise* with different forms of organisation, the interface has the aim to be *consistent* in terms of presenting repeatable results, and it allows for *practise* to develop skills to create expressions of a more sophisticated level. The feature of skill development is best to be understood as facilitating a detail-oriented and precise attitude of the learner. Figure 16 and its further explanation in this section tell about the different stages of interest development and the different modes of engagement of the learner there in.

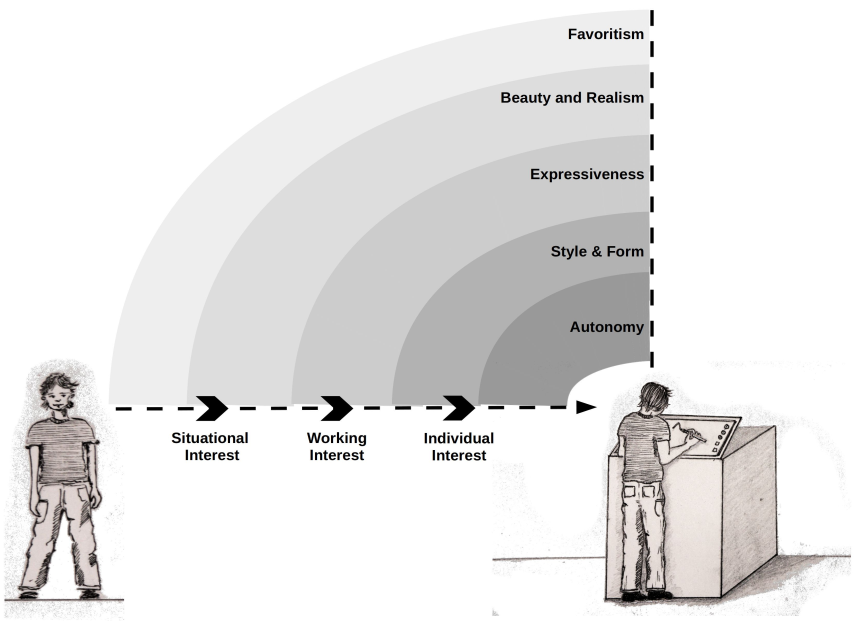


Figure 16: A graphic outline of interest development in the learner. This outline integrates 2 concepts that set out how interest in an artistic concept and the aesthetic understanding thereof, develops in individuals. (Parsons, 1987; Benedict, 2008; Krapp, 2002)

SITUATIONAL INTEREST A User develops a situational interest when he finds something in his environment of personal significance and speaks to his personal affective qualities.

- *Favoritism* A child chooses to engage with an artistic concept out of a personal, intuitive preference: 'because I like it'. This form of aesthetic judgement is motivated by prior knowledge and experiences that refer to an individual's identity. However, this does not necessarily mean that the understanding of the presented aesthetics are part of the learner's repertoire. As described in Chapter 1, when the situation permits playful engagement, a learner can be more perceptible to engage with novel stimuli.
- *Beauty & Realism* This stage of aesthetic judgement involves an understanding of the concept that is demonstrated in the presented artefact. Children have formed concepts of the world before they begin to acquire words. They search for ways to communicate what they know, therefore their first words are likely to express those early concepts(Kuczaj & Hill, 2003). Their concepts are shaped by *initial mental models* that lends consistency to their beliefs and conceptions and grow to *mature, culturally received mental models* through the child's interaction with peers, parents, educators and other individuals of authority in the culture they live in (Vosniadou, 1994; Siegal, 2003). In terms of learners it means that they have formed conceptual prototypes before they engage with the interface: a mental look and feel of media that can be understood in different configurations.

WORKING INTEREST The presented artistic concept provides a learning opportunity to the user. He can envision meaningful goals, which relate to his actual goals, and longer-lasting motives and values.

- *Expressiveness* The aesthetic judgement of the learner expresses a dialogue; an interactive relationship between the artist's point of view and the learner that is mediated by the presented learning materials. This can be viewed as an understanding that a presented artistic concept is an expression of someone else's point of view. But this view can also resonate with aspects of experience, states of mind, meanings and emotions that belong to the repertoire of the learner. This form of understanding that has emerged can be underpinned by moments of insight that has been formed during prior engagements with the materials. Such insights are one-shot learning experiences where initial, meaningless patterns are associated to meaningful patterns: a new concept is gained that was unknown before the moment of insight (Ishikawa & Mogi, 2011). In a study by Ludmer et al. (2011) about one-shot learning experiences that lead to perceptual insight, participants report that they feel the perceptual transition they experienced was so dramatic that they are going to remember the solution for a long time thereafter. Whether such an insight can be actually recalled from long-term memory depends on the affective state and autobiographical relatedness during the formation of the insight (Eichenbaum, 2004; Ludmer et al., 2011).

- *Style & Form* This stage involves the explorability of a problem specification that is being brought in by the learner. Interaction with the artistic concept becomes a creative activity where a flexibility of connections are being sought with the concepts that were learned.

INDIVIDUAL INTEREST This form of interest only occurs when the user identified himself with the actions and topics that are represented by the artistic concept, prior to his engagement with the interface.

- *Autonomy* Interaction with the artistic concept in this stage is expressed by the learner as a conscious decision to structure the presented relationships in such a way that it can faithfully represent the view of the learner. The concepts have been mastered as a tool for self-expression.

(Krapp, 2002; Parsons, 1987; Benedict, 2008; Smith, 1991)

3.1.2 *Teaching Len Lye's Discovery Process for Novel Figures of Motion*

> "One of my art teachers put me onto trying to find my own art theory. After many morning walks...an idea hit me that seemed like a complete revelation. It was to compose motion, just as musicians compose sound. [The idea] was to lead me far, far away from wanting to excel in...traditional art." - Len Lye (Horrocks & Lye, 2001)

Len Lye was a New Zealand-born visual artist who sought to portray *novel figures of motion*. His career spanned the greater part of the early and mid twentieth century, during which he worked on abstract music videos and motorized kinetic sculptures. He conceived this aim for artistic expression during his time as a student of the creative modern arts. During his studies he became aware of the of the Modernist movement in the creative arts in Western Europe. Inspired by the experimental explorations of visual form and stuctures by artists such as Malevich, Picasso and Duchamp, he was keen on finding his own niche that he could artistically explore. He came up with the term *"figures of motion"* because he could apply this concept on different types of media and allowed him to escape the static imagery that could be the result of a motion (e.g. a figure skater that leaves behind a figure eight on the ice). His interest lied therefore purely with the motion itself. Lye made his music videos by drawing directly on blank film using dyes, stencils, air-brushes, felt tip pens, stamps and combs and composed these on various well known dance music pieces of that time (Lye et al., 1984; Horrocks & Lye, 2001). His later work also explored non-western music, such as rhythmic drumming and singing by the African Bagirmi tribe that he used in his distinguished piece *"Free Radicals"* (Between Bridges, 2011).

Lye also recollected some specific features of his creative process to authors who were documenting his work: *"I made Free Radicals from 16mm black film leader, which you can get from DuPont. I took a graver, various kinds of needles. (My range included arrowheads for romanticism.) You stick down the sides with scotch tape and you get to work with scratching the stuff out. .... You hold your hand at the right height and act is if you were making your signature. It goes on forever. You can carry a pictographic design in your head and make a little design. You can't see what you're doing because your hand is in the way. That's why those things have* *that kind of spastic look"* (Russett & Starr, 1988). In the documentary *"Flip and Two Twisters"* by Horrocks (1995), he briefly explained his process of conceiving his kinetic sculptures: *"I'm composing figures of motion, and I'm composing them from very springy spring steel ... You take a piece of steel, you know .. and I attach it to a motor, but you don't get into devising anything with it ... until you're in the mood. Because, unless you can keep trying to find something that is simply fascinating to you, there's not much point ... So you wait until you're in the mood, and then when you find a piece of steel, you [play with it] and roll it about, until you gradually get to grips with an idea."* These recollections speak of an attitude towards his creative process that puts a lot of value on the *emergence* of concepts though the playful engagement with materials, and *spontaneity* during the editing of media.

In regard to designing an installation that teaches Len Lye's artistic aims and mannerisms, I have conceived an electromechanical musical rhythm instrument that allows for a similar, emergent ideation process and manner of expression as the ones that are found in his creative process. This instrument is made up from a conveyor belt which, similar to the construction of an escalator, has *triangular* shaped steps bolted onto the belt. How the individual steps have been placed together on this belt is not random, but have several rhythmical loops encoded into the composition (See Figure 22). Rhythms are performed by placing a *slinky* on these steps. Slinkies are helical springs that are made from spring steel and have the ability to walk down a flight of stairs when they're set in motion (see Figure 17). These installation elements aim to create an explorative space where learners can experiment on the intersection of motion and rhythm.

Figure 17: A Slinky - Picture taken by McLassus (2006)

The learning experience that is aimed to be gained from playing with this installation is very different from learning about various techniques for art making that could eventually be related to Len Lye's work. The creation of polyrhythmic musical patterns, or the creation of a kinetic sculpture using the slinky as it's most basic mechanism, could be teachable techniques in their own right. If the acquaintance with such techniques would be the learning goal, then other types of installation designs would be better suited to serve that purpose. An installation that teaches about kinetic sculpture could greatly benefit from an "additive sculpturing" (i.e. "LEGO"-like) mechanism, where different types of spring steel objects, such as strips, wheels, and wires, could be connected to each other. Similarly, teaching the technique of creating a polyrhythmic musical pattern would greatly benefit if the installation would allow for the deliberate editing of the patterns that are encoded in the installation.

The particular play mechanism of placing slinkies on this conveyor belt focuses the scope and depth of play into a journey that puts the learners in a similar behavioural pattern that Len Lye demonstrates in the *"Flip and Two Twisters"* documentary (Horrocks, 1995) when discussing his ideation process. What this installation therefore aims to present to the learner is how the concepts of kinetic sculpture and polyrhythmic music come together in Len Lye's thinking. In order to elaborate how this is different from learning a technique, it also need to be considered that the arts can introduce learners to different forms of thinking that stand outside of the mastery of techniques. Eisner (2002) discusses a number of *"artistically rooted forms of intelligence"* in his article named "What can education learn from the arts about the practice of education?". Here he mentions *"Experiencing qualitative relationships and making judgements"* as a distinctive form of thinking in the arts. What he means by this notion is that artists have the ability to create a composition of an almost limitless array of elements. Examples of such elements can be the shapes, behaviours and interactions in their environments, their cultural practices and interpersonal relationships, and their imagination and ideation of objects and mannerisms not currently found in the environment. When combining these elements into a composition, an artist creates relationships between these elements on which he/she has to make judgements. These judgements are being made intuitively, rather than on the basis of explicit rules like in mathematics or physics. These judgements are also being made qualitatively, such as the temperature of a colour that might be too warm, an edge of a shape that might be to sharp, or a musical rhythm that might need to be a little more dynamic, with the aim of achieving a"rightness of fit" in the final composition. In the case of this installation, the play mechanism is conceived as such that it demonstrates how kinetic sculpture and polyrhythmic musical patterns come together in Len Lye's ideation process and how these two media fit together in his artistic views. Also, because the outcomes of playing with this installation are repeatable, learners can test whether this particular view of art making is valuable to them and whether they gain aesthetic satisfaction from these results. The experiences that the learners gained from playing with this installation could then form an entry-point for learning about the various techniques that Len Lye used to create his works of art.

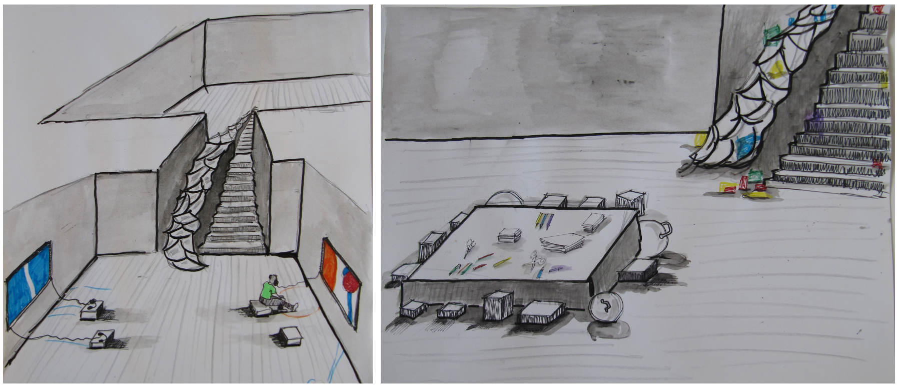


Figure 18: Sketches of a hypothetical Len Lye exhibition in a Children's museum. These sketches were made during the ideoation of the installation. It was originally conceived as a flight of stairs with triangular steps allow learners to investigate novel rhythmical patterns by placing the slinky on these steps. This conception of the installation design changed into the use of a conveyor belt instead of a static flight of stairs, because a conveyor belt makes it possible to clarify the musical properties of the downward motion of the slinky.

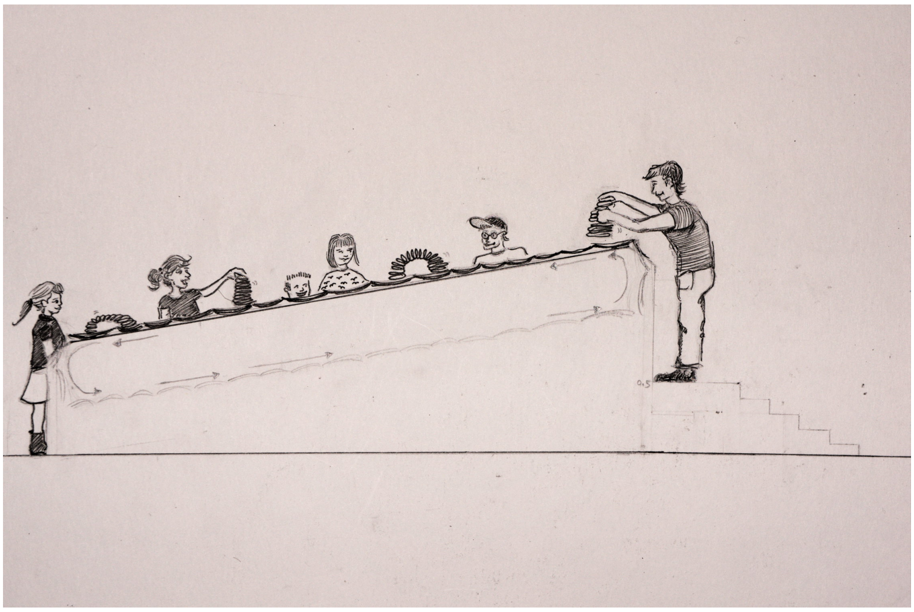


Figure 19: Example use-case scenario of the conveyor belt-based musical rhythm instrument

3.1.2.1 *Further elaboration of the Installation Design*

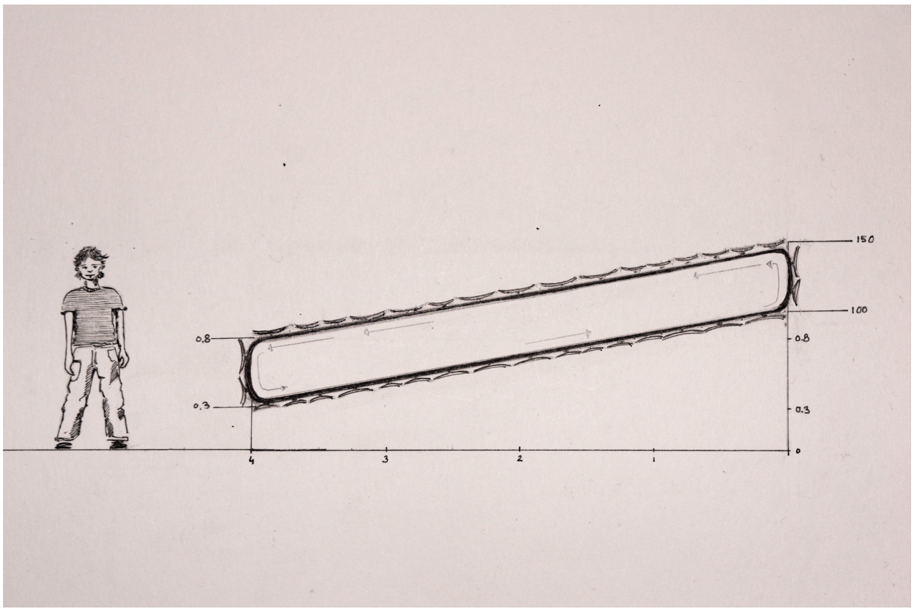


Figure 20: Dimensions of the conveyor belt. The conveyor belt is 4 meters long, has a thickness of 50 centimeter, and is lifted 30 centimeter above the ground to provide space for the underneath movement of the steps. The guidelines for these dimensions are taken from the steps from an actual flight of stairs (commercially available slinkies are designed to walk off such stairs). These steps have an average width of 25 centimeters and have an average depth of 15 centimeters. In the case of a step width of 25 centimeters, the conveyor belt length of 4 meters would correspond to a musical rhythm that is 16 quarter notes (4 measures) long.

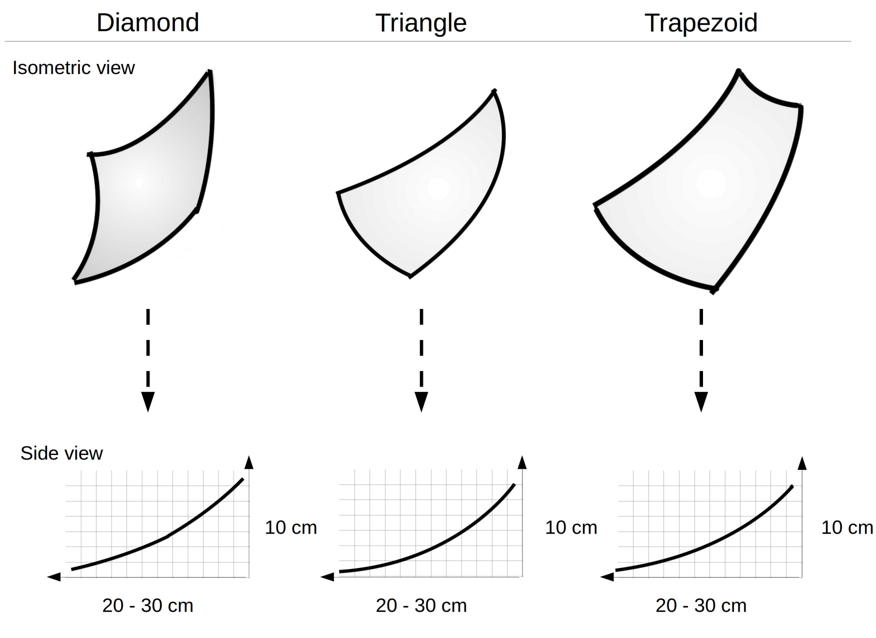


Figure 21: The different types of triangular step forms used in the design. The mentioned minimum and maximum sizes of 20 and 30 centimeters aim to enable rhytmic variation, while minding the average step width of 25 cm that is commonly found in stairs.

3.1.2.2 *Implemeting Musicality into the Design*

Non-Western rhythms were an inspiration for the works that Len Lye created in the later stages of his career. The design of the conveyor belt musical rhythm instrument allows for the experimentation with polyrhythmic patterns, which are commonly found in Sub-Saharan African music. Due to the size constaints of the steps, only one type of polyrhythm is possible, namely a 5:4 rhythm (5 evenly spaced notes over 4). In terms of musical organisation of the placements of the steps, it would mean that over a length of 1 meter of belt, 5 steps of 20 centimeter could form the basis for the rhythmical patterns performed on one side, and 4 steps of 25 centimeters could form the basis for the patterns performed on the other. Figure 22 shows a possible rhythm that can be composed during the *design and construction* of this instrument and Figure 23 shows a possible organic design that can be constructed using this rhythm. Such an organic design also allows learners to further experiment with the positioning of the slinkies in regard to the possible rhythms it can produce.

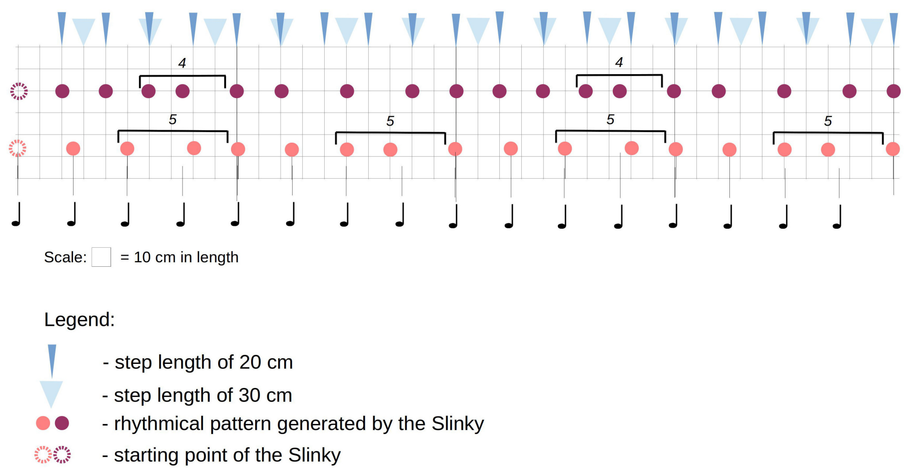


Figure 22: 5:4 Polyrhythmic beat pattern with a length of 4 measures. The rhythm is 2 measures long and is repeated in the other two measures. The aim of this depiction (not to indicate the repetition of the rhythm) is to clarify the dimensions of the steps in regard to the design of the triangular shapes of the steps.

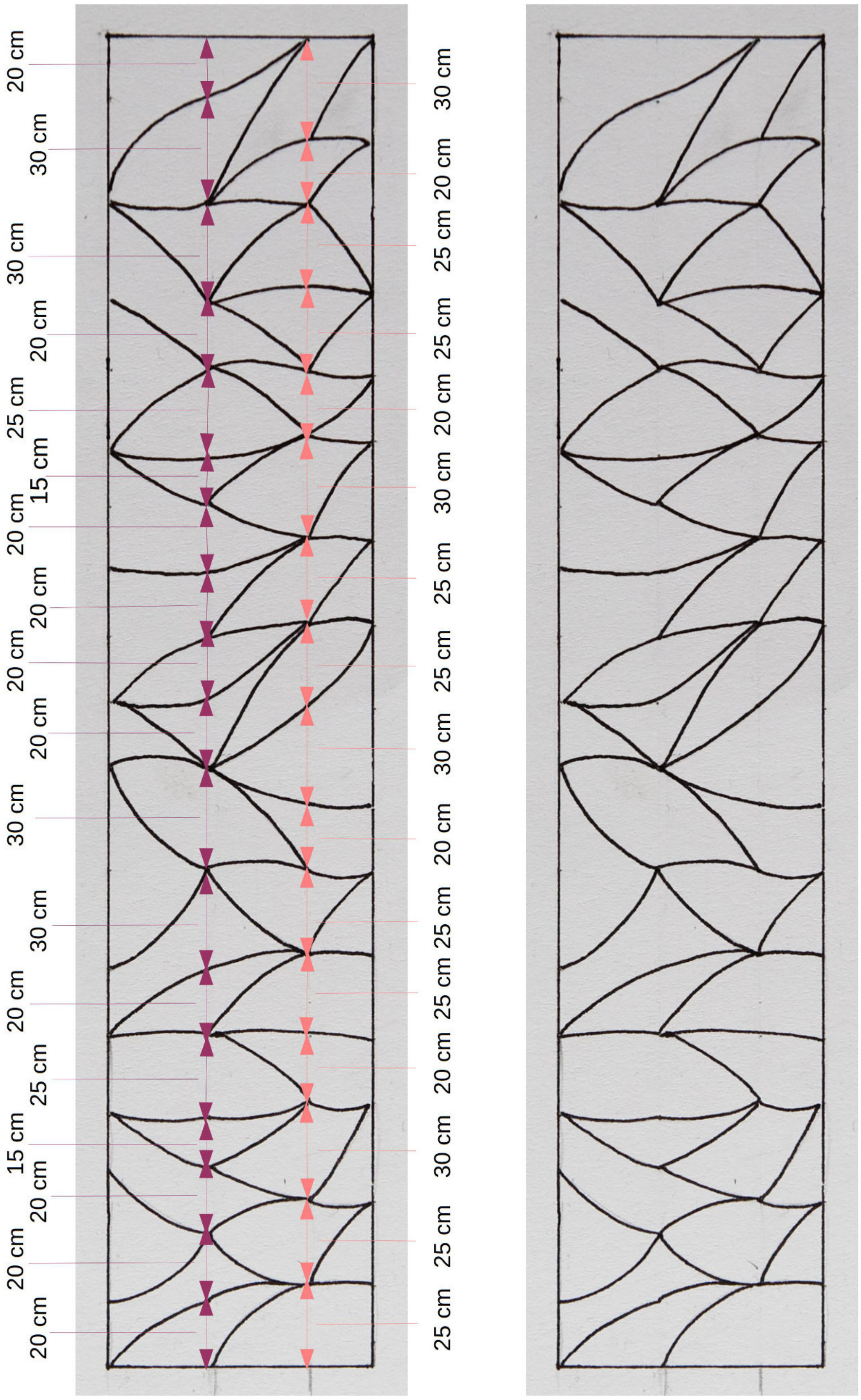


Figure 23: An organic step design pattern for the construction of the conveyor belt musical instrument

3.1.3 *Teaching Matisse's Composition Process behind his Paper Cut-Outs*

Henri Matisse was a visual artist whose professional career spanned the first half of the twentieth century. He had gained international recognition for his paintings and his artistic style, but his poor health condition led him to spend the last 13 years of his life in a wheelchair. Because of this physical impairment, he had to change his technique for creating works of art and switched from painting directly to canvas to *"painting with scissors"*. Through a creation process of applying dye on sheets of paper, cutting shapes into these sheets and composing them into a picture, he created works that sought to unite the formal elements of *colour* and *line*. These elements were key to to his artistic abilities. In the first two decades of the twentieth century he worked with non-realistic colour palettes and described his conduct of painting as *"construction by means of color."* The resulting works gave him the credentials of being a *"master colourist"*. He was also celebrated for drawings and prints that describe a figure in fluid arabesque lines. He regarded his style of line drawings as *"the purest and most direct translation of my emotion." (MoMA, 2014)* His cut-out paintings also introduced the element of *composition* in his creation process. As a result, his cutting and composing actions became inspired on the way Jazz music was composed and improvised. His cutting action was very spontaneous, mimicking the improvised melodies in live jazz performances. The colour schemas that he used in his compositions reflected commonly used Jazz tone scales and most of the time that went into a work was spent on a rather precise organization of the individual cuttings (Jaubert, 1996; see also Figure 24).

(a) Matisse and one of his interns working on a cut-out painting at the Hôtel Régina in Nice (Matisse, H., 1952)

(b) 'Sorrows of the king', 1952. Self-portrait of Matisse that he made using his paper cut-out technique. The black figure with the white hands playing guitar depicts Matisse himself. The green figure, playing the tambourine, refers to his intern. The dancer on the right side of this composition represents the painting they were working on. The orange leaf-shaped figures originate as tones from the guitar and represents his cut-out shapes (Jaubert, 1996).

Figure 24: Portraits of Henri Matisse that depict his creative process and his conceptual envisionment of this process

The aim for the design of an installation that teaches the artistic concept of Matisse's cut-outs is therefore to make Matisse's conceptual idea tanglible that lies behind his creative process. The resulting conceptual model is a computer music instrument that makes use of the Matisse's process of color selection, making cut-out figures, and composing them into a picture, to compose Jazz music that consists of rhythmic and melodic loops. This instrument consist of a touchscreen and can be operated using touch gestures and a pen stylus (See Figures 25 and 26). The use of the pen stylus is analogous to Matisse's use of scissors. A colour selection can be made by cyling through preset colour schemas that are derived from Matisse's actual cut-out paintings (See Figure 28). Compositions are being made by dragging and zooming the created figures. These interaction styles were chosen to be as much as possible true to Matisse's use and philosophy behind the elements of *colour*, *line* and *composition*.

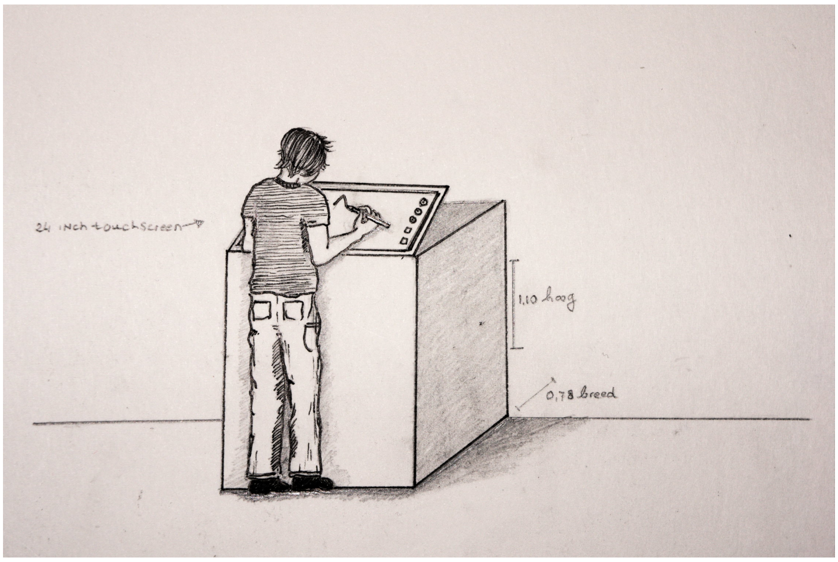


Figure 25: Illustration of the installation for the multimodal expression of cut-out compositions in the style of Matisse. The learner in this illustration is drawing cut-out shapes using a pen stylus. The installation consists of a table-like structure (the rectangular box in the picture) that supports a 24" touchscreen monitor and a speaker that is hidden within this surface. The structure itself is 1.10 meters high and 78 centimeters wide on each side. These dimensions were chosen to ensure that children with the average age of 12 can make use of the device in a ergonomic manner. Twelve-year-olds have an average size of 1.50 metres (CDC, 2014a; 2014b). The table height of 1.10 metres allows their elbows to rest at a 90 degree when working on their compositions, which is the ideal arm posture for working behind a standing desk (Bright, 2014).

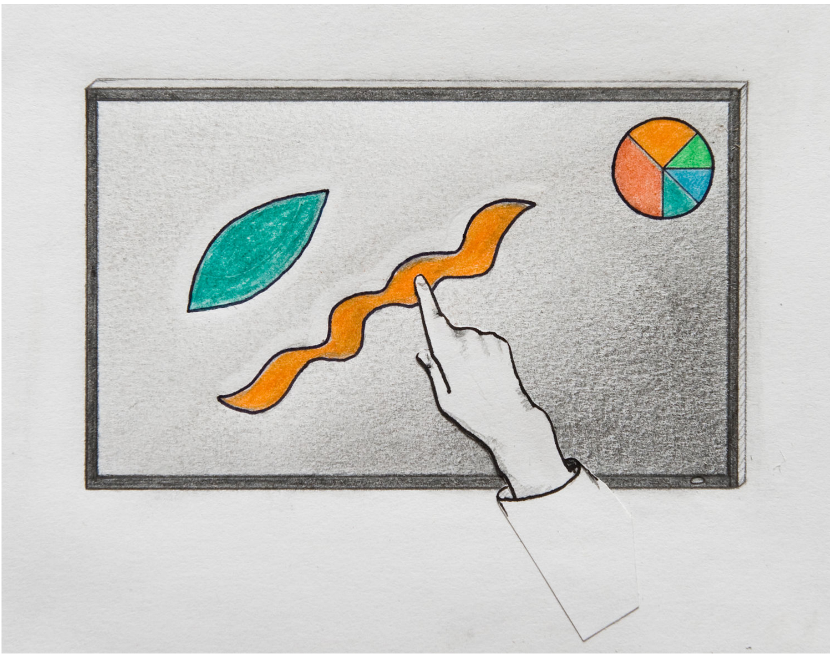


Figure 26: Positioning and resizing of drawn cut-out objects can be done using single and multi-touch finger commands on the touchscreen.

The learning experience that this installation design aims to convey is to let learners experience the *qualitative relationships* that Matisse draws between colours, lines, visual composition, and the tonal and rhythmical aspects of jazz music, as opposed to learning about the individual art making *techniques* used in jazz music and visual composition. Similar to the installation presented in Chapter 3.2.1, which aims to teach Len Lye's discovery process for novel figures of motion, the mechanism for creative expression is focused as such that creating compositions with this installation becomes a journey where Matisse's qualitative relationships between visuals and music can be understood. As indicated in Chapter 3.1.3.1, *"Further elaboration on the Interaction Features"*, the installation essentially acts as a mirror where the learner enters his gestures into the interface and gets presented the particular view that Matisse had with this gesture, both as a figure as well as a music loop. Also similar to the installation about Len Lye, is purpose of the repeatability of the outcomes of the learners' creative interaction with this installation. With this repeatability, the learners can test whether this particular view of art making is valuable to them and whether they gain aesthetic satisfaction from these results. In turn, this experience could then serve as an entry-point for further learning about art making techniques.

Whereas with regard to the Len Lye installation design various changes to the installation hardware could be conceived to teach the techniques that he uses in his artworks, in the case of the Matisse installation it would be sufficient to use a stack of coloured papers, scissors, and an instructional book with examples to teach the techniques used to create cut-out paintings. That the aspect of jazz music is explicitly present in this installation design, is to make clear to learners where Matisse drew his inspiration from, but it wouldn't be necessary if the topic of this installation would be about the techniques involved in creating a cut-out painting.

3.1.3.1 *Further elaboration on the Interaction Features*

PEN_STYLUS The learner makes Matisse style cut-out figures by drawing cut-out gestures using a stylus on the touchscreen. Such a gesture tells the computer to present an image of Matisse's actual cut-outs on the screen and select a music loop for playback over the speaker (see Figure 30). The computational process consists of a look-up table where the *motion* of a particular gesture is assigned to a particular image (see Figure 27). This computer input method is inspired from the *Graffiti* text entry technique created by the company *Palm Inc. Graffti* uses a single stroke gesture alfabet where each stoke resembles its assigned Roman letter (Castellucci & MacKenzie, 2008). This requires the user to learn each of the gestures before it can reliably be used for text entry. The learning curve for this method of text entry is, however, very low. MacKenzie & Zhang (1997)'s study on the immediacy of the use of this gesture alfabet showed that users demonstrated 97% accuracy after only 5 minutes of practice. The computational process that is involved in selecting a particular music loop on the basis of the way the gesture is expressed is explained in Chapter 3.1.3.2

COLOR_WHEEL A colour wheel is presented on the top right of the screen (See Figure 26). Matisse used specific colour schemas for his Cut-Out paintings. These can be selected by swiping up and down over the colour wheel using your finger (See Figure 28). Even though individual colours can be selected by touching one of the colours in the wheel, a change of colour schema will affect all previously selected colours: these selections will be remapped to the colours of the currently selected wheel. Similarly, a new colour wheel selection also selects the according set of music loops that is being played back (See Chapter 3.1.3.2).

TOUCH_GESTURES Cut -Out figures can be dragged around the screen by touching and moving the figure using your finger, and they can be resized using the *pinch-to-zoom* two finger touch gesture. This also influences the playback sequence of the selected music loops (See Figure 31).

FLASING_LIGHT The top left corner of the screen flashes in a slight manner (See Figure 26) to indicate the musical tempo that is being used by the interface to read gestures and play back the music loops.

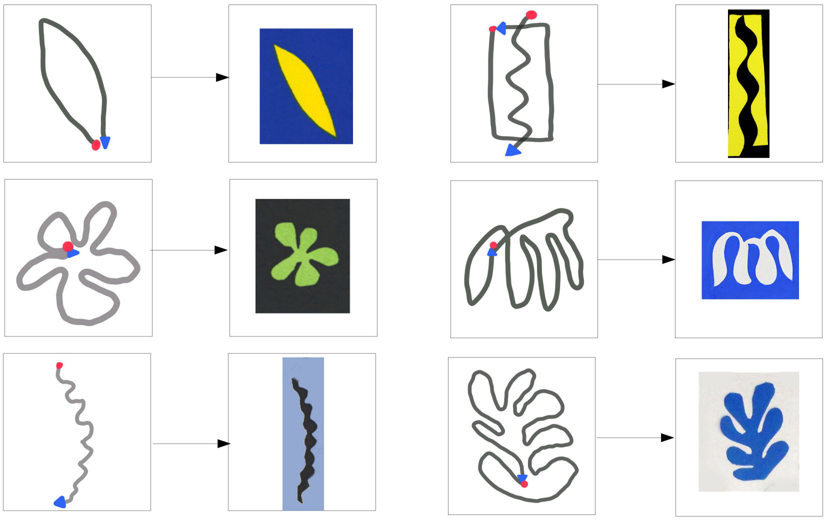
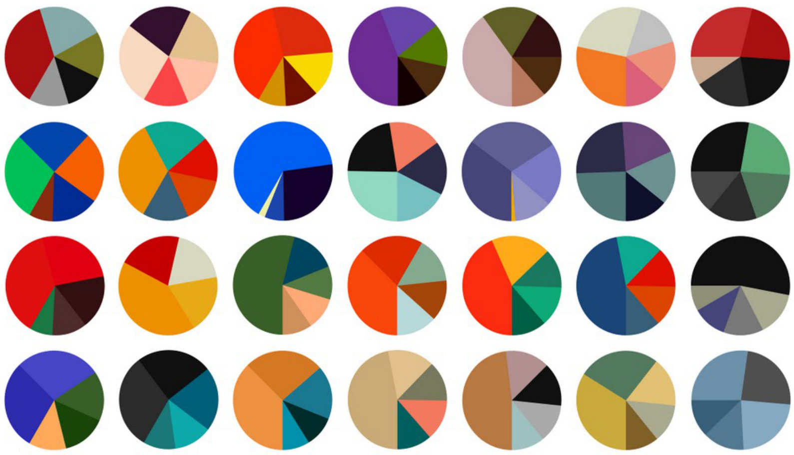
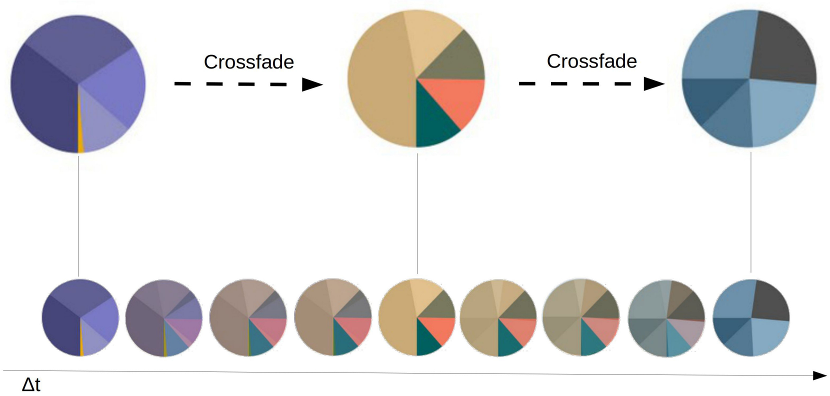


Figure 27: Examples of cut-out gestures that can be drawn on the touchscreen using a stylus. This action tells the computer to present an image of Matisse's actual cut-outs on the screen.



(a) An infographic made by Arthur Buxton depicting the different colour schemas that Matisse used in his Cut-Outs (Buxton, 2014)



(b) The colour wheels of Arthur Buxton's infographic are being used as an interaction element for the selection of a colour schema. Swiping up and down using your finger over the colour wheel will respectively select the next or previous colour wheel available. This selection is presented as a crossfade animation, going from one colour wheel to the other. Individual colours can be selected by touching one of the colours in the wheel.

Figure 28: Interface component for the selection of a colour schema

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3.1.3.2 *Computational Processes for the Gesture-based selection of Musical Loops*

The music engine of this installation is very similar to that of loop sequencer applications like Garageband or Fruity Loops. The interface of these programs allows a user to create songs by choosing different music loops out of a preset collection of loops and dragging these onto a timeline. From the perspective of this installation being a musical instrument, the focus of the musical composition aspect is to make the conceptual view that Matisse had on his creative process, and the cultural enviroment that he lived in, tangible and explorable. The learner is therefore limited to making use of the pre-programmed associations between Matisse's colour organisations, his line expressivity, and melodic and rhythmic music loops as they can be found in the Jazz music of that time period. The role of the interaction mechanisms in the creation of a cut-out painting is therefore analogous to their role in the composition of music:

CUT-OUT The *performance* of a cut-out gesture will be converted into musical parameters (See Figure 29). In turn, the system will select a musical loop for playback on the basis of these parameters.

COLOUR This musical loop selection process will happen within the constraints of the seleted colour schema and individual selected coilour for the created cut-out figure (See figure 30).

COMPOSITION How the individual cut-out figures are placed on the screen influences the playback sequence of the music loops (See Figure 31).

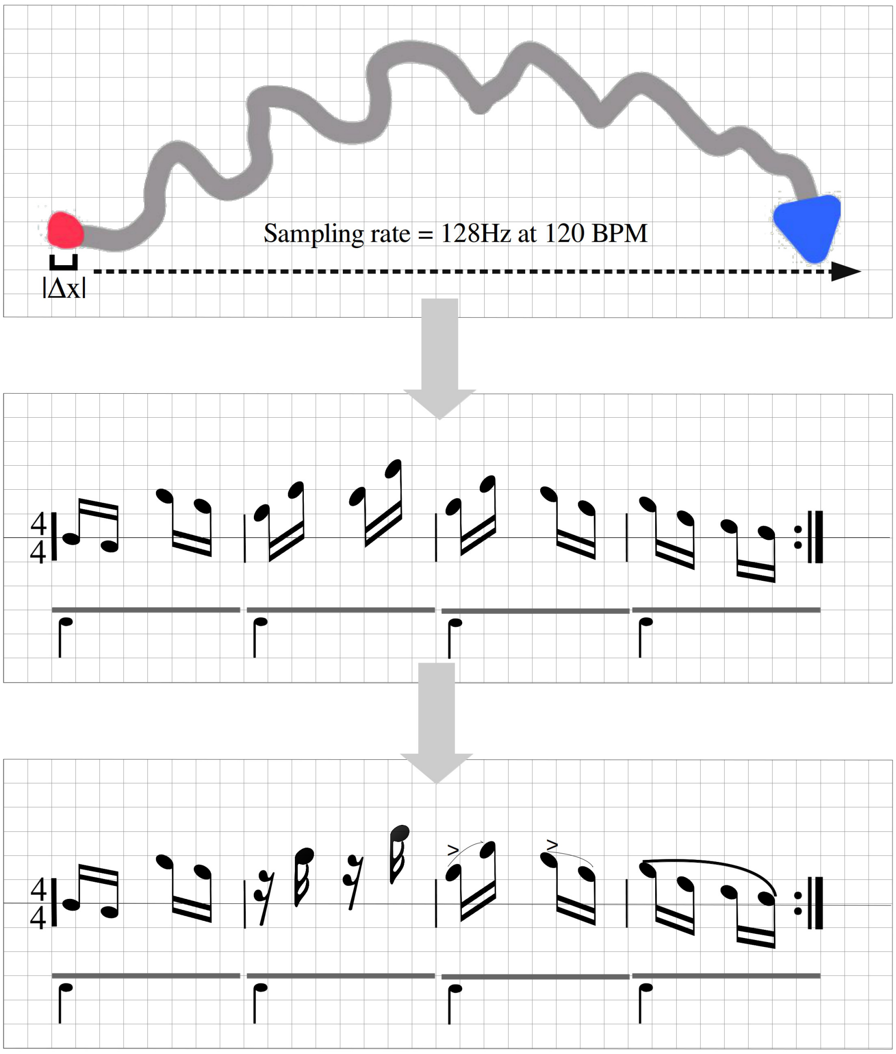

Figure 29: An example of how a gesture that is performed along the X axis is sampled and interpreted into a set of (relative) pitches and durations. The system maintains a musical tempo that is shown to the user as a flashing light, and it is assumed that the user will perform a pen gesture against the tempo that is indicated by this light. In this case of the gesture shown in this graphic, the movement of the pen over the Y axis is interpreted as pitch information and movement over the X axis, from *pen down* to *pen up*, is interpreted as the duration of the phrase. In this case, the gesture is 1 measure long. Also, if the pen stylus would move in constant velocity over the X axis, it would mean that all note durations would be identical, as shown in the second graph of this figure. The system, however, calculates the velocity of the pen for each sample by taking the absolute value of the distance travelled between the time of the previous sample and the current sample. This allows for pauses, accelerations and decelerations in the drawing of the gesture to be interpreted as rests, note durations, and other expressive musical features, as shown in the third graph of this figure.

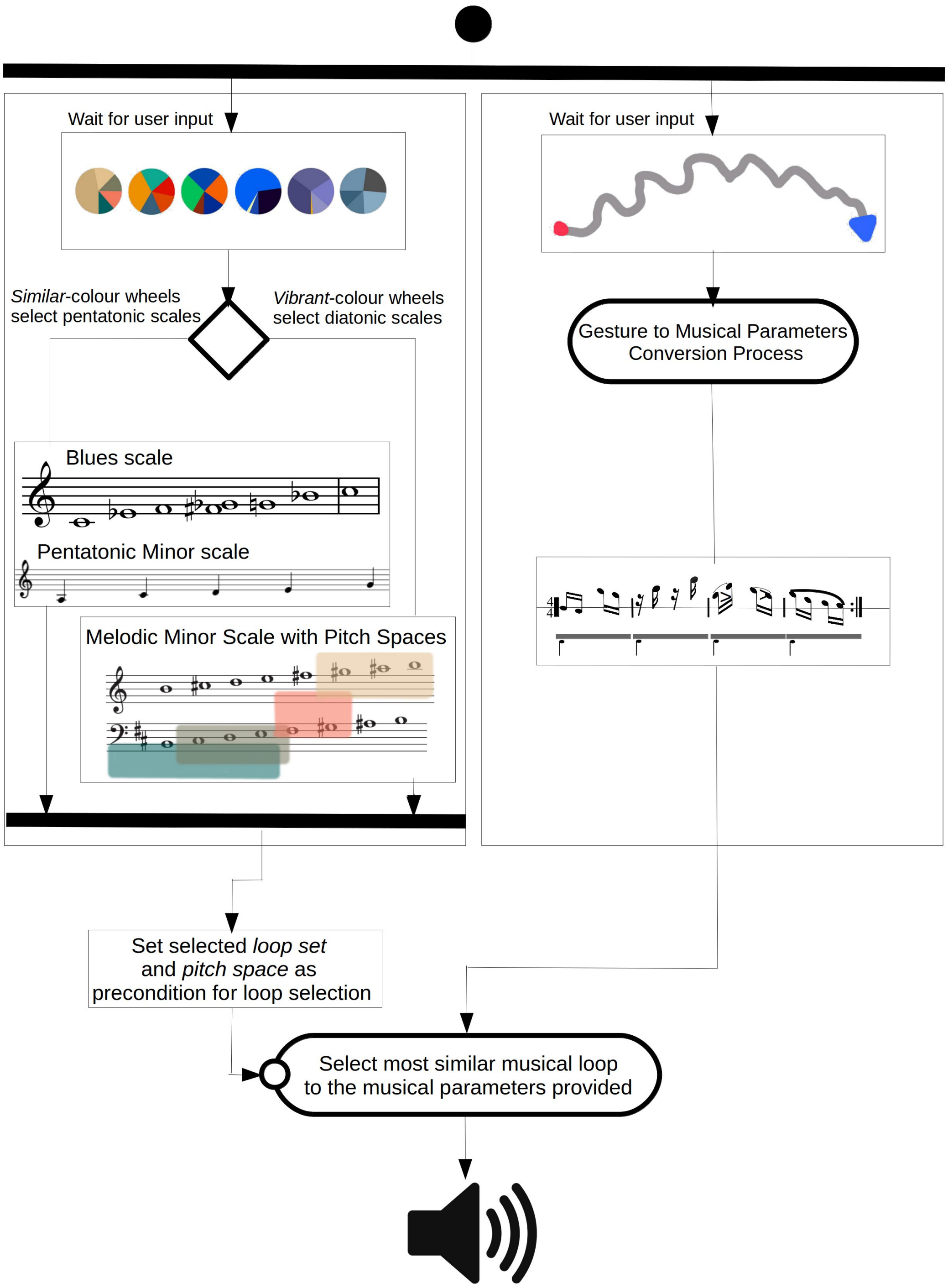

Figure 30: Activity Diagram of the music loop selection process. The left lane of this diagram depicts how the the selection of a colour wheel and the selection of an individual colour influence the *loop set* and *pitch space* where a particular melodic loop is selected from. The colour wheels refer to different types of musical scales: those that are vibrant refer to diatonic scales (7 tones in an octave) that can possibly be augmented with additional colouring notes, and those that are similar-coloured refer to pentatonic scales (5 tones in an octave), but also allow for augmentation with additional colouring notes, such as the example of the blues scale provided in this figure. *Pitch space* refers to the domain of pitches within a particular scale and limit the selection of a melodic loop on the basis of its *root note*. The performance of a pen gesture will create a new music loop on the basis of the selected colour wheel and individual colour.

Figure 31: The sequence of the playback of the individual musical loops (which is also of itself a loop) is organised through the cartesian placement of the individual figures. The system reads the sequence from a diagonal line of a rectangle of which its dimensions are defined by the most left, right, top, and bottom outer edges of the *graphical* composition. The vertical placement of the figures refer to the simultaneous playback of the music loops at that given moment in time. This manner of reading a musical composition from a graphical composition aims to motivate the learner to use the whole screen.

4 DISCUSSION OF THE DESIGN SPECIFICATIONS

4.1 DISCUSSION OF THE INTERFACE DESIGNS

The two designs proposed in Chapter 3, an installation that aims to teach *"Len Lye's Discovery Process for Novel Figures of Motion"* (Chapter 3.1.2) and a touchscreen interface that aims to teach the *"Matisse's Composition Process behind his Paper Cut-Outs"* (Chapter 3.1.3) embody play mechanisms that address how information from the learner's different sensory systems is being integrated in the Inferior Parietal Lobule (see Chapter 1.5.2.4), a key brain region that is involved in the perception of the environment. To reiterate the introduction of the "Cognitive Model for Learning through Creative Engagement with Artefacts" (Figure 15) in Chapter 3, this integration process seeks to disentangle the origin of the sensory events in the environment and therefore construes the objects and events respectively as *action representations* (see page 10) or as *intentional agents* (see page 11) using the following *action representation modes*:

MANNER The various ways in which a particular action can be executed, including its meaning, complexity and its relationship to the observer (Gallese & Lakoff, 2005; Shmuelof & Zohary, 2006).

PHASE A purposeful action can be divided into segmented temporal phases (Gallese & Lakoff, 2005). In terms of an artistic expression these can be viewed as temporal phases of inscription and editing of media.

TOOL-IDENTITY the functional identity of a tool is construed as a *motor experience* in regard to the purpose of a particular action (Creem-Regehr & Lee, 2005)

The play mechanisms of the designs in presented in Chapter 3, the act of creating rhythm and motion through the placement of slinkies on a conveyor belt in the case of Lye, or the creation of a parallel composition of abstract figures and jazz music through the drawing and placement of these figures in the case of Matisse, are closely linked to the *manner* action representation mode. Here, *manner* refers to how specific aspects of the artists' personality have been embodied in these play mechanisms (see Chapter 3.1.2 and 3.1.3). In the case of the Len Lye installation, the learner is made to behave similarly as the artist during his process of ideation. In the case of Matisse, the touchscreen display is intended to act like a mirror to the intentions expressed by the learner, where any kind of gesture drawn on the touchscreen would be linked to a figure that Matisse would have created using a similar gesture with his scissors, and then presented back to learner, both visually and musically. The underlying idea of this play mechanism is to display "what the artist would have thought when he would have created likewise cutting gestures and composing actions" as those of the learner. This dissonance between the learner's gestures and Matisse's representations of those gestures allows them to learn about Matisse's actions by ascribing *intentional agency* to this touchscreen interface (see page 11).

The play mechanisms are also linked to the *Phase* action representation mode. Playing with the Len Lye installation allows learners to understand the behaviour of the slinky, how it interacts with the conveyor belt and form a basic idea on how the create rhythm and motion, that could possibly lead to the learners ascribing the resulting motion as "dancing" on the polyrhymical pattern that the slinky creates on the conveyor belt. This is analogous to the various phases of ideation that Len Lye mentions in his interviews (see Chapter 3.1.2). With regard to the Matisse installation, the sequence of gestures that the learners use on the touchscreen also intends to closely mimic Matisse's composition process. Starting off with intensive rhythmical gestures that create the abstract figures and accompanying loops, and experimenting with the colour and musical tone by adjusting the colour wheel (see figure 28), it is intended that the learner then engages in a reflective process where he arranges the figures until it results in a composition that speaks to his aesthetic satisfaction. With both installations, the temporal outline of playing and creating with these installations intend to closely follow those in the art-making process of the artists.

The action representation mode of *Tool Identity* is seen the clearest in the Matisse installation, where a distinction is being made between gestures drawn onto the touchscreen using the pen stylus, and gestures from directly touching the touchscreen. The purpose for this distinction is that it is analogous to the way that tools are used in his art making process, where Matisse is cutting paper using a scissors, rhythmically related to the beat of jazz music. Hence, the analogy that gestures drawn onto the touchscreen using the pen stylus serve as a rhythmical and melodic template using which the computer looks up corresponding musical loops (see figure 29 and 30). In the case of the Len Lye installation, this action representation mode has informed the choice of designing the installation around a slinky, after having reviewed other spring steel objects like singing saws. The requirement was that the object chose must fulfill the purpose of supporting the conception of a creative work in a similar manner as Len Lye and preferably with a similar purpose. The triangular steps were conceived to allow learners to pursue "novel figures of motion" using this slinky, which then was later further developed into a conveyor belt which would allow for rhythms to emerge.

Aside from the action representation modes of Manner, Phase, and Tool Idenity, the different processes described in the "Cognitive Model for Learning through Creative Engagement with Artefacts" (Figure 15) deal primarily with the formation of the cognitive conditions that lead to insight, it's consolidation in long-term memory, and its subsequent use in gaining conceptual knowledge about the topic that has been embodied in the educational installation design. The properties that installation needs to possess to address these cognitive processes lie more in features of the installation itself, rather than the play mechanism. An analogy can be made with a car on a road. Where the play mechanism is the car, the installation itself is analogous to a road. The more features a road has, such as a variety of surroundings, but also bend, valleys, hills, and the materials that this road is constructed with, allow the user to maintain interest in this road in order to make repeated use of it, and explore different routes and driving styles that this road makes possible. If an educational installation design emanates a purposely chosen balance between novelty, typicality and surprisingness, conveys a certain amount of uncertainty, and provides a balance between explorability and being challenging to the user, then this can potentially lead increased associative flexibility in the learner's thinking, ability to adopt new rules for engagement, and effortful behaviour (see page 38 - *"Formation of the cognitive conditions that lead to Insight"*). In the case of the Len Lye installation, the element of typicality is found in the slinky. Even if a learner has never seen a slinky before, they are very accessible objects for learners to familiarize themselves with. They are also are very animative because of their elastic properties, possibly allowing them to engage in pretend play (i.e. the attribution of human traits, emotions, and intentions to the slinky), or to explore the motoric potential of the slinky (similar to the installation discussed in Chapter 2.2). The other elements of novelty and surprisingness, uncertainty and providing a balance between explorability and being challenging to the user can be found in the conveyor belt, and particularly in the random-esque distribution for the triangular shaped steps over the surface of the conveyor belt (see Figure 23). While this pattern is underpinned by a highly repetitive and regular distribution of points where the slinky can land on, this random-esque distribution aims to motivate learners to explore its properties. In the case of the Matisse installation, the properties that can potentially lead to increased associative flexibility and effortful behaviour lies in the relationship between the gestures that are drawn onto the touchscreen, the rhythm with which this is done, and how this calls up an abstract figure and a music loop that is related to it. Learners do not know beforehand what they are exactly calling up from the system when drawing their gestures. The aim with this installation is that a gradual process of exploration of the figure-music combinations available to them, will allow them to create something that is to their aesthetic satisfaction in the stage once they are in the process of composing a synthesis of visuals and music.

Both installation designs also have properties that intend to aid the process of the consolidation of insights in long-term memory. This process is governed by the learner's state of positive affect, the richness of the associated elements in which an insight emerged, and the self-relatedness of some of these elements in regard to the individual (see page 43). From these three requirements, only the richness of the associated elements can be controlled using the design of an educational installation, and specifically that the design must address the learners multimodally. The multimodality of both installation designs can be found in the play mechanisms. In both cases, the play mechanisms intend to relate to the visual, kinaesthetic, and musical elements of the artistic views and art making process of the artists, throughout all the activities that are performed with them by the learner.

An educational installation should also allow the learner to further elaborate on the particular concepts that the learner has in mind. This allows the learner to develop *conceptual knowledge* about the topic that is embodied in the installation design (see Chapter 1.5.2.3 - The emergence of Conceptual Knowledge). In the case of the Len Lye installation, this is supported by underpinning the random-esque distribution for the triangular shaped steps over the surface of the conveyor belt (see Figure 23) with two rhythm lines. This allows the learners to experiment with different rhymical patterns, and could possibly allow them to compose a rhythm using multiple slinkies. In the case of the Matisse installation, this development of conceptual knowledge is best supported by the colour-wheel (see Figure 28), which both changes the colour schema that is presented in the composition of abstract figures as well as the melodic and harmonic structure of the jazz music loops (i.e. changing from a major scale to a minor scale). This allows the learner to explore and compose in different colour and musical spaces, further strengthening his concept of Matisse's composition process.

4.2 DISCUSSION OF THE COGNITIVE MODEL FOR LEARNING THROUGH CREATIVE ENGAGEMENT

> *"Thinking is movement, confined to the brain"*
>
> - Greenfield (2012); as she presumably quotes Arvid Carlsson, et. al., who developed the L-Dopa treatment for Parkinson's disease.

Throughout the this research, I had several discussions about the limitations of use of *"Cognitive Model for Learning through Creative Engagement with Artefacts"* with scholars in the fields of the arts, education and neuroscience. Is it limited to artists who create artefacts using explicit sensory-motor means, such as Matisse, or can it also be applied to the conceptual, thought experiments from artists such as Duchamp? Is it even limited to artists, or can it be applied to other practices of seeking meaning in our natural environment? Can this Cognitive Model for Learning through Creative Engagement be broadly applied?

In order to address these questions, it is useful to reconsider how perception is architecturally organized in the neo-cortex and how the delineated action representation modes of *Tool Identity, Manner and Phase* of the Cognitive Model for Learning through Creative Engagement maps onto this architecture. Kurzweil (2012) developed a theory that provides a clear and plausible explanation of the way that the neo-cortex processes perception, called 'Pattern Recognition Theory of Mind'. He views that the neo-cortex is made up from 300 million pattern recognizers, neuronal assemblies that are about 100 neurons in size, that are essentially similar in their composition. These pattern recognizers are connected in a hierarchical structure, where each successive tier in this hierarchy processes higher level (or more abstract) perceptual information. Each of these successive pattern recognizers do not differ in complexity from the lower level recognizers, they are only different in the type of information that is being processed. Kurzweil (2012) gives an example of such hierarchical processing in in the V1, V2 and MT (or V5) areas in the primary visual cortex (see Figure 22): V1 recognizes very basic edges and primitive shapes. V2 can recognize contours, the disparity of images presented by each of the eyes, spatial orientation and whether or not a portion of the image is part of an object or the background. And, V5 is involved in the processing of feature motion (Zanto et al., 2011). Kurzweil further elaborates that higher-level regions of the neocortex recognize concepts such as the identity of objects and faces. Felleman & Van Essen (1991) observed such an hierarchical organization among 25 neocortical areas that are predominantly or exclusively visual in function, plus an additional 7 areas that they regard as visual-association areas on the basis of their extensive visual inputs. They found that as they went further up this hierarchy, the processing of patterns became more abstract, comprised larger spatial areas, and involved larger time periods. Also, with every connection they found communication both up and down the hierarchy. Furthermore, evidence for Kurzweil (2012)'s view that the neo-cortex is composed of 100-neuron-sized neural assemblies is supported by a finding from Perin et al. (2011). In this study they were investigating neuronal clusters at the most elementary level of the neo-cortex. Here they found neural assemblies whose connectivity and synaptic weights are highly predictable and constrained: experience cannot easily mold the synaptic connections of these assemblies.Markram & Perin (2011) further speculate that these assemblies serve as innate, Lego-like building blocks of knowledge for perception and that the acquisition of memories involves the combination of these building blocks into complex constructs. These innate Lego-like assemblies are several dozen neurons in size. Connections between assemblies may combine them into super-assemblies within a neocortical layer, then in higher-order assemblies in a cortical column and even higer-order assemblies in a brain region. Markram & Perin (2011) view that each assembly is equivalent to a Lego block holding some piece of elementary, innate knowledge about how to process, perceive and respond to the world. When different blocks come together, they form a unique combination of these innate percepts that represents an individual's specific knowledge and experience (Kurzweil, 2012).

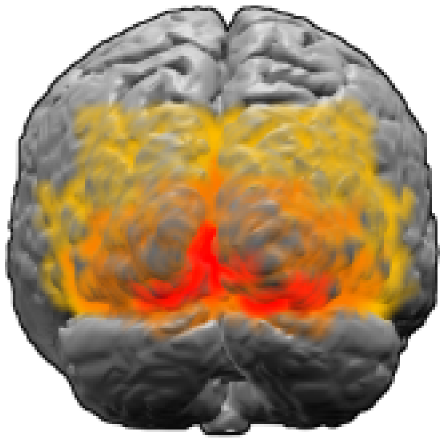

Figure 32: View of the brain from behind. Red = Brodmann area 17 (primary visual cortex, or area V1). Orange = Brodmann area 18 (visual area V2); yellow = Brodmann area 19 (Talairach & Tournoux, 1988).

When considering whether and how Duchamp's style of art creation can be taught on the basis of these action representation modes, it is important to understand how fundamental the mapping of this perceptual processing is that this model aims to address. Duchamp popularized the idea of presenting his subjective sense of irony or humour to his audience by making simple transformations of existing objects: either by repositioning, turning objects or joining different objects. He referred to these objects as 'readymades' and were created with the aim of being understood by means of an individual's attention to his work (Tomkins, 1996). Such a presentation of a subjective point of view does not diverge from the notion that concepts of concrete objects and actions are *embodied* (Gallese & Lakoff, 2005; Mahon & Caramazza, 2008), as stated in the first point in the research objectives of this dissertation. It also does not diverge from the mapping of *manner*, *tool-identity* and *phase* that is represented in the Cognitive Model for Learning through Creative Engagement. In Duchamp's case, *manner* refers to the *flexibility* and *appropriateness* in his thinking, and *tool-identity* to the mental transformations he applies to the objects that he found. In order to assert the best approach to identify the *phase* parameter, it is useful to look at the goal of the artistic exercise and further delineate the steps of inscription and editing . Even if these steps are of a purely conceptual nature, they still can consist of epistemic actions; physical, external actions that an individual performs to change his or her own computational state (Kirsh & Maglio, 1994). The construction of a digital interface for the purpose of teaching

Duchamp's artistic concept is therefore in line with the aim of this research, namely that it is feasible that learners can acquaint themselves with the cognitive style of others.

When looking at the aforementioned hierarchical organization of the neo-cortex, the mapping where the Cognitive Model for Learning through Creative Engagement is based on refers to the brain regions that are involved in disentangling the origin of sensory events, which is initially characterised by the way that we function with our bodies in the world (see page 9 of this dissertation). In Kurzweil (2012)'s proposed hierarchical model of pattern recognizers, such action representations are being recognized in the tier where multimodal integration occurs of the individual sensory streams. This occurs on a higher level in this hierarchy, but well before the concepts that has been formed in this tier have entered the stages of emotional processing, preference judgement or decision-making.

(a) 'Fountain', Duchamp, 1917. This is a photograph from a replica of the original 'Fountain'. This replica is part of the Tate collection in the UK.

(b) 'Bicycle Wheel', Duchamp, 1913. This is a replica that is made by Duchamp himself and is part of The Museum of Modern Art (MoMA) in New York.

Figure 33: Duchamp's 'Readymades'

The Cognitive Model for Learning through Creative Engagement could possibly demonstrate its universal value when it is applied to contexts outside of the domains that are usually associated with artistic thinking. I discussed its use in the tuition of physics with a professor in science education. The point of view that I'm elaborating in this dissertation is that all of human knowledge has its origin in the cognitive style and experiences of an individual. When I was discussing the meaning of my work with this education professor, I put forward that an introductory explanation of physics is best to be started with an explanation of the way a physicist attends his environment. I used Albert Einstein's cognitive style as an example, because the documentation that is available about his specific way of thinking, development and education are plentiful. He relied strongly on mental visualization in the early stages of his thinking and only later he put these ideas into words. He emphasized this visual imagery as conducting thought experiments in his scientific research work. 'The thought experiment combines the visual and abstract mathematical modes of thinking in a manner that can permit the scientist to "see" the deep structure of a problem situation' (Wallace & Gruber, 1989). It are these kind of examples of mental inquiries that can be made tangible using a digital interface that is designed on the basis of the Cognitive Model for Learning through Creative Engagement. The result would give learners the opportunity to identify themselves with a specific style of thinking that has been proven useful for a given discourse. It could provide them with a starting point for further exploration of a cognitive style, but also with an entry point that allows to experiment with various concepts in physics (see Hassard et al., 2008, p. 10 - 14).

The relevancy of conscious awareness of a learner's creative or playful engagement with the proposed digital interface is a question that is often raised by scholars in the creative arts that have read draft chapters of this dissertation. In general terms, it can be stated that the majority of neuronal mechanisms that are being discussed in this dissertation function outside of conscious awareness. When focusing on a learner's creative engagement, it can be argued that the conscious experience of learning starts with the learner's voluntary *decision* to (or how to) *attend* an inquiry, while *envisioning* alternative scenarios and plausible outcomes. Cohen & Dennett (2011) set out the two main governing views on conscious experience, namely the 'hard' problem of consciousness; how phenomenal ('what it is like') experience arises from physical events in the brain, and the 'easy' problems; those that aim to characterize the mechanisms supporting cognitive functions. On the basis of the 'easy' problem of consciousness, it is viewed that attention, working memory and decision making interact and come together in a certain way to form a conscious experience. Cohen & Dennett (2011) further argue that we're conscious of less stimuli than we think that we're attending. He exemplifies this with a study from Simons & Rensink (2005) on change blindness. In this study, participants was asked to observe changes in a 'flicker task' where they were viewing an original and modified scene alternate repeatedly, which were separated a brief blank display. When the change was observed, the alternation stopped and a new scene was displayed. The participants eventually find most changes, but can take an astonishingly long time to do so, even for large changes. Similarly, when I look at the neuronal mechanisms that I've described in that chapters about play and creativity as learning mechanisms, we are, for example, not conscious of the increased flexibility and/or fluency of our thinking that is gained by positive affect. Yet these processes do impact how we make decisions and alter the scope in which we can think up alternative scenarios, while we're 'only' conscious of the task that we're attending.

The completeness and accuracy of the Cognitive Model for Learning through Creative Engagement as it is described in Chapter 3, can be put to further discussion, most certainly when it's applied in a universal context. It is a hypothesis that is largely conceived on the basis of measurements of regional brain activity on human perception and interaction, the architectural view that has been derived from anatomical studies, and the discussions about these studies in a broader psychological/educational context. These materials have two problems: it is very coarse in resolution when looking at the neuronal activity using all non-invasive methods of measurement (MRI, rTMS, EEG, etc ..), and the architecture of the human brain is not yet fully understood in clear terms. I have managed to reduce the way that the brain attempts disentangle the perception of the (subjective) representations that are created by others into *manner*, *tool-identity*, *phase* (and form) on the basis of the data I had available at the time. But, recent (theoretical) advances in the understanding of the brain's architecture such as the one from Kurzweil (2012) already suggest that the *manner* in which perceive and recognize patterns, even those on the most rudimentary level, can be specific to each individual, yet uniformly spread over the hierarchical tiers of the neo-cortex. However, the most prominent question now is how it will play out when the parameters of this model are being put into practice, and what the relevant research questions are on the basis of those results.

5 CONCLUSION

If I would come back to the classroom where I was teaching about digital media to secondary school learners, and particularly the question that my experiences teaching the learners from the theatre production classes left with me: "wouldn't they benefit if, using their creativity and playfulness, they could create their own pathway to the knowledge I would want to teach them?", would the outcomes of this research provide me with the means to allow learners to create these pathways in our learning institutions?

The benefit of the undertaken research process with regard to this question is that pointers can be found towards answering this question once a different perspective is taken on learning. The research process inquires both, into the literature of the cognitive and neurosciences on whether and which triggers there are for learning when a learner is creatively engaged with educational materials, and into the installation design practices of children's museums and likewise arts education institutions. The literature review explores the neuronal mechanisms underpinning creative behaviour in order to make the case that creativity is a viable mechanism for learning, using a clear definition of what learning is. In this thesis this is defined as "a process of formation and consolidation of insights in Long-Term Memory, which in turn informs the changes in the behaviour of the learner". It would have been very hard to make the case that creativity is a viable mechanism for learning, if I would have solely depended on the outcomes of my field research in the children's museums and the body of literature that discusses these types of educational activities. This has to do with a key difference between classroom-based education and children's museums, namely that the classroom is an environment that prepares learners for standardized testing, while children's museums escape this method for evaluating learning outcomes because they are extracurricular activities. Therefore, it becomes important to understand what the virtues and limitations are of creativity as a learning mechanism when bringing in the installation design practices of children's museums into the context of the classroom-based education environment.

The conceptual installation designs in Chapter 3 are tailored around these virtues and limitations of creativity as a learning mechanism. They demonstrate that the cognitive process of consolidation and formation of insights in long-term memory can be addressed by fairly simple play mechanisms, provided that the installation itself provides a context for this play mechanism that provides challenges to the learner, has sufficient depth to maintain a learner's working interest, and is multimodal (i.e. addresses the learner through visual, auditory, and tactile stimuli), where each of these modalities can tell something about the topic being taught using this installation. The other benefit of such installation design is that it allows learners to understand the artistic behaviours and decisions of individual artists, rather then a series of objectified techniques for art making, which essentially depersonalizes the art making process away from the artist. By putting the artist central to the narrative of an installation, it allows learners to understand how they identify with these artistic behaviours and decisions. In turn, this can make arts education in the context of the classroom much more relatable to learners when comparing it to their current struggle of trying to grasp the arts through the lens of a photo editing program on a computer.

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